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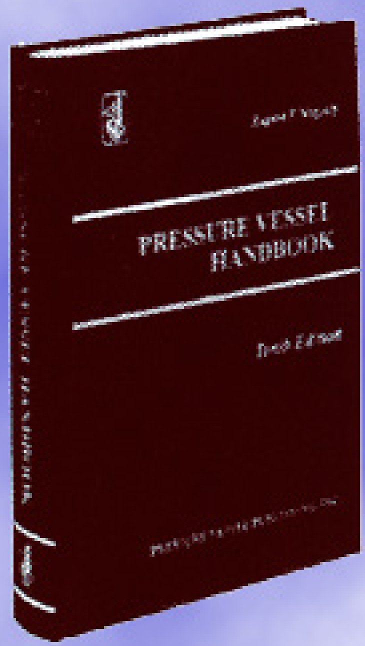
WARNING!

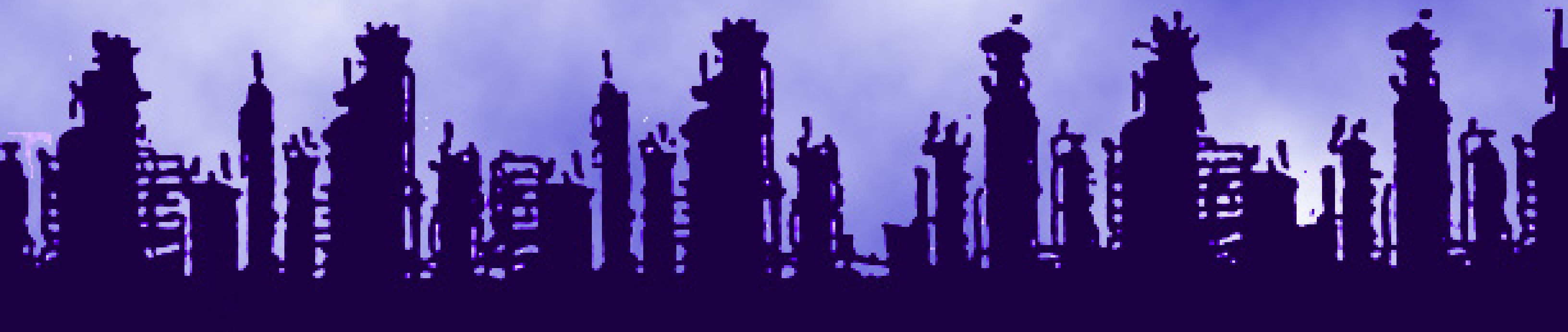
Pressure Vessels Incorporated
P.O. Box 35365
Tulsa, OK 74153 USA

www.pressure-vessel.com

PRESSURE VESSEL HANDBOOK



10th EDITION



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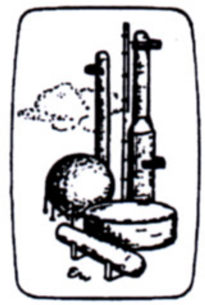

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PRESSURE VESSEL HANDBOOK

Tenth Edition

with foreword by
Paul Buthod
Professor of Chemical Engineering
University of Tulsa
Tulsa, Oklahoma

Eugene F. Megyesy

PRESSURE VESSEL PUBLISHING, INC.
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FOREWORD

Engineers who design equipment for the chemical process industry are sooner or later confronted with the design of pressure vessels and mounting requirements for them. This is very often a frustrating experience for anyone who has not kept up with current literature in the field of code requirements and design equations.

First he must familiarize himself with the latest version of the applicable code. Then he must search the literature for techniques used in design to meet these codes. Finally he must select material properties and dimensional data from various handbooks and company catalogs for use in the design equations.

Mr. Megyesy has recognized this problem. For several years he has been accumulating data on code requirements and calculational methods. He has been presenting this information first in the form of his "Calculation Form Sheets" and now has put it all together in one place in the Pressure Vessel Handbook.

I believe that this fills a real need in the pressure vessel industry and that readers will find it extremely useful.

Paul Buthod

PREFACE

This reference book is prepared for the purpose of making formulas, technical data, design and construction methods readily available for the designer, detailer, layoutmen and others dealing with pressure vessels. Practical men in this industry often have difficulty finding the required data and solutions, these being scattered throughout extensive literature or advanced studies. The author's aim was to bring together all of the above material under one cover and present it in a convenient form.

The design procedures and formulas of the ASME Code for Pressure Vessels, Section VIII Division I have been utilized as well as those generally accepted sources which are not covered by this Code. From among the alternative construction methods described by the Code the author has selected those which are most frequently used in practice.

In order to provide the greatest serviceability with this Handbook, rarely occurring loadings, special construction methods or materials have been excluded from its scope. Due to the same reason this Handbook deals only with vessels constructed from ferrous material by welding, since the vast majority of the pressure vessels are in this category.

A large part of this book was taken from the works of others, with some of the material placed in different arrangement, and some unchanged.

The author wishes to acknowledge his indebtedness to Professor Sándor Kalinszky, János Bodor, László Félegyházy and József Györfi for their material and valuable suggestions, to the American Society of Mechanical Engineers and to the publishers, who generously permitted the author to include material from their publications.

The author wishes also to thank all those who helped to improve this new edition by their suggestions and corrections.

Suggestions and criticism concerning some errors which may remain in spite of all precautions shall be greatly appreciated. They contribute to the further improvement of this Handbook.

Eugene F. Megyesy

PRESSURE VESSEL HANDBOOK

Tenth Edition

NOTE:
The CODE "does not contain rules - [as it states in Par. U-2 (g)] - to cover all details of design and construction. Where complete details are not given . . . the manufacturer . . . shall provide details . . ."

BUILD

BETTER VESSEL

FASTER

AND MORE

ECONOMICALLY

Design and construction details **not covered by the code,** have been selected from generally accepted sources, utilizing the most practical and economical methods.

PRESSURE VESSEL PUBLISHING, INC. P.O. BOX 35365 TULSA, OK 74153

CONTENTS

PART I.

DESIGN AND CONSTRUCTION OF PRESSURE VESSEL

IN REFERENCES THROUGHOUT THIS BOOK "CODE" STANDS FOR ASME (AMERICAN SOCIETY OF MECHANICAL ENGINEERS) BOILER AND PRESSURE VESSEL CODE SECTION VIII RULES FOR CONSTRUCTION OF PRESSURE VESSELS, DIVISION 1 — AN AMERICAN STANDARD.

1995 EDITION.

STRESSES IN PRESSURE VESSELS

Pressure vessels are subject to various loadings, which exert stresses of different intensities in the vessel components. The category and intensity of stresses are the function of the nature of loadings, the geometry and construction of the vessel components.

LOADINGS (Code UG-22)

a. Internal or external pressure

b. Weight of the vessel and contents

c. Static reactions from attached equipment, piping, lining, insulation, internals, supports

d. Cyclic and dynamic reactions due to pressure or thermal variations

e. Wind pressure and seismic forces

f. Impact reactions due to fluid shock

g. Temperature gradients and differential thermal expansion

STRESSES (Code UG-23)	MAXIMUM ALLOWABLE STRESS
a. Tensile stress	S_a
b. Longitudinal compressive stress	The smaller of S_a or the value of factor B determined by the procedure described in Code UG 23 (b) (2)
c. General primary membrane stress induced by any combination of loadings. Primary membrane stress plus primary bending stress induced by combination of loadings, except as provided in d. below.	S_a $1.5\ S_a$
d. General primary membrane stress induced by combination of earthquake or wind pressure with other loadings (See definitions pages beginning 473.)	1.2 times the stress permitted in a., b., or c. This rule applicable to stresses exerted by internal or external pressure or axial compressive load on a cylinder.

Seismic force and wind pressure need not be considered to act simultaneously.

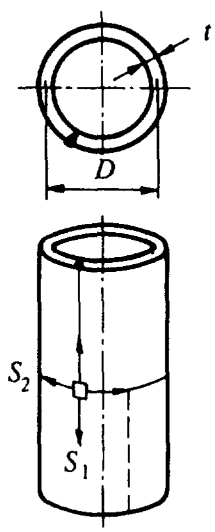
S_a = Maximum allowable stress in tension for carbon and low alloy steel Code Table UCS-23; for high alloy steel Code Table UHA-23., psi. (See properties of materials page 180 - 184.)

STRESSES IN CYLINDRICAL SHELL

Uniform internal or external pressure induces in the longitudinal seam two times larger unit stress than in the circumferential seam because of the geometry of the cylinder.

A vessel under external pressure, when other forces (wind, earthquake, etc.) are not factors, must be designed to resist the circumferential buckling only. The Code provides the method of design to meet this requirement. When other loadings are present, these combined loadings may govern and heavier plate will be required than the plate which was satisfactory to resist the circumferential buckling only.

The compressive stress due to external pressure and tensile stress due to internal pressure shall be determined by the formulas:



FORMULAS

CIRCUMFERENTIAL JOINT	LONGITUDINAL JOINT
$S_1 = \dfrac{PD}{4t}$	$S_2 = \dfrac{PD}{2t}$

NOTATION

D = Mean diameter of vessel, inches
P = Internal or external pressure, psi
S_1 = Longitudinal stress, psi
S_2 = Circumferential (hoop) stress, psi
t = Thickness of shell, corrosion allowance excluded, inches

EXAMPLE

Given D = 96 inches
P = 15 psi
t = 0.25 inches

$$S_1 = \frac{PD}{4t} = \frac{15 \times 96}{4 \times 0.25} = 1440 \text{ psi}$$

$$S_2 = \frac{PD}{2t} = \frac{15 \times 96}{2 \times 0.25} = 2880 \text{ psi}$$

For towers under internal pressure and wind load the critical height above which compressive stress governs can be approximated by the formula:

$$H = \frac{PD}{32t}$$ where H = Critical height of tower, ft.

INTERNAL PRESSURE

1. OPERATING PRESSURE

The pressure which is required for the process, served by the vessel, at which the vessel is normally operated.

2. DESIGN PRESSURE

The pressure used in the design of a vessel. It is recommended to design a vessel and its parts for a higher pressure than the operating pressure. A design pressure higher than the operating pressure with 30 psi or 10 percent, whichever is the greater, will satisfy this requirement. The pressure of the fluid and other contents of the vessel should also be taken into consideration. See tables on page 29 for pressure of fluid.

3. MAXIMUM ALLOWABLE WORKING PRESSURE

The internal pressure at which the weakest element of the vessel is loaded to the ultimate permissible point, when the vessel is assumed to be:

(a) in corroded condition
(b) under the effect of a designated temperature
(c) in normal operating position at the top
(d) under the effect of other loadings (wind load, external pressure, hydrostatic pressure, etc.) which are additive to the internal pressure.

When calculations are not made, the design pressure may be used as the maximum allowable working pressure (MAWP) code 3-2.

A common practice followed by many users and manufacturers of pressure vessels is to limit the maximum allowable working pressure by the head or shell, not by small elements as flanges, openings, etc.

See tables on page 28 for maximum allowable pressure for flanges.

See tables on page 142 for maximum allowable pressure for pipes.

The term, maximum allowable pressure, new and cold, is used very often. It means the pressure at which the weakest element of the vessel is loaded to the ultimate permissible point, when the vessel:

(a) is not corroded (new)
(b) the temperature does not affect its strength (room temperature) (cold)

and the other conditions (c and d above) also need not to be taken into consideration.

4. HYDROSTATIC TEST PRESSURE

One and one-half times the maximum allowable working pressure or the design pressure to be marked on the vessel when calculations are not made to determine the maximum allowable working pressure.

If the stress value of the vessel material at the design temperature is less than at the test temperature, the hydrostatic test pressure should be increased proportionally.

Hydrostatic test shall be conducted after all fabrication has been completed.

In this case, the test pressure shall be:

$$1.5 \times \begin{matrix}\text{Max. Allow. W. Press.}\\ \text{(Or Design Press.)}\end{matrix} \times \frac{\text{Stress Value S At Test Temperature}}{\text{Stress Value S At Design Temperature}}$$

Vessels where the maximum allowable working pressure limited by the flanges, shall be tested at a pressure shown in the table:

Primary Service Pressure Rating	150 lb	300 lb	400 lb	600 lb	900 lb	1500 lb	2500 lb
Hydrostatic Shell Test Pressure	425	1100	1450	2175	3250	5400	9000

Hydrostatic test of multi-chamber vessels: Code UG-99 (e)

A Pneumatic test may be used in lieu of a hydrostatic test per Code UG-100

Proof tests to establish maximum allowable working pressure when the strength of any part of the vessel cannot be computed with satisfactory assurance of safety, prescribed in Code UG-101.

5. MAXIMUM ALLOWABLE STRESS VALUES

The maximum allowable tensile stress values permitted for different materials are given in table on page 189. The maximum allowable compressive stress to be used in the design of cylindrical shells subjected to loading that produce longitudinal compressive stress in the shell shall be determined according to Code par. UG-23 b, c, & d.

6. JOINT EFFICIENCY

The efficiency of different types of welded joints are given in table on page 172. The efficiency of seamless heads is tabulated on page 176.

The following pages contain formulas used to compute the required wall thickness and the maximum allowable working pressure for the most frequently used types of shell and head. The formulas of cylindrical shell are given for the longitudinal seam, since usually this governs.

The stress in the girth seam will govern only when the circumferential joint efficiency is less than one-half the longitudinal joint efficiency, or when besides the internal pressure additional loadings (wind load, reaction of saddles) are causing longitudinal bending or tension. The reason for it is that the stress arising in the girth seam pound per square inch is one-half of the stress in the longitudinal seam.

The formulas for the girth seam accordingly:

$$t = \frac{PR}{2SE + 0.4P} \qquad P = \frac{2SEt}{R - 0.4t}$$

See notation on page 22.

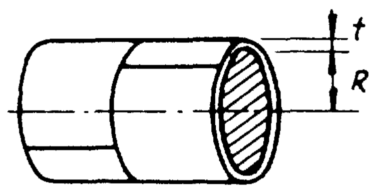
INTERNAL PRESSURE

FORMULAS IN TERMS OF INSIDE DIMENSIONS

NOTATION

P = Design pressure or max. allowable working pressure psi
S = Stress value of material psi, page **189**
E = Joint efficiency, page **172**
R = Inside radius, inches
D = Inside diameter, inches
t = Wall thickness, inches
$C.A.$ = Corrosion allowance, inches

A



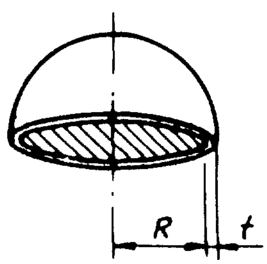
CYLINDRICAL SHELL (LONG SEAM)[1]

$$t=\frac{PR}{SE-0.6P}$$

$$P=\frac{SEt}{R+0.6t}$$

1. Usually the stress in the long seam is governing. See preceding page.
2. When the wall thickness exceeds one half of the inside radius or P exceeds 0.385 SE, the formulas given in the Code Appendix 1-2 shall be applied.

B



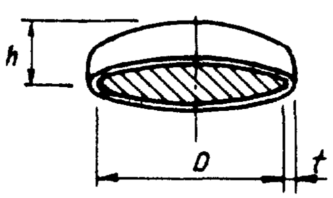
SPHERE and HEMISPHERICAL HEAD

$$t=\frac{PR}{2SE-0.2P}$$

$$P=\frac{2SEt}{R+0.2t}$$

1. For heads without a straight flange, use the efficiency of the head to shell joint if it less than the efficiency of the seams in the head.
2. When the wall thickness exceeds 0.356 R or P exceeds 0.665 SE, the formulas given in the Code Appendix 1-3, shall be applied.

C



h = D/4

2:1 ELLIPSOIDAL HEAD

$$t=\frac{PD}{2SE-0.2P}$$

$$P=\frac{2SEt}{D+0.2t}$$

1. For ellipsoidal heads, where the ratio of the major and minor axis is other than 2:1, see Code Appendix 1-4(c).

EXAMPLES

DESIGN DATA:

P = 100 psi design pressure
S = 17500 psi stress value of SA 515-70 plate @ 650°F
E = 0.85, efficiency of spot-examined joints of shell and hemis. Head to shell
E = 1.00, joint efficiency of seamless heads
R = 48 inches inside radius*
D = 96 inches inside diameter*
t = required wall thickness, inches
$C.A.$ = 0.125 inches corrosion allowance

*in corroded condition greater with the corrosion allowance

SEE DESIGN DATA ABOVE

Determine the required thickness, t of a shell

$$t = \frac{100 \times 48.125}{17500 \times 0.85 - 0.6 \times 100} = 0.325 \text{ in.}$$

+ C.A. 0.125 in.

0.450 in.

Use: 0.500 in. plate

SEE DESIGN DATA ABOVE

Determine the maximum allowable working pressure, P for 0.500 in. thick shell when the vessel is in new condition.

$$P = \frac{17500 \times 0.85 \times 0.500}{48 + 0.6 \times 0.500} = 154 \text{ psi}$$

SEE DESIGN DATA ABOVE

The head furnished without straight flange.

Determine the required thickness, t of a hemispherical head.

$$t = \frac{100 \times 48.125}{2 \times 17500 \times 0.85 - 0.2 \times 100} = 0.162 \text{ in.}$$

+ C.A. 0.125 in.

0.287 in.

Use: 0.3125 in MIN. THK. HEAD

SEE DESIGN DATA ABOVE

Determine the maximum allowable working pressure, P for 0.3125 in. thick head, when it is in new condition.

$$P = \frac{2 \times 17500 \times 0.85 \times 0.3125}{48 + 0.2 \times 0.3125} = 193 \text{ psi}$$

SEE DESIGN DATA ABOVE

Determine the required thickness of a seamless ellipsoidal head.

$$t = \frac{100 \times 96.25}{2 \times 17500 \times 1.0 - 0.2 \times 100} = 0.275 \text{ in.}$$

+ C.A. 0.125 in.

0.400 in.

Use: 0 4375 in. MIN. THK. HEAD

SEE DESIGN DATA ABOVE

Determine the maximum allowable working pressure, P for 0.275 in. thick, seamless head when it is in corroded condition.

$$P = \frac{2 \times 17500 \times 1.0 \times 0.275}{96.25 + 0.2 \times 0.275} = 100 \text{ psi}$$

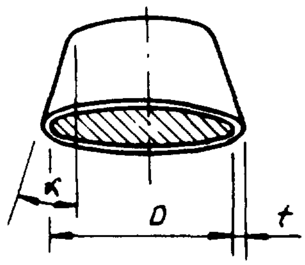
INTERNAL PRESSURE

FORMULAS IN TERMS OF INSIDE DIMENSIONS

NOTATION

P = Design pressure or max. allowable working pressure psi
S = Stress value of material psi, page 189
E = Joint efficiency, page 172
R = Inside radius, inches
D = Inside diameter, inches
α = One half of the included (apex) angle, degrees
L = Inside radius of dish, inches
r = Inside knuckle radius, inches
t = Wall thickness, inches
$C.A.$ = Corrosion allowance, inches

D



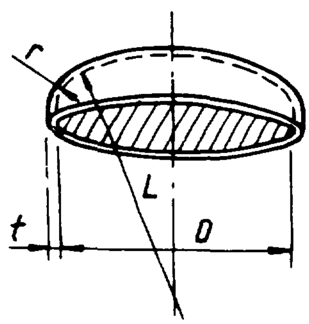
CONE AND CONICAL SECTION

$$t=\frac{PD}{2\cos\alpha\,(SE-0.6P)}$$

$$P=\frac{2SEt\cos\alpha}{D+1.2t\cos\alpha}$$

1. The half apex angle, α not greater than 30°
2. When α is greater than 30°, special analysis is required. (Code Appendix 1-5(e))

E



ASME FLANGED AND DISHED HEAD (TORISPHERICAL HEAD)

When $L/r = 16\,2/3$

$$t=\frac{0.885PL}{SE-0.1P}$$

$$P=\frac{SEt}{0.885L+0.1t}$$

When L/r less than $16\,2/3$

$$t=\frac{PLM}{2SE-0.2P}$$

$$P=\frac{2SEt}{LM+0.2t}$$

VALUES OF FACTOR "M"

L/r	1.00	1.25	1.50	1.75	2.00	2.25	2.50	2.75	3.00	3.25	3.50	4.00	4.50	5.00	5.50	6.00	6.50
M	1.00	1.03	1.06	1.08	1.10	1.13	1.15	1.17	1.18	1.20	1.22	1.25	1.28	1.31	1.34	1.36	1.39
L/r	7.00	7.50	8.00	8.50	9.00	9.50	10.0	10.5	11.0	11.5	12.0	13.0	14.0	15.0	16.0	$16\frac{2}{3}$	*
M	1.41	1.44	1.46	1.48	1.50	1.52	1.54	1.56	1.58	1.60	1.62	1.65	1.69	1.72	1.75	1.77	

* THE MAXIMUM ALLOWED RATIO : L = D + 2t (see note 2 on facing page)

EXAMPLES

DESIGN DATA:

P = 100 psi design pressure
S = 17500 psi stress value of SA 515-70 plate @ 650°F
E = 0.85, efficiency of spot-examined joints
E = 1.00, joint efficiency of seamless heads

R = 48 inches inside radius*
D = 96 inches inside diameter*
α = required wall thickness, inches
L = 30° one half of the apex angle
t = Resuired wall thickness inches
$C.A.$ = 0.125 inches corrosion allowance
* in corroded condition greater with the corrosion allowance

SEE DESIGN DATA ABOVE

cos 30° = 0.866

Determine the required thickness, t of a cone

$$t = \frac{100 \times 96.25}{2 \times 0.866\,(17500 \times 0.85 - 0.6 \times 100)} = 0.375 \text{ in.}$$

+C.A. 0.125 in.

0.500 in.

Use 0.500 in. plate

SEE DESIGN DATA ABOVE

Determine the maximum allowable working pressure, P for 0.500 in. thick cone, when the vessel is in new condition.

$$P = \frac{2 \times 17500 \times 0.85 \times 0.500 \times 0.866}{96 + 1.2 \times 0.500 \times 0.866} = 133 \text{ psi}$$

SEE DESIGN DATA ABOVE

$L/r = 16\frac{2}{3}$

Determine the required thickness, t of a seamless ASME flanged and dished head.

$$t = \frac{0.885 \times 100 \times 96.125}{17500 \times 1.0 - 0.1 \times 100} = 0.486 \text{ in.}$$

+C.A. 0.125 in.

0.611 in.

Use 0.625 in. plate

SEE DESIGN DATA ABOVE

Determine the maximum allowable working pressure, P for 0.6875 in. thick seamless head, when the vessel is in new condition.

$$P = \frac{17500 \times 1.0 \times 0.6875}{0.885 \times 96 + 0.1 \times 0.6875} = 141 \text{ psi}$$

SEE DESIGN DATA ABOVE

Knuckle radius r = 6 in. $L/r = \frac{96}{6} = 16$

M = 1.75 from table.

Determine the required thickness t of a seamless ASME flanged and dished head.

$$t = \frac{100 \times 96.125 \times 1.75}{2 \times 17500 - 0.2 \times 100} = 0.481 \text{ in.}$$

+C.A. 0.125 in.

0.606 in.

Use 0.625 in. min. thick head

SEE DESIGN DATA ABOVE

Knuckle radius r = 6 in. $L/r = \frac{96}{6} = 16$

M = 1.75 from table

Determine the maximum allowable working pressure, P for a 0.481 in. thick seamless head when the vessel is in corroded condition.

$$P = \frac{2 \times 17500 \times 1.0 \times 0.481}{96.125 \times 1.75 + 0.2 \times 0.481} = 100 \text{ psi}$$

NOTE: When the ratio of L/r is greater than $16\frac{2}{3}$, (non-Code construction) the values of M may be calculated by the formula: $M = \frac{1}{4}(3 + \sqrt{L/r})$

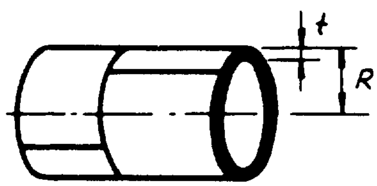
INTERNAL PRESSURE

FORMULAS IN TERMS OF OUTSIDE DIMENSIONS

NOTATION

P = Design pressure or max. allowable working pressure psi
S = Stress value of material psi, page 189
E = Joint efficiency, page 172
R = Outside radius, inches
D = Outside diameter, inches
t = Wall thickness, inches
$C.A.$ = Corrosion allowance, inches

A



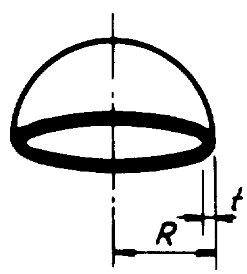
CYLINDRICAL SHELL (LONG SEAM)[1]

$$t = \frac{PR}{SE + 0.4P}$$

$$P = \frac{SEt}{R - 0.4t}$$

1. Usually the stress in the long seam is governing. See page 14
2. When the wall thickness exceeds one half of the inside radius or P exceeds 0.385 SE, the formulas given in the Code Appendix 1-2 shall be applied.

B



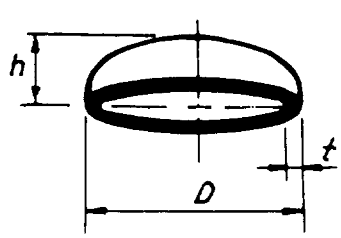
SPHERE and HEMISPHERICAL HEAD

$$t = \frac{PR}{2SE + 0.8P}$$

$$P = \frac{2SEt}{R - 0.8t}$$

1. For heads without a straight flange, use the efficiency of the head to shell joint if it is less than the efficiency of the seams in the head.
2. When the wall thickness exceeds 0.356 R or P exceeds 0.665 SE, the formulas given in the Code Appendix 1-3, shall be applied.

C



h = D/4

2:1 ELLIPSOIDAL HEAD

$$t = \frac{PD}{2SE + 1.8P}$$

$$P = \frac{2SEt}{D - 1.8t}$$

1. For ellipsoidal heads, where the ratio of the major and minor axis is other than 2:1, see Code Appendix 1-4(c).

EXAMPLES

DESIGN DATA:

P = 100 psi design pressure
S = 17500 psi stress value of SA 515-70 plate @ 650°F
E = 0.85, efficiency of spot-examined joints of shell and hemis. head to shell
E = 1.00, joint efficiency of seamless heads

E = 1.00 joint efficiency of seamless heads
R = 48 inches outside radius
D = 96 inches outside diameter
t = Required wall thickness, inches
$C.A.$ = 0.125 inches corrosion allowance

SEE DESIGN DATA ABOVE

Determine the required thickness, t of a shell

$$t = \frac{100 \times 48}{17500 \times 0.85 - 0.4 \times 100} = 0.322 \text{ in.}$$

+C.A. 0.125 in.
0.447 in.

Use: 0.500 in. thick plate

SEE DESIGN DATA ABOVE

Determine the maximum allowable working pressure, P for 0.500 in. thick shell when the vessel is in new condition.

$$P = \frac{17500 \times 0.85 \times 0.500}{48 - 0.4 \times 0.500} = 155 \text{ psi}$$

SEE DESIGN DATA ABOVE

Head furnished without straight flange.

Determine the required thickness, t of a hemispherical head.

$$t = \frac{100 \times 48}{2 \times 17500 \times 0.85 + 0.8 \times 100} = 0.161 \text{ in.}$$

+C.A. 0.125 in.
0.286 in.

Use: 0.3215 in. min. thick head

SEE DESIGN DATA ABOVE

Determine the maximum allowable working pressure, P for 0.3125 in. thick head, when the vessel is in new condition.

$$P = \frac{2 \times 17500 \times 0.85 \times 0.3125}{48 - 0.8 \times 0.3125} = 194 \text{ psi}$$

SEE DESIGN DATA ABOVE

Determine the required thickness t of a seamless ellipsoidal head.

$$t = \frac{100 \times 96}{2 \times 17500 \times 1.0 + 1.8 \times 100} = 0.273 \text{ in.}$$

+C.A. 0.125 in.
0.398 in.

Use 0.4375 in. min. thick head

SEE DESIGN DATA ABOVE

Determine the maximum allowable working pressure, P for 0.273 in. thick head, when it is in new condition.

$$P = \frac{2 \times 17500 \times 1.0 \times 0.273}{96 - 1.8 \times 0.273} = 100 \text{ psi}$$

INTERNAL PRESSURE

FORMULAS IN TERMS OF OUTSIDE DIMENSIONS

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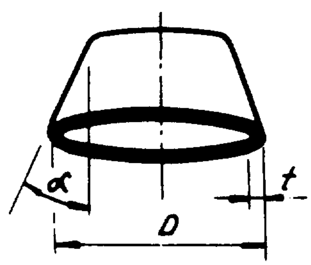
R = Outside radius, inches
D = Outside diameter, inches
α = One half of the included (apex) angle, degrees
L = Outside radius of dish, inches
r = Inside knuckle radius, inches
t = Wall thickness, inches
$C.A.$ = Corrosion allowance, inches

D



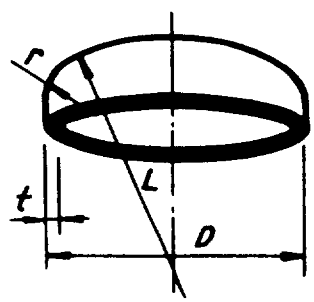
CONE AND CONICAL SECTION

$$t=\frac{PD}{2\cos\alpha\,(SE+0.4P)}$$

$$P=\frac{2SEt\cos\alpha}{D-0.8t\cos\alpha}$$

1. The half apex angle, α not greater than 30°
2. When α is greater than 30°, special analysis is required. (Code Appendix 1-5(e))

E



ASME FLANGED AND DISHED HEAD
(TORISPHERICAL HEAD)

When $L/r = 16^2/_3$

$$t=\frac{0.885PL}{SE+0.8P}$$

$$P=\frac{SEt}{0.885L-0.8t}$$

When L/r Less Than $16^2/_3$

$$t=\frac{PLM}{2SE+P(M-0.2)}$$

$$P=\frac{2SEt}{ML-t(M-0.2)}$$

VALUES OF FACTOR M

L/r	1.00	1.25	1.50	1.75	2.00	2.25	2.50	2.75	3.00	3.25	3.50	4.00	4.50	5.00	5.50	6.00	6.50
M	1.00	1.03	1.06	1.08	1.10	1.13	1.15	1.17	1.18	1.20	1.22	1.25	1.28	1.31	1.34	1.36	1.39
L/r	7.00	7.50	8.00	8.50	9.00	9.50	10.0	10.5	11.0	11.5	12.0	13.0	14.0	15.0	16.0	16⅔	•
M	1.41	1.44	1.46	1.48	1.50	1.52	1.54	1.56	1.58	1.60	1.62	1.65	1.69	1.72	1.75	1.77	

• THE MAXIMUM ALLOWED RATIO : L - t = D (see note 2 on facing page)

EXAMPLES

DESIGN DATA:

P = 100 psi design pressure
S = 17500 psi stress value of SA 515-70 plate @ 650°F
E = 0.85, efficiency of spot-examined joints
E = 1.00, joint efficiency of seamless heads
R = 48 inches outside radius
D = 96 inches outside diameter
α = 30° one half of the apex angle
L = 96 inches outside radius of dish
t = Required wall thickness, inches
$C.A.$ = 0.125 inches corrosion allowance

SEE DESIGN DATA ABOVE

cos 30° = 0.866

Determine the required thickness, t of a cone

$$t = \frac{100 \times 96}{2 \times 0.866 \times (17500 \times 0.85 + 0.4 \times 100)} = 0.372 \text{ in.}$$

+C.A.	0.125 in.
	0.497 in.

Use: 0.500 in. thick plate

SEE DESIGN DATA ABOVE

Determine the maximum allowable working pressure, P for 0.500 in. thick cone.

$$t = \frac{2 \times 17500 \times 0.85 \times 0.500 \times 0.866}{96 - (0.8 \times 0.500 \times 0.866)} = 134 \text{ psi}$$

SEE DESIGN DATA ABOVE

$L/r = 16\frac{2}{3}$

Determine the required thickness, t of a seamless ASME flanged and dished head.

$$t = \frac{0.885 \times 100 \times 96}{17500 \times 1.0 + 0.8 \times 100} = 0.483 \text{ in.}$$

+C.A.	0.125 in.
	0.608 in.

Use: 0.625 in. min. thick head

SEE DESIGN DATA ABOVE

Determine the maximum allowable working pressure, P for 0.625 in. thick seamless head, when the vessel is in corroded condition.

$$P = \frac{17500 \times 1.0 \times 0.625}{0.885 \times 96 - 0.8 \times 0.625} = 129 \text{ psi}$$

SEE DESIGN DATA ABOVE

Knuckle radius r = 6 in. $L/r = \frac{96}{6} = 16$

M = 1.75 from table.

Determine the required thickness t of a seamless ASME flanged and dished head.

$$t = \frac{100 \times 96 \times 1.75}{2 \times 17500 \times 1.0 \times 100 (1.75 - 0.2)} = 0.478 \text{ in.}$$

+C.A.	0.125 in.
	0.603 in.

Use 0.625 in. min. thick head

SEE DESIGN DATA ABOVE

Knuckle radius r = 6 in. $L/r = \frac{96}{6} = 16$

M = 1.75 from table.

Determine the maximum allowable working pressure, P for a 0.478 in. thick seamless head when the vessel is in corroded condition.

$$t = \frac{2 \times 17500 \times 1.0 \times 0.478}{1.75 \times 96 - 0478 (1.75 - 0.2)} = 100 \text{ psi}$$

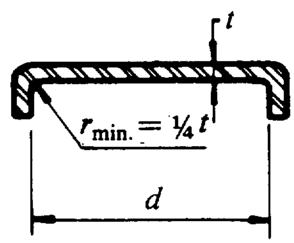
NOTE: When the ratio of L/r is greater than $16\frac{2}{3}$, (non-Code construction) the values of M may be calculated by the formula: $M = \frac{1}{4}(3 + \sqrt{L/r})$

INTERNAL OR EXTERNAL PRESSURE
FORMULAS

NOTATION

P = Internal or external design pressure psi **E=joint efficiency**
d = Inside diameter of shell, in.
S = Maximum allowable stress value of material, psi
t = Minimum required thickness of head, exclusive of corrosion allowance, in.
t_h = Actual thickness of head exclusive of corrosion allowance, in.
t_r = Minimum required thickness of seamless shell for pressure, in.
t_s = Actual thickness of shell, exclusive of corrosion allowance, in.

A

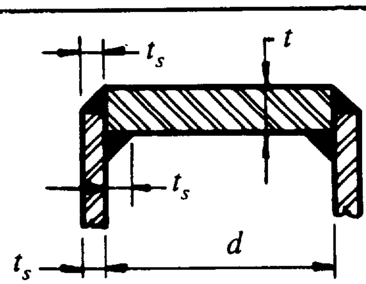


CIRCULAR FLAT HEADS

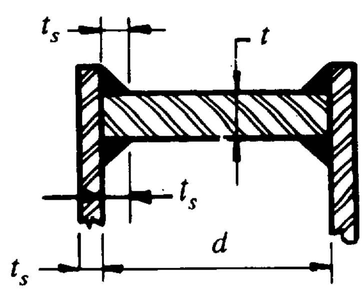
$$t = d\sqrt{0.13\,P/SE}$$

This formula shall be applied:
1. When d does not exceed 24 in.
2. t_h/d is not less than 0.05 nor greater than 0.25
3. The head thickness, t_h is not less than the shell thickness, t_s

B



C



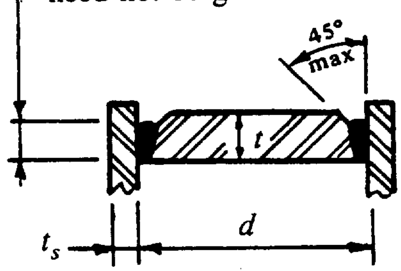
$$t = d\sqrt{CP/SE}$$

$$C = 0.33\,t_r/t_s$$

$$C \text{ min.} = 0.20$$

D

2 $t_r$min. nor less than $1.25t_s$
need not be greater than t



If a value of t_r/t_s less than 1 is used in calculating t, the shell thickness t_s shall be maintained along a distance inwardly from the inside face of the head equal to at least

$$2\sqrt{dt_s}$$

Non-circular, bolted flat heads, covers, blind flanges Code UG-34; other types of closures Code UG-35

INTERNAL OR EXTERNAL PRESSURE
EXAMPLES

DESIGN DATA

P = 300 psi design pressure E=joint efficiency

d = 24 in. inside diameter of shell

S = 15,000 psi maximum allowable stress value of SA-515-60 plate

t_r = 0.243 in. required thickness of seamless shell for pressure.

t_s = 0.3125 in. actual thickness of shell.

DETERMINE THE MINIMUM REQUIRED THICKNESS, t

$$t = d\sqrt{0.13\ P/SE} = 24\sqrt{0.13 \times 300/15{,}000 \times 1} = 1.223 \text{ in.}$$

Use 1.250 in. head

Checking the limitation of $\dfrac{t_h}{d} = \dfrac{1.250}{24} = 0.052$,

The ratio of head thickness to the diameter of the shell is satisfactory

SEE DESIGN DATA ABOVE

$$C = 0.33\frac{t_r}{t_s} = 0.33\frac{0.243}{0.3125} = 0.26$$

$$t = d\sqrt{CP/SE} = 24\sqrt{0.26 \times 300/15{,}000 \times 1} = 1.731 \text{ in.}$$

Use 1.75 in. plate

Using thicker plate for shell, a lesser thickness will be satisfactory for the head

t_s = 0.375 in.

$$C = 0.33\frac{t_r}{t_s} = 0.33\frac{0.243}{0.375} = 0.214$$

$$t = d\sqrt{CP/SE} = 24\sqrt{0.214 \times 300/15{,}000 \times 1} = 1.57 \text{ in.}$$

Use 1.625 in. plate

The shell thickness shall be maintained along a distance $2\sqrt{dt_s}$ from the inside face of the head

$$2\sqrt{24 \times 0.375} = 6 \text{ in.}$$

PRESSURE – TEMPERATURE RATINGS

FOR STEEL PIPE FLANGES AND FLANGED FITTINGS

American National Standard ANSI B16.5-1981

CLASS	150 lb.	300 lb.	400 lb.	600 lb.	900 lb.	1500 lb.	2500 lb.
HYDROSTATIC TEST PRESSURE, PSIG	450	1125	1500	2225	3350	5575	9275
TEMPERATURE, F	MAXIMUM ALLOWABLE NON-SHOCK PRESSURE PSIG.						
-20 to 100	285	740	990	1480	2220	3705	6170
200	260	675	900	1350	2025	3375	5625
300	230	655	875	1315	1970	3280	5470
400	200	635	845	1270	1900	3170	5280
500	170	600	800	1200	1795	2995	4990
600	140	550	730	1095	1640	2735	4560
650	125	535	715	1075	1610	2685	4475
700	110	535	710	1065	1600	2665	4440
750	95	505	670	1010	1510	2520	4200
800	80	410	550	825	1235	2060	3430
850	65	270	355	535	805	1340	2230
900	50	170	230	345	515	860	1430
950	35	105	140	205	310	515	860
1000	20	50	70	105	155	260	430

Ratings apply to materials:

SA-105[1,2] SA-515-70[2] SA-516-70[2] SA-181-70[1,2] SA-350-LF2
SA-537-C1.1[3] SA-216-WCB[2]

NOTES:

1. For service temperatures above 850 F it is recommended that killed steels containing not less than 0.10% residual silicon be used.
2. Upon prolonged exposure to temperatures above 800 F, the carbide phase of carbon steel may be converted to graphite.
3. The material shall not be used in thickness above 2½ in.

Flanges of ANSI B16.5 shall not be used for higher ratings except where it is justified by the design methods of the Code.

Ratings are maximum allowable non-shock working pressures expressed as gage pressure, at the tabulated temperatures and may be interpolated between temperatures shown.

Temperatures are those on the inside of the pressure-containing shell of the flange. In general, it is the same as that of the contained material.

PRESSURE OF FLUID

STATIC HEAD

The fluid in the vessel exerts pressure on the vessel wall. The intensity of the pressure when the fluid is at rest is equal in all directions on the sides or bottom of the vessel and is due to the height of the fluid above the point at which the pressure is considered.

The static head when applicable shall be added to the design pressure of the vessel.

The tables below show the relations between the pressure and height of the water.

To find the pressure for any other fluids than water, the values given in the tables shall be multiplied with the specific gravity of the fluid in consideration.

Pressure in Pounds per Square Inch for Different Heads of Water

Head, Feet	0	1	2	3	4	5	6	7	8	9
0		0.43	0.87	1.30	1.73	2.16	2.60	3.03	3.46	3.90
10	4.33	4.76	5.20	5.63	6.06	6.49	6.93	7.36	7.79	8.23
20	8.66	9.09	9.53	9.96	10.39	10.82	11.26	11.69	12.12	12.56
30	12.99	13.42	13.86	14.29	14.72	15.15	15.59	16.02	16.45	16.89
40	17.32	17.75	18.19	18.62	19.05	19.48	19.92	20.35	20.78	21.22
50	21.65	22.08	22.52	22.95	23.38	23.81	24.25	24.68	25.11	25.55
60	25.98	26.41	26.85	27.28	27.71	28.14	28.58	29.01	29.44	29.88
70	30.31	30.74	31.18	31.61	32.04	32.47	32.91	33.34	33.77	34.21
80	34.64	35.07	35.51	35.94	36.37	36.80	37.24	37.67	38.10	38.54
90	38.97	39.40	39.84	40.27	40.70	41.13	41.57	42.00	42.43	42.87

NOTE: One foot of water at 62° Fahrenheit equals .433 pound pressure per square inch. To find the pressure per square inch for any feet head not given in the table above, multiply the feet head by .433.

Heads of Water in Feet Corresponding to Certain Pressure in Pounds per Square Inch

Pressure, Lbs.	0	1	2	3	4	5	6	7	8	9
0		2.3	4,6	6.9	9.2	11.5	13.9	16.2	18.5	20.8
10	23.1	25.4	27.7	30.0	32.3	34.6	36.9	39.3	41.6	43.9
20	46.2	48.5	50.8	53.1	55.4	57.7	60.0	62.4	64.7	67.0
30	69.3	71.6	73.9	76.2	78.5	80.8	83.1	85.4	87.8	90.1
40	92.4	94.7	97.0	99.3	101.6	103.9	106.2	108.5	110.8	113.2
50	115.5	117.8	120.1	122.4	124.7	127.0	129.3	131.6	133.9	136.3
60	138.6	140.9	143.2	145.5	147.8	150.1	152.4	154.7	157.0	159.3
70	161.7	164.0	166.3	168.6	170.9	173.2	175.5	177.8	180.1	182.4
80	184.8	187.1	189.4	191.7	194.0	196.3	198.6	200.9	203.2	205.5
90	207.9	210.2	212.5	214.8	217.1	219.4	221.7	224.0	226.3	228.6

NOTE: One pound of pressure per square inch of water equals 2.309 feet of water at 62° Fahrenheit. Therefore, to find the feet head of water for any pressure not given in the table above, multiply the pressure pounds per square inch by 2.309.

TABLES

for quick comparison of required plate thickness and weight for various materials and at different degree of radiographic examination.

A Stress values at temp. -20 to 650° F.

	SA-285 C	SA 53B SA 515-60 SA 516-60	SA 515-70 SA 516-70
85% J. E.	11730	12750	14875
100% J. E.	13800	15000	17500

B Ratios of Stress Values

	11730	12750	13800	14875	15000	17500
11730	—	1.09	1.18	1.27	1.28	1.49
12750	0.92	—	1.08	1.17	1.18	1.37
13800	0.85	0.92	—	1.08	1.09	1.27
14875	0.79	0.86	0.93	—	1.01	1.18
15000	0.78	0.85	0.92	0.99	—	1.17
17500	0.67	0.73	0.79	0.85	0.86	—

Table **A** shows the stress value of the most frequently used shell and head materials.

Table **B** shows the ratios of these stress values.

EXAMPLE:

1. For a vessel using SA 515-70 plate, when spot radiographed, the required thickness 0.4426 inches and the weight of the vessel 12600 lbs.
2. What plate thickness will be required and what will the weight of the vessel be, using SA 285-C plate and full radiographic examination:

   In case 1. The stress value of the material 14875

   In case 2. The stress value of the material 13800

The ratio of the two stress values from Table B = 1.08. In this proportion will be increased the required plate thickness and the weight of the vessel.

$0.4426 \times 1.08 = 0.4780$ in.

$12600 \times 1.08 = 13608$ lb.

EXTERNAL PRESSURE

Design Pressure

Vessels intended for service under external working pressures of 15 psi or less, which are to be stamped with the Code symbol denoting compliance with the rules for external pressure, shall be designed for a maximum allowable external pressure of 15 psi or 25 per cent more than the maximum possible external pressure, whichever is smaller. Code UG - 28 (f)

A vessel which is designed and constructed to Code requirements for internal pressure and which is required to be designed for an external pressure of 15 psi or less need not be designed to Code rules for the external pressure condition. However, no external pressure rating may be shown with the Code stamping unless Code requirements for external pressure are met. Code UG-28 (f) note.

This shall not be applied if the vessel is operated at a temperature below minus 20 F and the design pressure is determined by the Code UCS - 66 (c) (2) or Code UHA - 51 (b) to avoid the necessity of impact test.

Vessels with lap joints: Code UG - 28 (g) Non cylindrical vessel, jacket: Code UG - 28 (i)

Test Pressure

Single-wall vessels designed for vacuum or partial vacuum only, shall be subjected to an internal hydrostatic test or when a hydrostatic test is not practicable, to a pneumatic test. UG - 99 (f)

Either type of test shall be made at a pressure not less than 1 1/2 times the difference between normal atmospheric pressure and the minimum design internal absolute pressure. UG - 99 (f)

Pneumatic test: Code UG - 100

The design method on the following pages conform to ASME Code for Pressure Vessels Section VIII. DIV. 1. The charts on pages 42 thru 47 are excerpted from this Code.

EXTERNAL PRESSURE

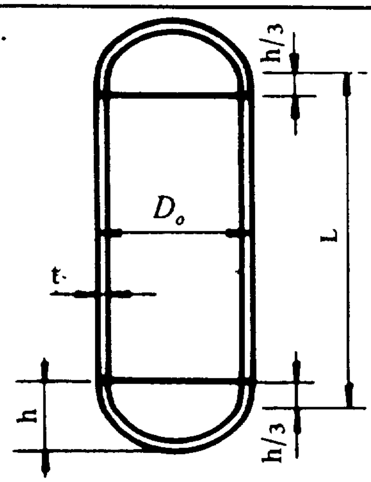
FORMULAS

NOTATION

P = External design pressure, psig.
P_a = Maximum allowable working pressure, psig.
D_o = Outside diameter, in.
L = the length, in. of vessel section between:
1. circumferential line on a head at one-third the depth of the head-tangent line,
2. stiffening rings
3. jacket closure
4. cone-to-cylinder junction or knuckle-to-cylinder junction of a toriconical head or section,
5. tube sheets (see page 39)

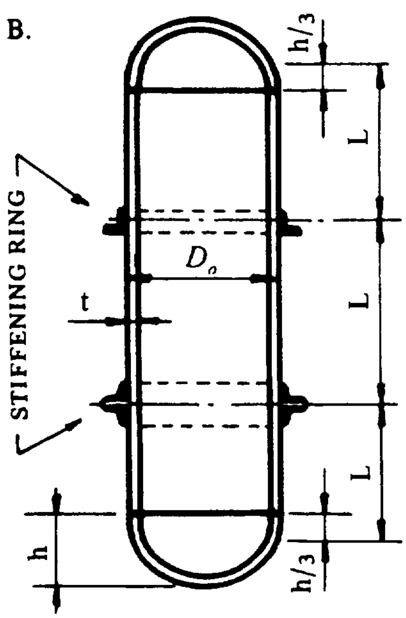
t = Minimum required wall thickness, in.

A.



VESSEL
WITHOUT STIFFENING RING

B.



VESSEL
WITH STIFFENING RING

CYLINDRICAL SHELL
Seamless or with Longitudinal Butt Joints

When D_o/t equal to or greater than 10 the maximum allowable pressure:

$$P_a = \frac{4B}{3(D_o/t)}$$

The value of B shall be determined by the following procedure:
1. Assume a value for t; (See pages 49-51) Determine L/D_o and D_o/t
2. Enter Fig. UGO-28.0 (Page 42) at the value of L/D_o. Enter at 50 when L/D_o is greater than 50, and at 0.05 when L/D_o is less than 0.05.
3. Move horizontally to the line representing D_o/t. From the point of intersection move vertically to determine the value of factor A.
4. Enter the applicable material chart (pages 43-47) at the value of A. Move vertically to the applicable temperature line*.
5. From the intersection move horizontally and read the value of B.

Compute the maximum allowable working pressure, P_a.

If the maximum allowable working pressure is smaller than the design pressure, the design procedure must be repeated increasing the vessel thickness or decreasing L by stiffening ring.

*For values of A falling to the left of the applicable temperature line, the value of P_a can be calculated by the formula:

$$P_a = \frac{2AE}{3(D_o/t)}$$

When the value of D_o/t is less than 10, the formulas given in the Code UG-28(c)(2) shall be applied.

EXAMPLES

DESIGN DATA

P = 15 psig. external design pressure

D_o = 96 in. outside diatmeter of the shell

Length of the vessel from tangent line to tangent line: 48 ft. 0 in. = 576 in.

Heads 2:1 ellipsoidal

Material of shell SA - 285 C plate

Temperature 500° F

E = Modulus of elasticity of material, 27,000,000 psi. @ 500 °F (see chart on page 43)

Determine the required shell thickness.

Assume a shell thickness: t = 0.50 in. (see page 49)

Length L = 592 in. (length of shell 576 in. and one third of the depth of heads 16 in.)

L/D_o = 592/96 = 6.17 D_o/t = 96/0.5 = 192

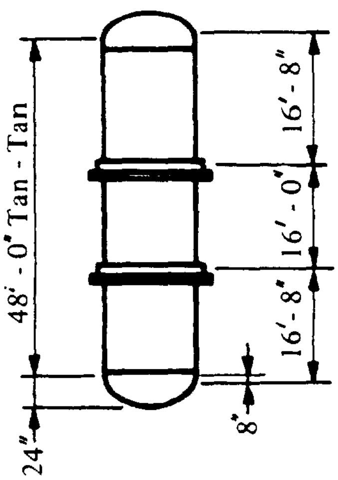
A=0.00007 from chart (page 42) determined by the procedure described on the facing page.

Since the value of A is falling to the left of the applicable temperature-line in Fig. UCS-28.2 (page 43),

$P_a = 2AE/3(D_o/t)$ = 2 x 0.00007 x 27,000,000/3 x 192 = 6.56 psi.

Since the maximum allowable pressure P_a is smaller than the design pressure P stiffening rings shall be provided.

Using 2 stiffening rings equally spaced between the tangent lines of the heads, Length of one vessel section, L = 200 in.(length of shell 192 in. plus one third of depth of head 8 in.)



L/D_o = 200/96 = 2.08 D_o/t = 96/0.5 = 192

A = 0.00022 from chart (page 42)

B = 3000 from chart (page 43)

determined by the procedure described on facing page.

$P_a = 4B/3(D_o/t)$ = 4 x 3000/3 x 192 = 20.8 psi.

Since the maximum allowable pressure P_a is greater than the design pressure P, the assumed thickness of shell using two stiffening rings, is satisfactory.

See page 40 for design of stiffening rings.

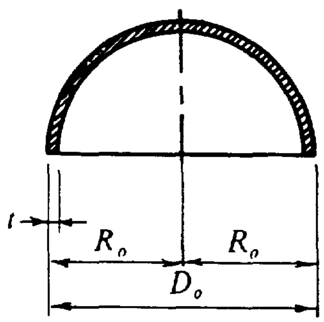
EXTERNAL PRESSURE

FORMULAS

NOTATION

P = External design pressure psig.
P_a = Maximum allowable working pressure psig.
D_o = Outside diameter of the head, in.
R_o = Outside radius of sphere or hemisphereical head, $0.9D_o$ for ellipsoidal heads, inside crown radius of flanged and dished heads, in.
t = Minimum required wall thickness, inches.
E = Modulus of elasticity of material, psi. (page 43)

SPHERE and HEMISPHERICAL HEAD



The maximum allowable pressure: $P_a = \dfrac{B}{(R_o/t)}$

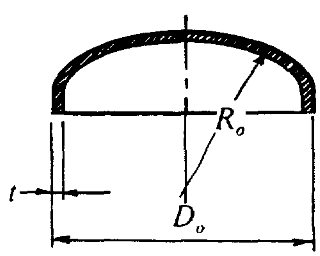
The value of B shall be determined by the following procedure:

1. Assume the value for t and calculate the value of A using the formula: $A=0.125/(R_o/t)$ (see page 49)
2. Enter the applicable material chart (pages 43–47) at the value of A. Move vertically to the applicable temperature line.*
3. From the intersection move horizontally and read the value of B.

*For values of A falling to the left of the applicable temperature line, the value of P_a can be calculated by the formula: $P_a = 0.0625E/(R_o/t)^2$

If the maximum allowable working pressure P_a computed by the formula above, is smaller than the design pressure, a greater value for t must be selected and the design procedure repeated.

2:1 ELLIPSOIDAL HEAD

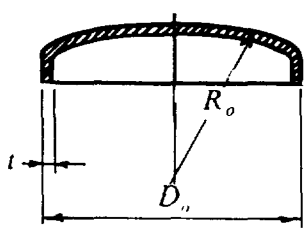


The required thickness shall be the greater of the following thicknesses.

(1) The thickness as computed by the formulas given for internal pressure using a design pressure 1.67 times the external pressure and joint efficiency E=1.00.

(2) The thickness proofed by formula $P_a=B/(R_o/t)$ where R_o=0.9 D_o, and B to be determined as for sphere.

ASME FLANGED AND DISHED HEAD
(TORISPHERICAL HEAD)



The required thickness and maximum allowable pressure shall be computed by the procedures given for ellipsoidal heads. (See above) R_o maximum=D_o

EXAMPLES

DESIGN DATA:

P = 15 psig external design pressure
D_o = 96 inches outside diameter of head
Material of the head SA-285C plate
500°F design temperature

Determine the required head thickness.

SEE DESIGN DATA ABOVE

Assume a head thickness: $t = 0.25$ in. $R_o = 48.00$ in.

$A = 0.125/(48.00/0.25) = 0.00065$

From Fig. UCS-28.2 (page 43) $B = 8500$ determined by the procedure described on the facing page.

$P_a = 8500/(48.00/0.25) = 44.27$ psi.

Since the maximum allowable working pressure P_a is exceedingly greater than the design pressure P, a lesser thickness would be satisfactory.

For a second trial, assume a head thickness: t = 0.1875 in.
$R_o = 48.00$ in.
$A = 0.125/(48.00/0.1875) = 0.0005$
$B = 6700$, from chart (page 43), $P_a = B/(R_o/t) = 6700/256 = 26.2$ psi.

The assumed thickness: t = 0.1875 in. is satisfactory.

SEE DESIGN DATA ABOVE. Procedure (2.)

Assume a head thickness: $t = 0.3125$ in., $R_o = 0.9 \times 96 = 86.4$ in.

$A = 0.125/(86.4/0.3125) = 0.00045$
$B = 6100$ from chart (page 43), $P_a = B/(R_o/t) = 6100/276 = 22.1$ psi.

Since the maximum allowable pressure P_a is greater than the design pressure P the assumed thickness is satisfactory.

SEE DESIGN DATA ABOVE. Procedure (2.)

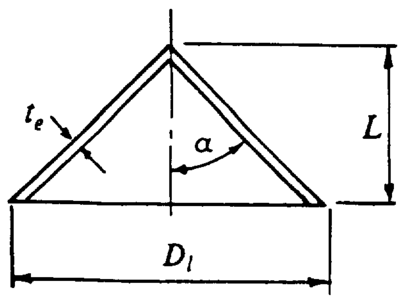
Assume a head thickness: $t = 0.3125$ in., $R_o = D_o = 96$ in.

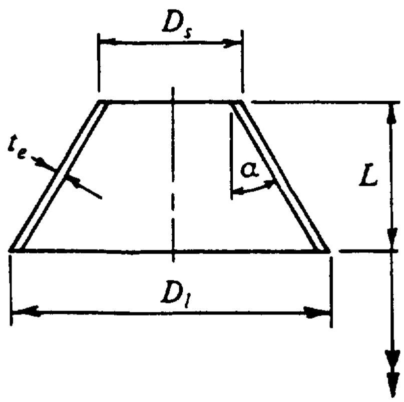
$A = 0.125/(96/0.3125) = 0.0004$
$B = 5200$ from chart (page 43), $P_a = B/(R_o/t) = 5200/307 = 16.93$ psi.

Since the maximum allowable pressure P_a is greater than the design pressure P the assumed thickness is satisfactory.

EXTERNAL PRESSURE

FORMULAS





NOTATION

A = factor determined from fig.UGO-28.0 (page 42)
B = factor determined from charts (pages 43-47)
α = one half of the included (apex) angle, degrees
D_l = outside diameter at the large end, in.
D_s = outside diameter at the small end, in.
E = modulus of elasticity of material (page 43)
L = length of cone, in. (see page 39)
L_e = equivalent length of conical section, in.$(L/2)(1+D_s/D_l)$
P = external design pressure, psi.
P_a = Maximum allowable working pressure, psi
t = minimum required thickness, in.
t_e = effective thickness, in. $= t \cos \alpha$

CONE AND CONICAL SECTION

Seamless or with Butt Joints

WHEN α IS EQUAL TO OR LESS THAN 60°
and $D_l/t_e \geq 10$
The maximum allowable pressure:

$$P_a = \frac{4B}{3(D_l/t_e)}$$

1. Assume a value for thickness, t_e
   The values of B shall be determined by the following procedure:
2. Determine t_e, L_e, and the ratios L_e/D_l and D_l/t_e
3. Enter chart UGO-28 (page 42) at the value of L_e/D_l (L/D_o) (Enter at 50 when L_e/D_l is greater than 50) Move horizontally to the line representing D_o/t. From the point of intersection move vertically to determine factor A.
4. Enter the applicable material chart at the value of A* and move vertically to the line of applicable temperature. From the intersection move horizontally and read the value of B.
5. Compute the maximum allowable working pressure, P_a.

If P_a is smaller than the design pressure, the design, the design procedure must be repeated increasing the thickness or decreasing L by using of stiffening rings.

*For values of A falling to the left of the applicable line, the value of P can be calculated by the formula:

$$P_a = 2AE/3(D_l/t_e)$$

For cones having D /t ratio smaller than 10, see Code UG-33 (f)(b)

WHEN α IS GREATER THAN 60°
The thickness of the cones shall be the same as the required thickness for a flat head, the diameter of which equals the largest outside diameter of the cone.

Provide adequate reinforcing of the cone-to-cylinder juncture. See page 159

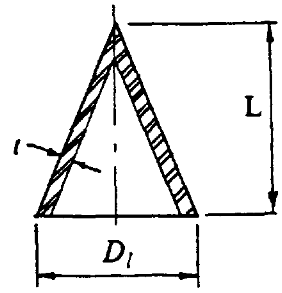
EXAMPLES

DESIGN DATA

P = 15 psi external design pressure
Material of the cone SA 285-C plate
500 F design temperature

CONICAL HEAD

D_l = 96 in. $\alpha = 22.5$ degrees $D_s = 0$



Determine the required thickness, t
Length, $L = (D_l/2)/\tan\alpha = 48/.4142 = 115.8$, say 116 in

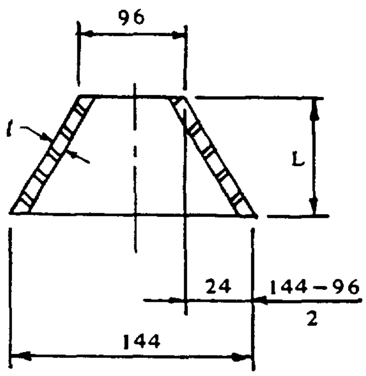
1. Assume a head thickness, t, 0.3125 in.
2. $t_e = t\cos\alpha = 0.3125 \times .9239 = 0.288$;
   $L_e = L/2\,(1+D_s/D_l) = 116/2 \times (1 + 0/96) = 58$
   $L_e/D_l = 58/96 = 0.6 \qquad D_l/t_e = 96/.288 = 333$
3. $A = 0.00037$ (from chart, page 42)
4. $B = 5{,}200$ (from chart, page 43)
5. $P_a = \dfrac{4B}{3(D_l/t_e)} = \dfrac{4 \times 5{,}200}{3(333)} = 20.8$ psi.

Since the maximum allowable pressure is greater than the design pressure, the assumed plate thickness is satisfactory.

CONICAL SECTION (See design data above)

$D_l = 144$ in. $D_s = 96$ in. $\alpha = 30$ deg.
Determine the required thickness,

Length, $L = [(D_l - D_s)/2]/\tan\alpha = 24/.5774 = 41.6$ in.



1. Assume a head thickness, t, 0.375 in.
2. $t_e = t\cos\alpha = 0.375 \times 0.866 = 0.324$
   $L_e = (L/2)(1 + D_s/D_l) = 41.6/2 \times (1 + 96/144) = 34.67$
   $L_e/D_l = 34.67/144 = 0.241$
   $D_l/t_e = 144/0.324 = 444$
3. $A = 0.00065$ (from chart, page 42)
4. $B = 8{,}600$ (from chart, page 43)
5. $P_a = \dfrac{4B}{3(D_l/t_e)} = \dfrac{4 \times 8600}{3 \times (144/0.324)}$
   $= 25.8$ psi.

Since the maximum allowable pressure P_a is greater than the design pressure P, the assumed thickness is satisfactory.

EXAMPLES FOR CONICAL HEAD, WHEN α IS GREATER THAN 60°
ARE GIVEN AT FLAT HEADS

PRESSURE VESSEL HANDBOOK

Tenth Edition

NOTE:
The CODE "does not contain rules - [as it states in Par. U-2 (g)] - to cover all details of design and construction. Where complete details are not given . . . the manufacturer . . . shall provide details . . ."

BUILD

BETTER VESSEL

FASTER

AND MORE

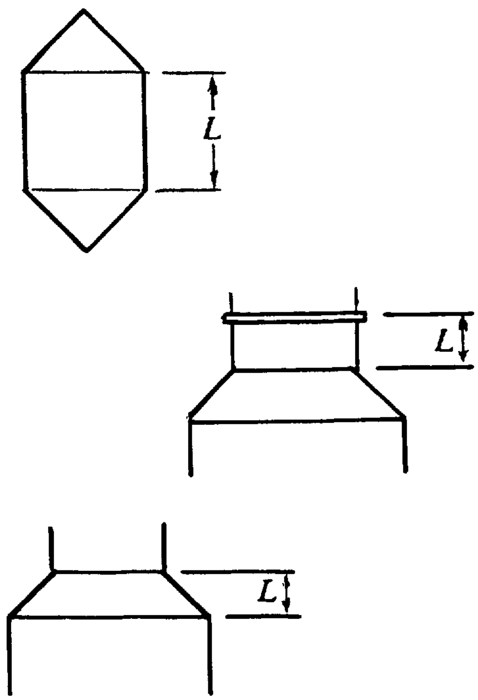
ECONOMICALLY

Design and construction details **not covered by the code,** have been selected from generally accepted sources, utilizing the most practical and economical methods.

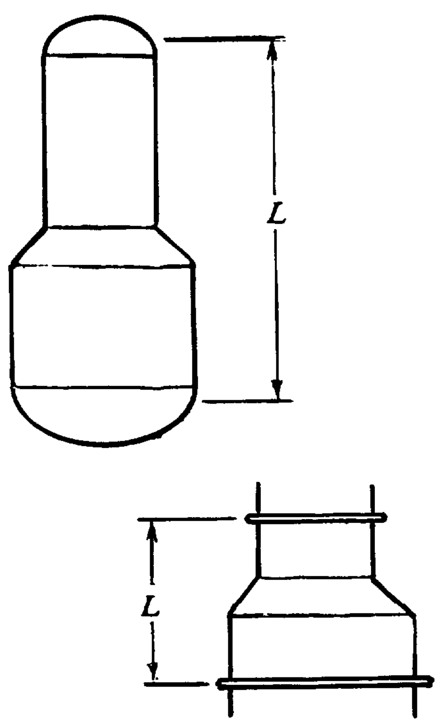
PRESSURE VESSEL PUBLISHING, INC. P.O. BOX 35365 TULSA, OK 74153

EXTERNAL PRESSURE

FORMULAS



Use L in calculation as shown when the strength of joints of cone to cylinder does not meet the requirements described on pages 163 - 169 It will result the thickness for the cone not less than the minimum required thickness for the joining cylindrical shell.



Use L in calculation as shown when the strength of joints of cone to cylinder meets the requirements described on pages 163 - 169

EXTERNAL PRESSURE

DESIGN OF STIFFENING RINGS

NOTATION

A = Factor determined from the chart (page 42) for the material used in the stiffening ring.

A_s = Cross sectional area of the stiffening ring, sq. in.

D_o = Outside Diameter of shell, in.

E = Modulus of elasticity of material (see chart on page 43)

I_s = Required moment of inertia of the stiffening ring about its neutral axis parallel to the axis of the shell, in.^{4}.

I'_s = Required moment of inertia of the stiffening ring combined with the shell section which is taken as contributing to the moment of inertia. The width of the shell section $1.10\sqrt{D_o t}$ in.^{4}.

L_s = The sum of one-half of the distances on both sides of the stiffening ring from the center line of the ring to the (1) next stiffening ring, (2) to the head line at ⅓ depth, (3) to a jacket connection, or (4) to cone-to-cylinder junction, in.

P = External design pressure, psi.

t = Minimum required wall thickness of shell, in.

I. Select the type of stiffening ring and determine its cross sectional area A.

II. Assume the required number of rings and distribute them equally between jacketed section, cone-to-shell junction, or head line at ⅓ of its depth and determine dimension, L_s.

III. Calculate the moment of inertia of the selected ring or the moment of inertia of the ring combined with the shell section (see page 95).

IV. The available moment of inertia of a circumferential stiffening ring shall not be less than determined by one of the following formulas:

$$I'_s = \frac{D_o^2 L_s (t + A_s/L_s) A}{10.9} \qquad I_s = \frac{D_o^2 L_s (t + A_s/L_s) A}{14}$$

The value of A shall be determined by the following procedure:

1. Calculate factor B using the formula:

$$B = \frac{3}{4}\left[\frac{PD_o}{t + A_s/L_s}\right]$$

2. Enter the applicable material chart (pages 43 -47) at the value of B and move horizontally to the curve of design temperature. When the value of B is less than 2500, A can be calculated by the formula: $A = 2B/E$.
3. From the intersection point move vertically to the bottom of the chart and read the value of A.
4. Calculate the required moment of inertia using the formulas above.

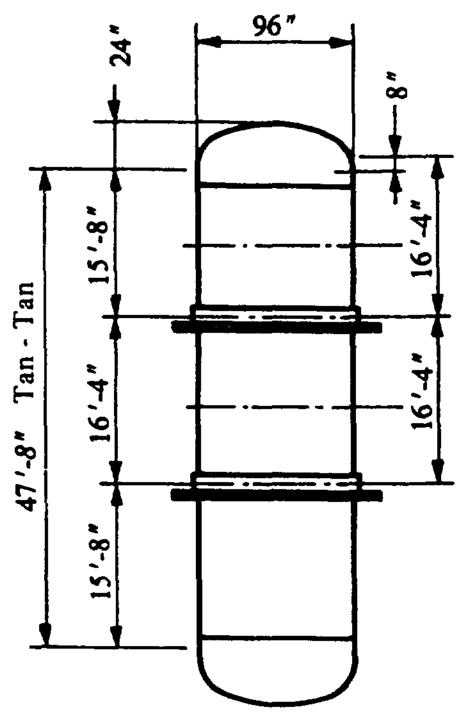
If the moment of inertia of the ring or the ring combined with the shell section is greater than the required moment of inertia, the stiffening of the shell is satisfactory. Otherwise stiffening ring with larger moment of inertia must be selected, or the number of rings shall be increased.

Stiffening ring for jacketed vessel: Code UG-29 (f)

EXAMPLES

DESIGN DATA:

P = 15 psi. , external design pressure.
D_o = 96 in., outside diameter of the shell.
Length of the vessel from tangent line to tangent line: 48 ft. 0 in. = 576 in.
Heads 2:1 ellipsoidal
Material of the stiffening ring SA - 36
Temperature 500° F
E = Modulus of elasticity of material, 27,000,000 psi. @ 500 °F (see chart on page 43)
t = 0.500 in. thickness of shell



I. An angle of 6 x 4-5/16 selected. A_s = 3.03 sq. in.

II. Using 2 stiffening rings equally spaced between one-third the depths of heads (see figure), L_s = 196 in.

III. The moment of inertia of the selected angle: 11.4 in.

1. The value of Factor B:

$$B = 3/4\left[PD_o/(t + A_s/L_s)\right] = 3/4\left[15 \times 96/(0.5 + 3.03/196)\right] = 2095$$

2. Since the value of B is less than 2500,

$$A = 2B/E = 2 \times 2095/27{,}000{,}000 = 0.00015$$

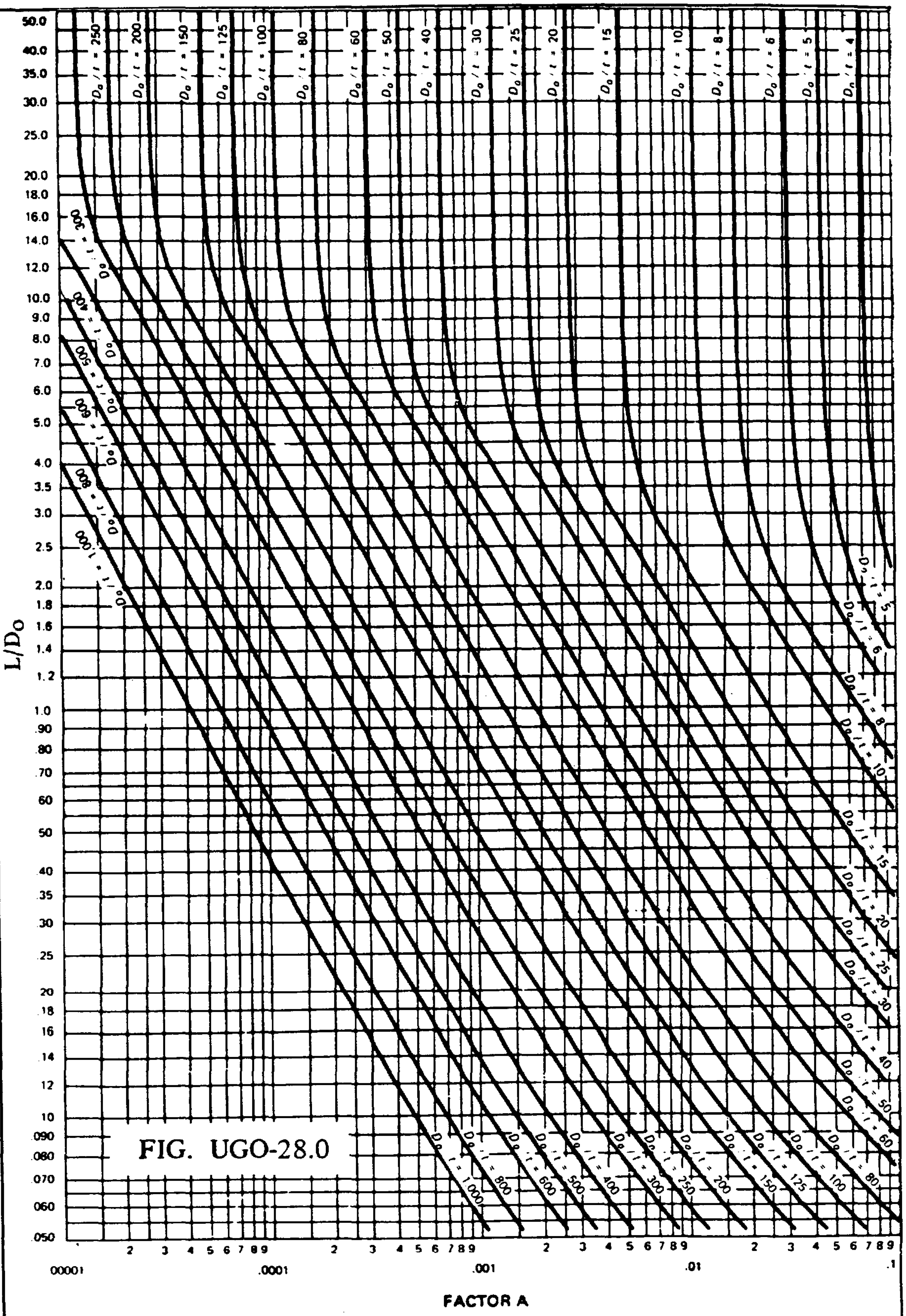
IV. The required moment of inertia:

$$I_s = \frac{[D_o^2 L_s(t + A_s/L_s)A]}{14} = \frac{96^2 \times 196 \times (0.5 + 3.03/196) \times 0.00015}{14} = 9.97 \text{ in.}^4$$

Since the required moment of inertia (9.97 in⁴) is smaller than the moment of inertia of the selected angle (11.4 in⁴) the vessel is adequately stiffened.

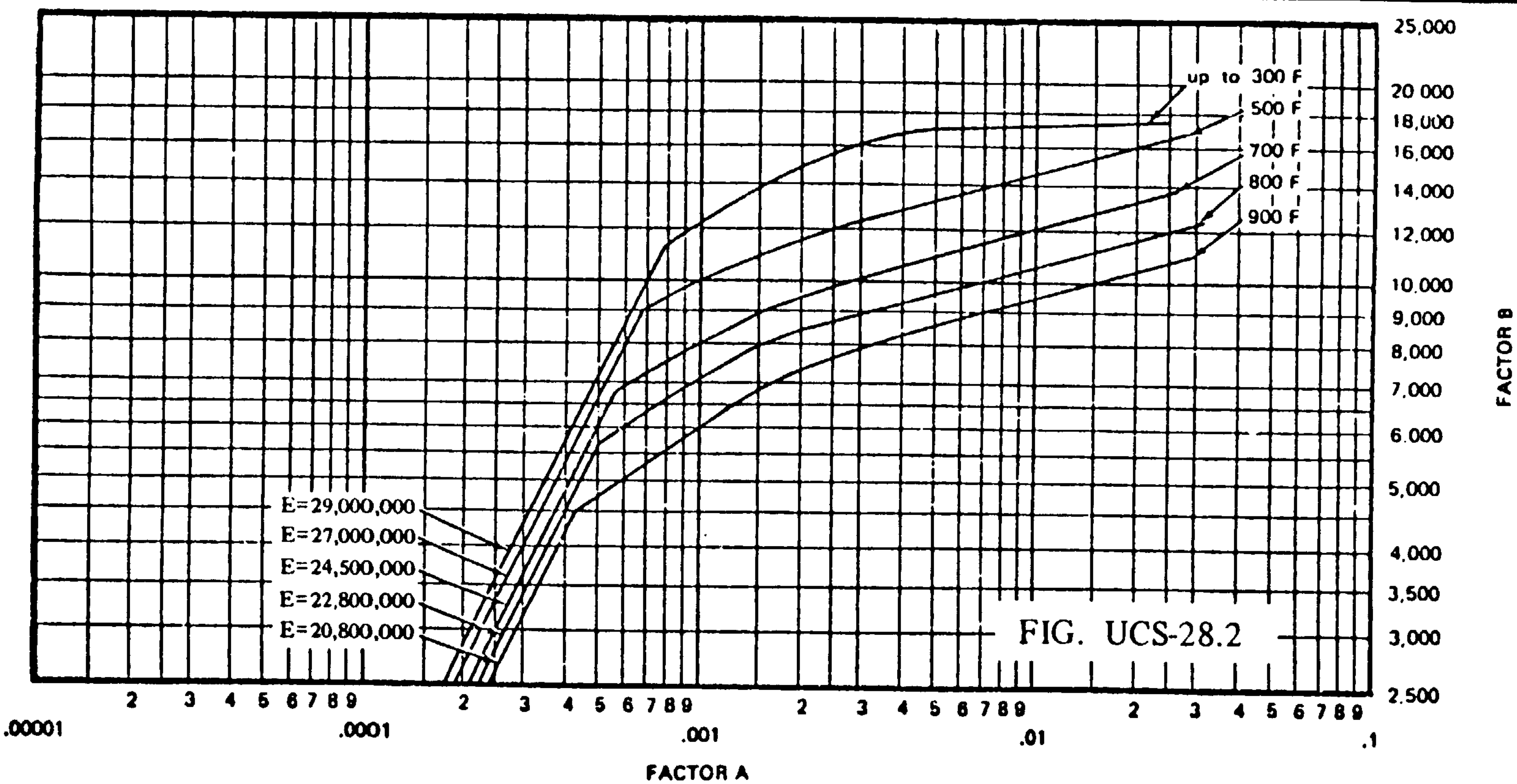
Stiffening rings may be subject to lateral buckling. This should be considered in addition to the required moment of inertia.

See pages 95-97 for stiffening ring calculations.



THE VALUES OF FACTOR A

USED IN FORMULAS FOR VESSELS UNDER EXTERNAL PRESSURE



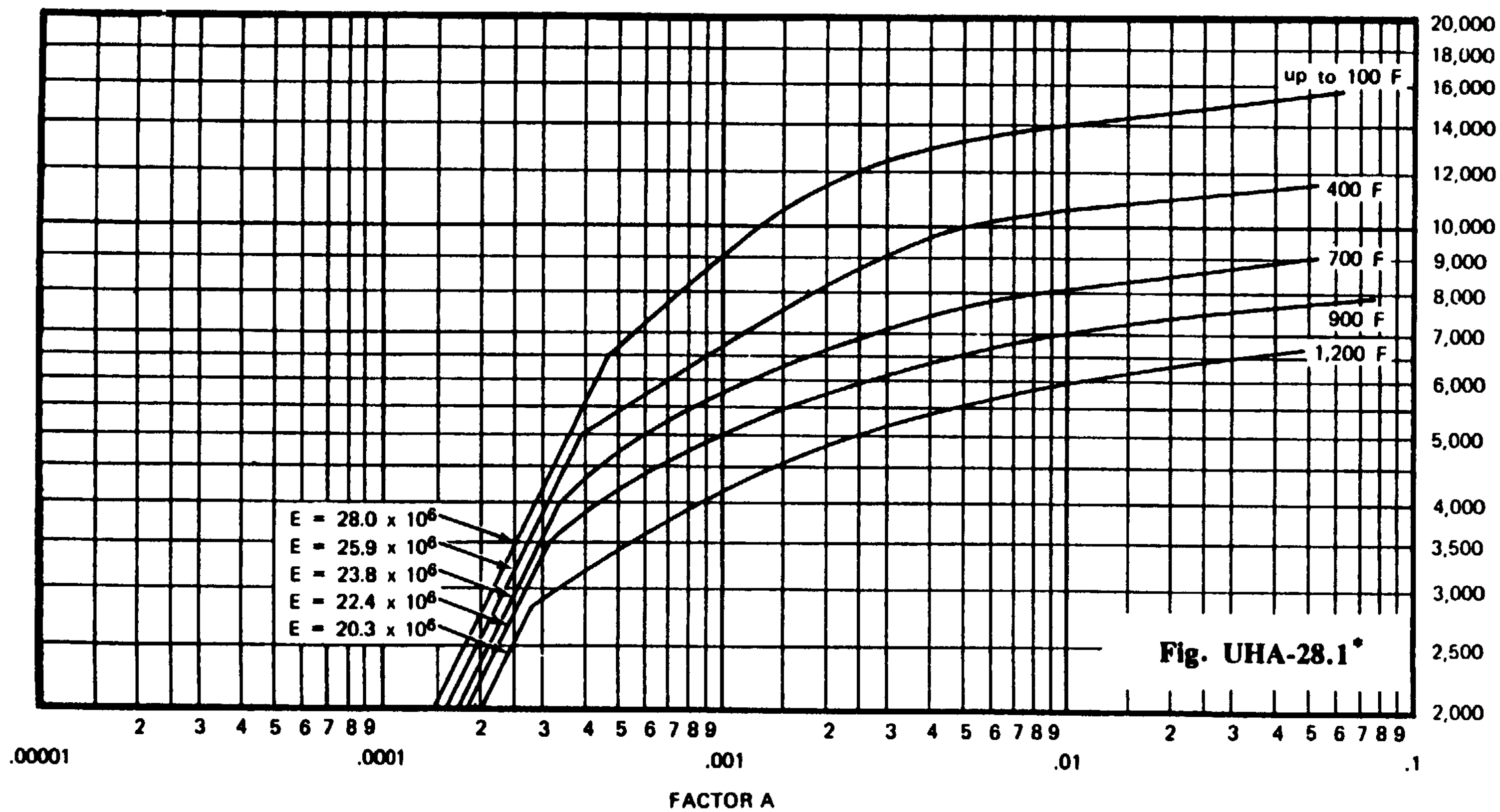
NOTE: In cases where the value of A falls to the right of the end of the temperature line, assume an interseciton with the horizontal projection of the upper end of the temperature line.

THE VALUES OF FACTOR B

USED IN FORMULAS FOR VESSELS UNDER EXTERNAL PRESSURE

The values of the chart are applicable when the vessel is constructed of carbon steel and the specified yield strength 30,000 psi. and over. To this category belong the following most frequently used materials:

SA - 283 C	SA - 515	All Grades	SA - 53 - B	Type 405	Stainless Steels
SA - 285 C	SA - 516		SA - 106 - B	Type 410	



NOTE: In cases where the value of A falls to the right of the end of the temperature line, assume an interseciton with the horizontal projection of the upper end of the temperature line.

THE VALUES OF FACTOR B

USED IN FORMULAS FOR VESSELS UNDER EXTERNAL PRESSURE

***The values of the chart are applicable when the vessel is constructed of austenitic steel (18Cr-8Ni, Type 304) (Table 1 on page 190)**

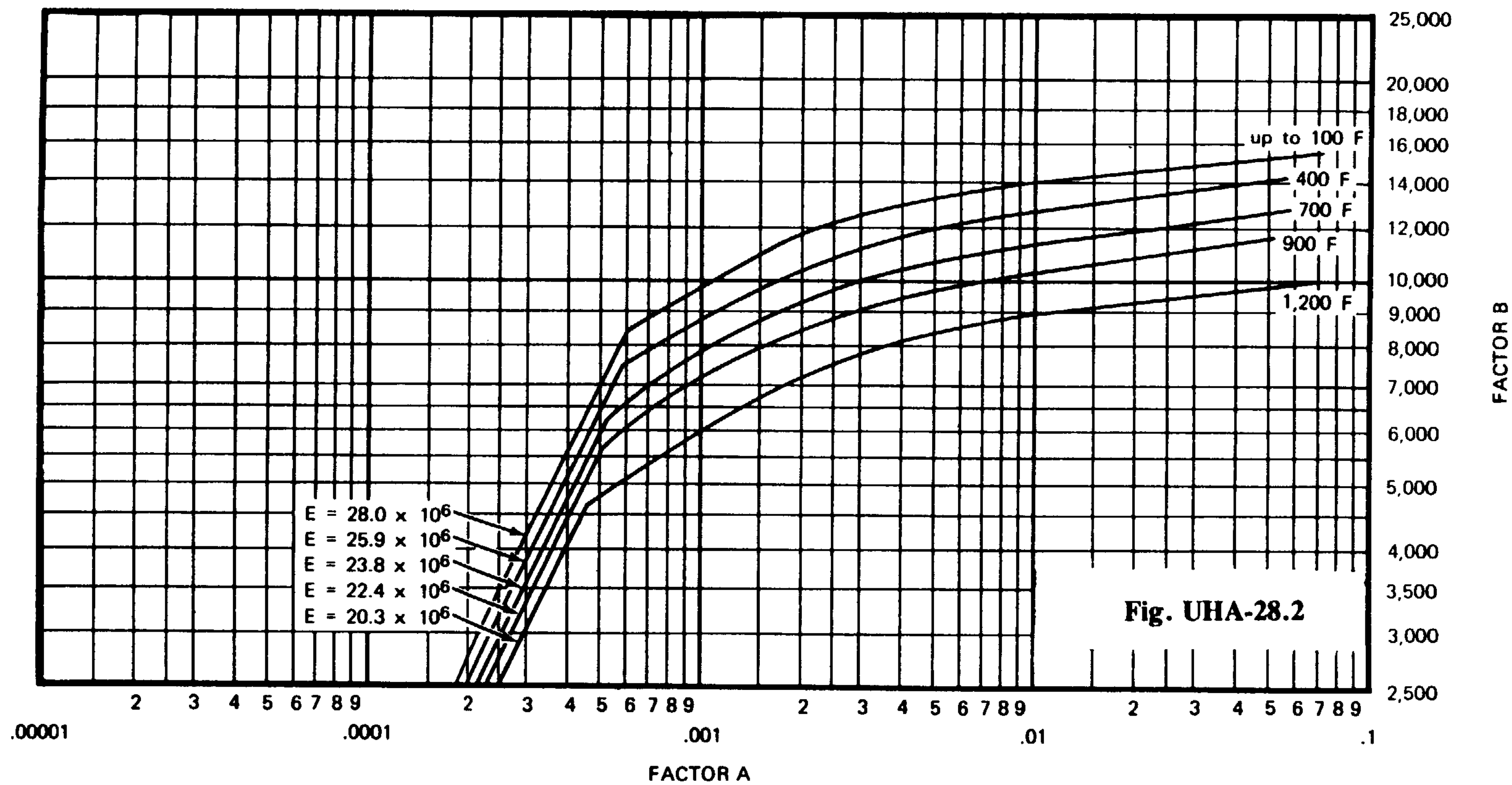


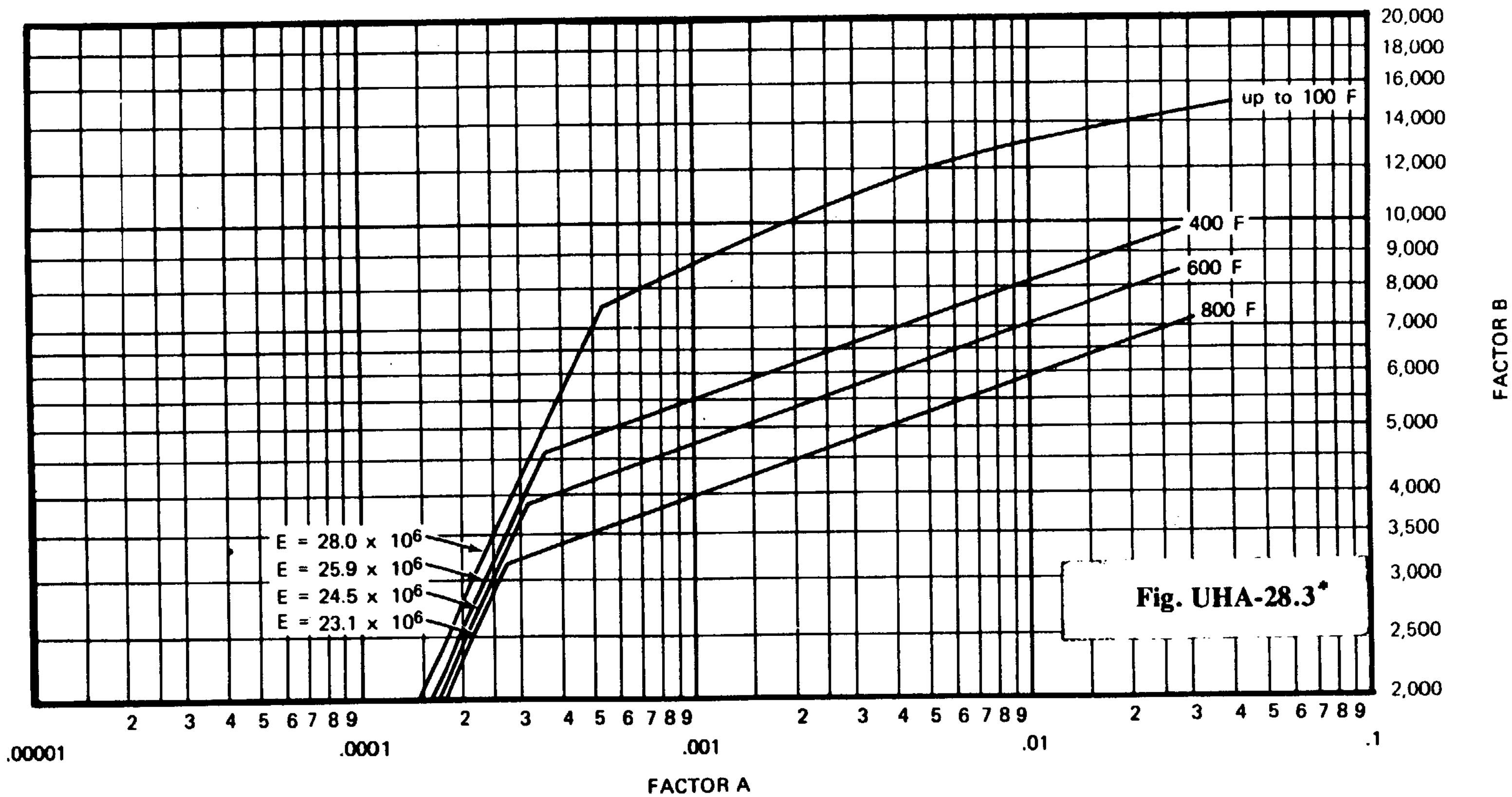
Fig. UHA-28.2

NOTE: In cases where the value of A falls to the right of the end of the temperature line, assume an interseciton with the horizontal projection of the upper end of the temperature line.

THE VALUES OF FACTOR B

USED IN FORMULAS FOR VESSELS UNDER EXTERNAL PRESSURE

*The values of the chart are applicable when the vessel is constructed of austenitic steel (18Cr-8Ni-Mo, Type 316) (Table 3 on page 190)



NOTE: In cases where the value of A falls to the right of the end of the temperature line, assume an interseciton with the horizontal projection of the upper end of the temperature line.

THE VALUES OF FACTOR B

USED IN FORMULAS FOR VESSELS UNDER EXTERNAL PRESSURE

*The values of the chart are applicable when the vessel is constructed of austenitic steel (18Cr-8Ni-0, 03 max. carbon, Type 304L) (Table 2 on page 190)

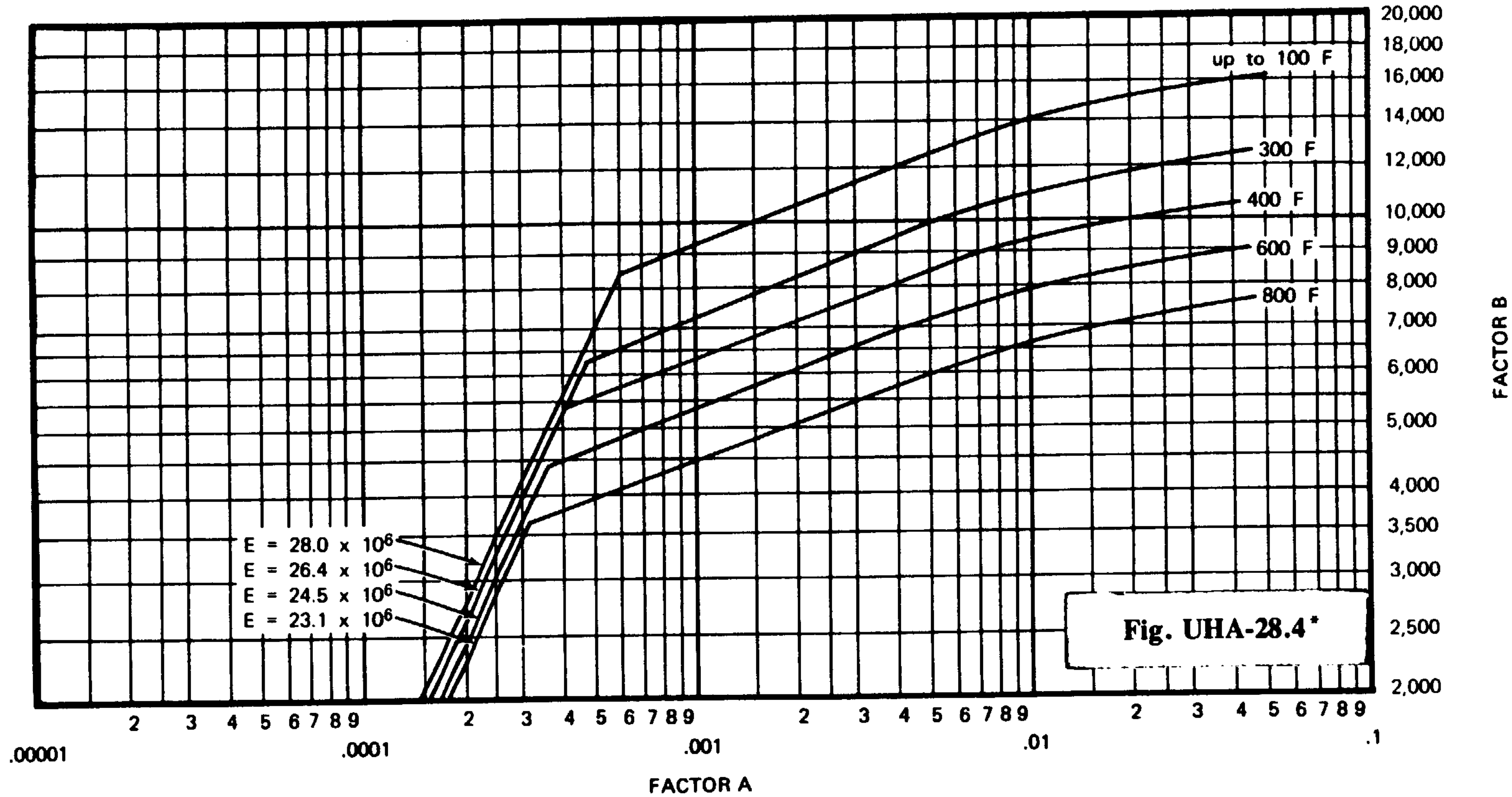


Fig. UHA-28.4*

NOTE: In cases where the value of A falls to the right of the end of the temperature line, assume an interseciton with the horizontal projection of the upper end of the temperature line.

THE VALUES OF FACTOR B

USED IN FORMULAS FOR VESSELS UNDER EXTERNAL PRESSURE

*The values of the chart are applicable when the vessel is constructed of Austenitic steel (18Cr-8Ni-Mo-0.03 max. carbon, Types 316L and 317L) (Table 4 on page 190)

EXTERNAL PRESSURE

CONSTRUCTION OF STIFFENING RINGS

LOCATION

Stiffening rings may be placed on the inside or outside of a vessel.

SHAPE OF RINGS

The rings may be of rectangular or any other sections.

CONSTRUCTION

It is preferable to use plates in constructing a composite-section stiffener ring, rather than using standard structural shapes. The reason for this lies not only in the difficulties of rolling heavy structural shapes, but also because of the necessity to adjust the ring to the curvature of the shell. For large diameter vessels the maximum permissible out of roundness can result in a 1 – 2 inch gap between the shell and the ring. This can be eliminated if the vertical member of the ring is cut out of the plate in sections. The sections can be flame cut, instead of rolled and then butt-welded together in place.

DRAIN AND VENT

Stiffener rings placed in the inside of horizontal shells have a hole or gap at the bottom for drainage and at the top for vent. Practically one half of a 3 inch diameter hole at the bottom and 1½ inch diameter hole at the top is satisfactory and does not affect the stress conditions. Figure A.

For the maximum arc of shell left unsupported because of gap in stiffening ring, see Code Figure UG.29.2.

WELDING

According to the ASME Code (UG 30): Stiffener rings may be attached to the shell by continuous or intermittent welding. The total length of intermittent welding on each side of the stiffener ring shall be:

1. for rings on the outside, not less than one half the outside circumference of the vessel;
2. for rings on the inside of the vessel, not less than one third of the circumference of the vessel.

Where corrosion allowance is to be provided, the stiffening ring shall be attached to the shell with continuous fillet or seal weld.ASME. Code (UG.30.)

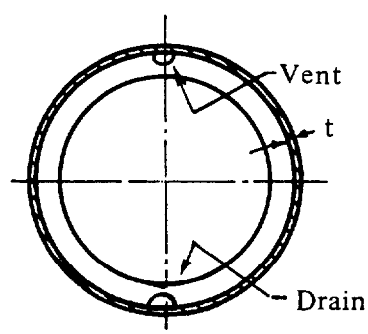


Figure A

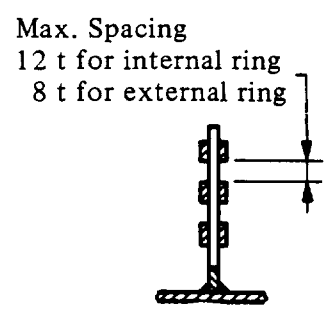


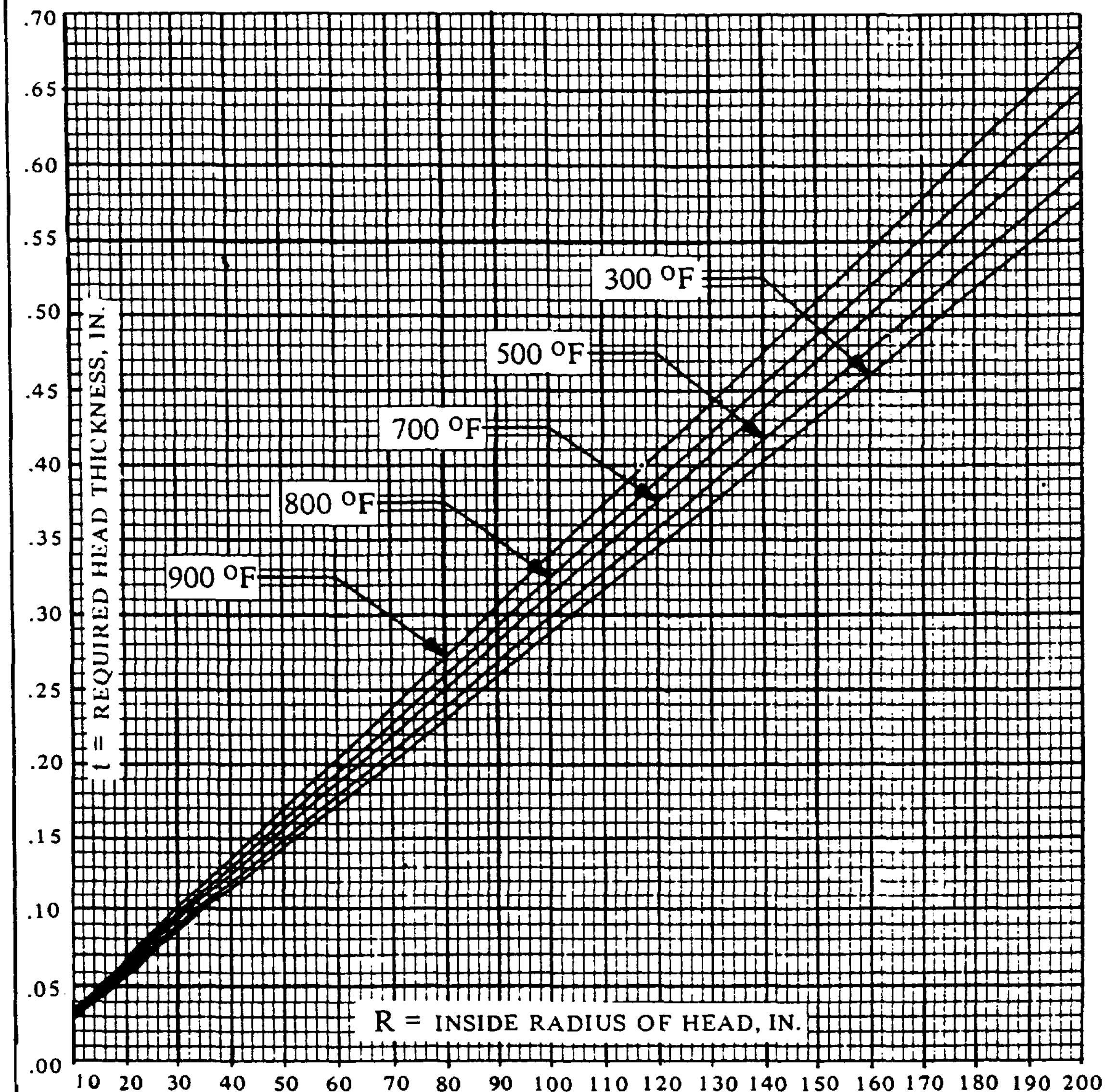
Figure B

EXAMPLE: RINGS OUTSIDE ¼" x 3" lg. fillet weld on 6" ctrs.
RINGS INSIDE ¼" x 2" lg. fillet weld on 6" ctrs.

The fillet weld leg-size shall be not less than the smallest of the following: 1/4 in, the thickness of vessel wall or stiffener at the joint.

CHARTS FOR DETERMINING THE WALL THICKNESS FOR VESSELS SUBJECTED TO FULL VACUUM

Using the charts, trials with different assumed thicknesses can be avoided. The charts has been developed in accordance with the design method of ASME Code, Section VIII, Division 1.

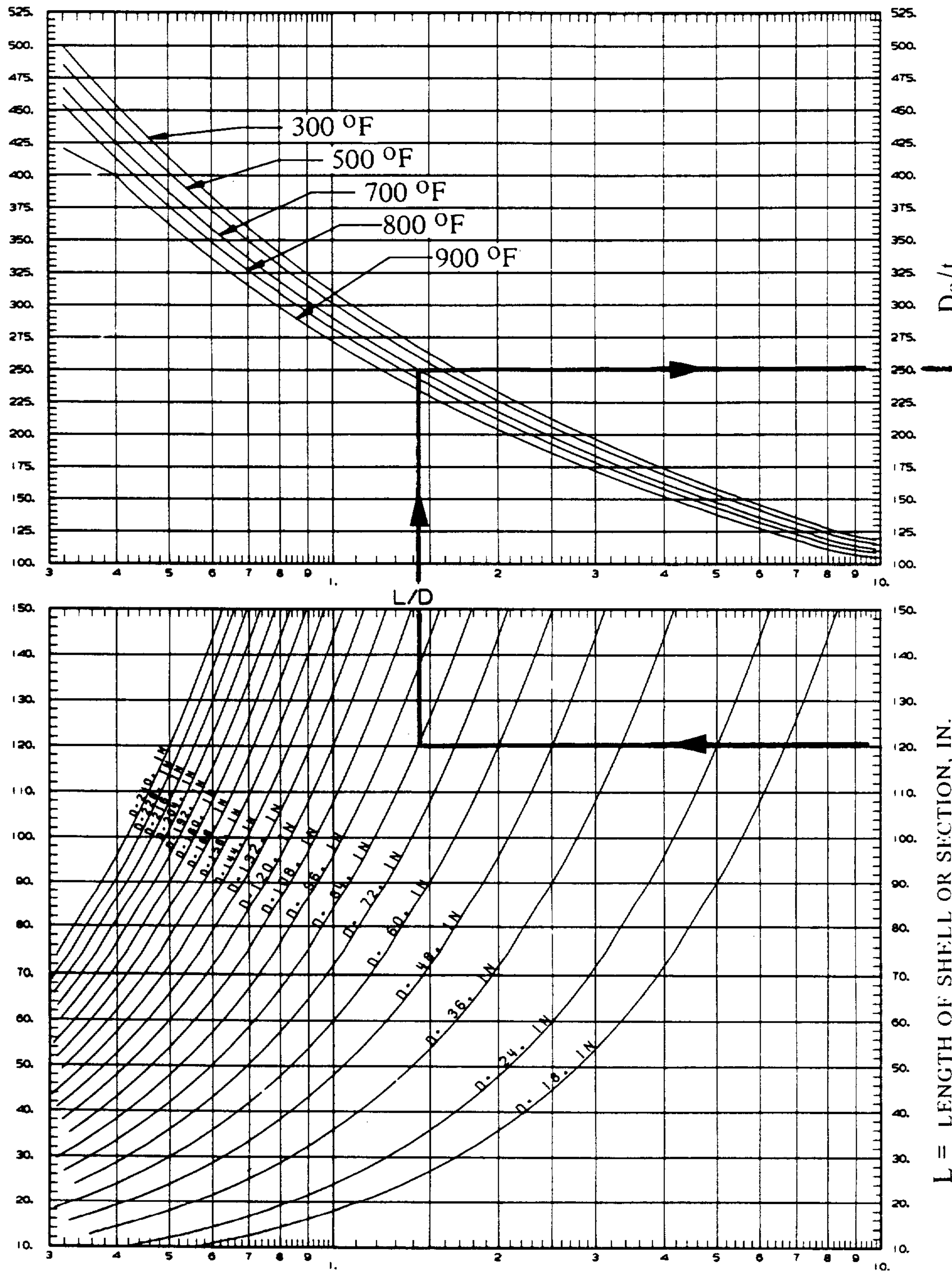


SPHERICAL, ELLIPSOIDAL, FLANGED AND DISHED HEADS
(Specified yield strength 30,000 to 38,000 psi, inclusive)

To find the required head thickness: 1. Determine R, 2. Enter the chart at the value of R, 3. Move vertically to temperature line, 4. Move horizontally and read t.

t = Required head thickness, in.
R = For hemispherical heads, the inside radius, in.
For 2:1 ellipsoidal heads $0.9xD_O$
For flanged and dished heads, the inside crown radius, in. $R_{max}=D_O$
D_O = Outside diameter of the head, in.

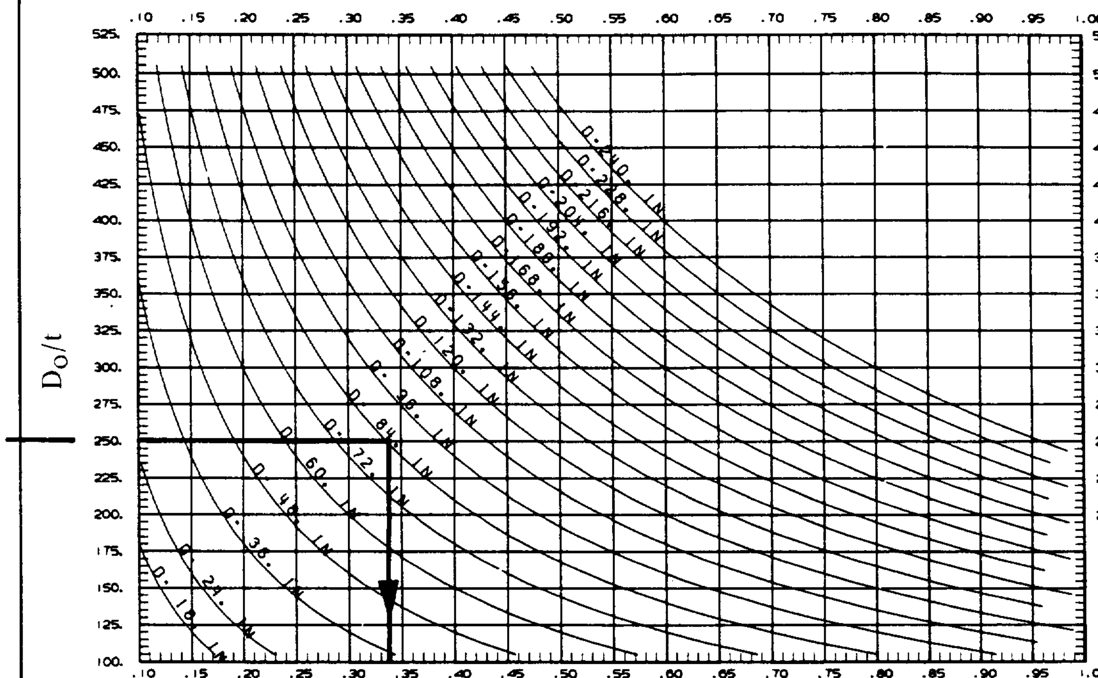
CHARTS FOR DETERMINING THE WALL THICKNESS FOR VESSELS SUBJECTED TO FULL VACUUM



CYLINDRICAL SHELL

(See facing page for explanation)

CHARTS FOR DETERMINING THE WALL THICKNESS FOR VESSELS SUBJECTED TO FULL VACUUM



t = REQUIRED SHELL THICKNESS, IN.

CYLINDRICAL SHELL

(Specified yield strength 30,000 to 38,000 psi, inclusive)

To find the required shell thickness:
1. Enter lower chart (facing page) at the value of L
2. Move horizontally to curves representing D_O
3. Move vertically to temperature line
4. Move horizontally and read D_O/t
5. Enter chart above at the value of D_O/t
6. Move horizontally to curve D
7. Move vertically down and read the value of t

NOTATION

t = Required shell thickness, in.

D_O = Outside diameter of shell, in.

L = Length of the vessel or vessel section, taken as the largest of the following:

1. Distance between the tangent lines of the heads plus one third of the depth of the heads if stiffening rings are not used, in.
2. The greatest distance between any two akjacent stiffening rings, in.
3. The distance from the center of the first stiffening ring to the head tangent line plus one third of the head depth, in.

The charts are from:

Logan, P. J., "Based on New ASME Code Addenda . . . Chart Finds Vessel Thickness," HYDROCARBON PROCESSING, 55 No. 5, May 1976 p. 217.

Logan, P. J., "A Simplified Approach to . . . Pressure Vessel Head Design," HYDROCARBON PROCESSING, 55 No. 11, November 1976 p. 265.

DESIGN OF TALL TOWERS

WIND LOAD

The computation of wind load is based on Standard ANSI/ASCE 7-93, approved 1994.

The basic wind speed shall be taken from the map on the following page.

The basic wind speed is 80 mph. in Hawaii and 95 mph. in Puerto Rico.

The minimum design wind pressure shall be not less than 10 lb./sq. ft.

When records and experience indicates that the wind speeds are higher than those reflected in the map, the higher values of wind speed shall be applied.

The wind pressure on the projected area of a cylindrical tower shall be calculated by the following formula.

$F = q_z G\ C_f A_f$ **(Table 4) ANSI/ASCE 7-93 STANDARD**
(References made to the tables of this standard)

A_f — Projected area of tower, sq. ft. = *(D x H)*

C_f — Shape factor = 0.8 for cylinndrical tower (Table 12)

G — Gust response factor = $(G_h \& G_z)$*
When the tower located:
in urban, suburban areas, Exposure *B;*
in open terrain with scattered obstruction, Exposure *C;*
in flat, unobstructed areas, Exposure *D.*
(Table 8)

q_z = Velocity pressure,
$0.00256\ K_z\ (IV)^2$

- V — Wind speed, mph.
- I — Importance factor, 1.0 (structures that represent low hazard to human life in event of failure).
- K_z — Velocity Pressure Exposure Coefficient* Exposures *B, C & D* (Table 6)

F — DESIGN WIND PRESSURE, lb. on projected area of towers

*See tables below for values of q and for combined values of G_h, G_z & K_z

VELOCITY PRESSURE, *q*

Basic wind speed, mph, V	70	80	90	100	110	120	130
Velocity Pressure psf $0.00256\ V^2$, q	13	17	21	26	31	37	44

DESIGN OF TALL TOWERS
WIND LOAD
(Continued)

COEFFICIENT *G* (Gust response factor combined with Exposure Coefficient)

HEIGHT Above ground, ft.	EXPOSURE B	EXPOSURE C	EXPOSURE D
0-15	0.6	1.1	1.4
20	0.7	1.2	1.5
40	0.8	1.3	1.6
60	0.9	1.4	1.7
80	1.0	1.5	1.8
100	1.1	1.6	1.9
140	1.2	1.7	2.0
200	1.4	1.9	2.1
300	1.6	2.0	2.2
500	1.9	2.3	2.4

The area of caged ladder may be approximated as 1 sq. ft. per lineal ft. Area of platform 8 sq. ft.

Users of vessels usually specify for manufacturers the wind pressure without reference to the height zones or map areas. For example: 30 lb. per sq. ft. This specified pressure shall be considered to be uniform on the whole vessel.

The total wind pressure on a tower is the product of the unit pressure and the projected area of the tower. With good arrangement of the equipment the exposed area of the wind can be reduced considerably. For example, by locating the ladder 90 degrees from the vapor line.

EXAMPLE:

Determine the wind load, *F*
DESIGN DATA:

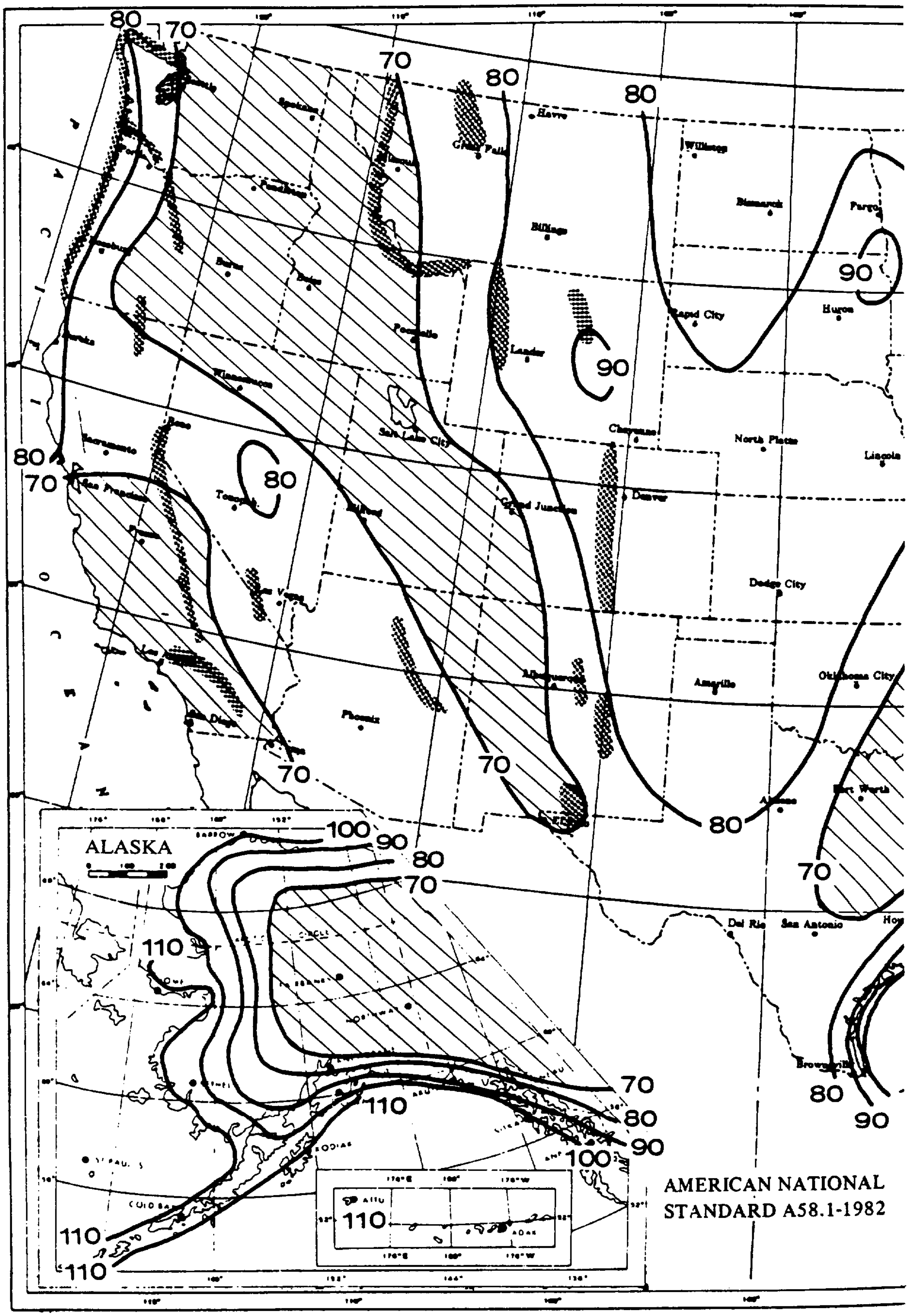
the wind basic speed, *V*	=	100 mph.
vessel diameter, *D*	=	6 ft.
vessel height, *H*	=	80 ft.
Diameter of tower, *D*	=	6 ft.
Height of the tower, *H*	=	80 ft.
The tower located in flat, unobstructed area, exposure	:	*D*

The wind load, $F = q \times G \times 0.8 \times A$

q from table = 26 psf
G from table = 1.8
Shape factor = 0.8
Area, $A = DH = 6 \times 80 = 480$ sq. ft.
$F = 26 \times 1.8 \times 0.8 \times 480 = 17{,}971$ lbs.

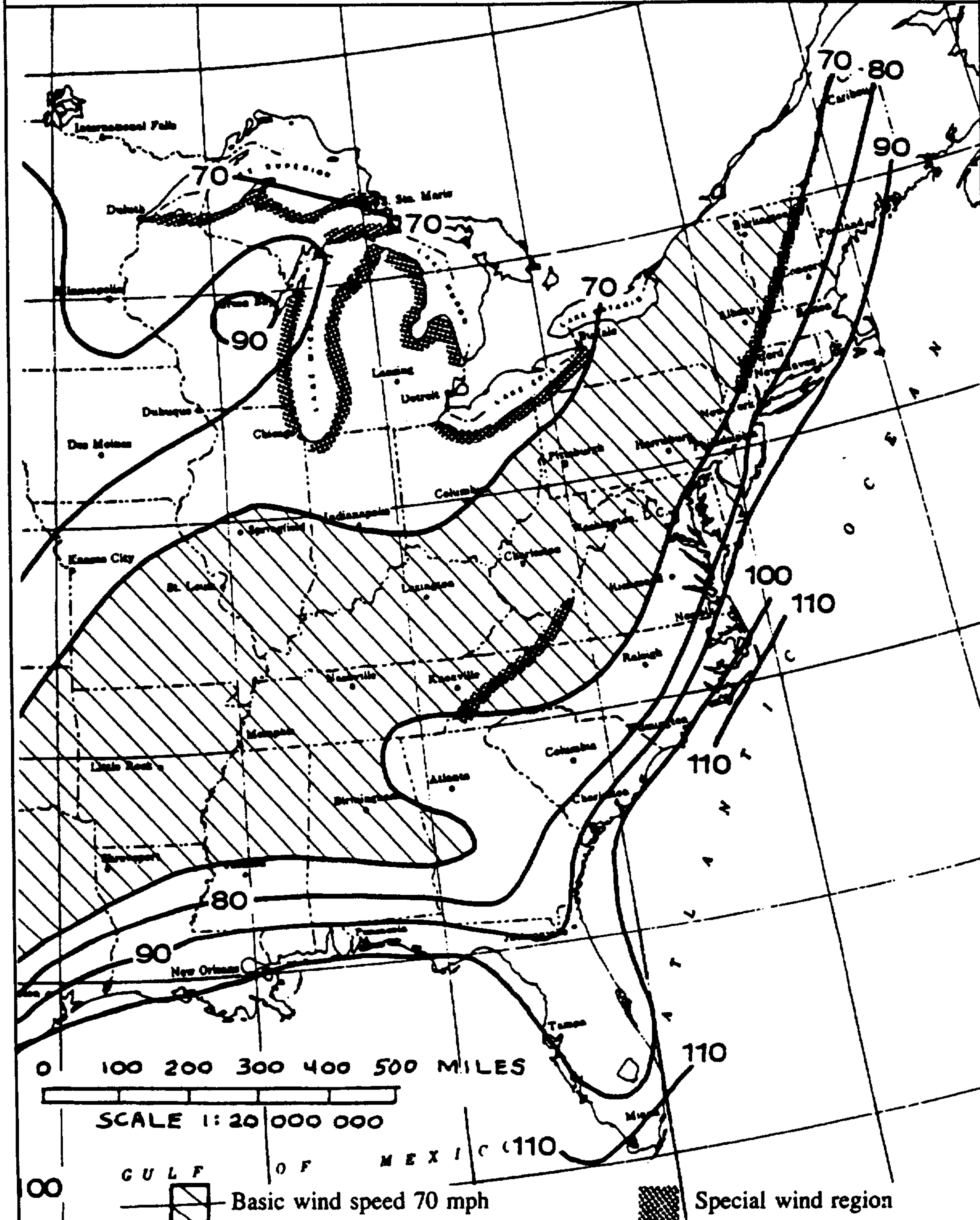
MAP OF WIND SPEED

(miles per hour)



MAP OF WIND SPEED

(miles per hour)



NOTES:
1. Values are fastest-mile speeds at 33 ft. above ground for exposure category C and are associated with an annual probability of 0.02.
2. Linear interpolation between wind speed contours is acceptable.
3. Caution in the use of wind speed contours in mountainous regions of Alaska is advised.
4. Wind speed for Hawaii is 80 and for Puerto Rico is 95 mph.
5. Where local records or terrain indicate higher 50-year wind speeds, they shall be used.
6. Wind speed may be assumed to be constant between coastline and the nearest inland contour.

DESIGN OF TALL TOWERS

WIND LOAD

Computation of wind load as alternate method based on standard ASA A58.1-1955. This standard is obsolete but still used in some codes and foreign countries.

The wind pressure at 30 ft. level above ground for the United States is shown on the map on the facing page.

The table below gives the wind pressures for various heights above ground for the areas indicated by the map.

WIND PRESSURE P_W WHEN THE HORIZONTAL CROSS SECTION SQUARE OR RECTANGULAR *							
HEIGHT	MAP AREAS						
Zone ft.	20	25	30	35	40	45	50
less than 30	15	20	25	25	30	35	40
30 to 49	20	25	30	35	40	45	50
50 to 99	25	30	40	45	50	55	60
100 to 499	30	40	45	55	60	70	75

*Multiply values of P_W with 0.80 when the horizontal cross section is hexagonal or octagonal and with 0.60 when the horizontal cross section is circular or elliptical.

EXAMPLE

Find the wind pressure P_W from map.

The vessel is intended to operate in Oklahoma, which is in the wind pressure map area marked 30. In this map area the wind pressures for various height zones are:

In the height zone less than 30 ft. 25 lb. per sq. ft.
In the height zone from 30 to 49 ft. 30 lb. per sq. ft.

For cylindrical tower these values shall be multiplied by shape factor 0.6, then the wind pressure in different zones will be 15 and 18 lb. per sq. ft. respectively.

If many equipments are attached to the tower it is advisable to increase the shape factor (according to Brownell) up to 0.85 for cylindrical vessel.

Users of vessels usually specify for manufacturers the wind pressure without reference to the height zones or map areas. For example: 30 lb. per sq. ft. This specified pressure shall be considered to be uniform on the whole vessel.

Relation between wind pressure and wind velocity when the horizontal cross section is circular, is given by the formula:

$$P_w = 0.0025 \times V_w^2$$

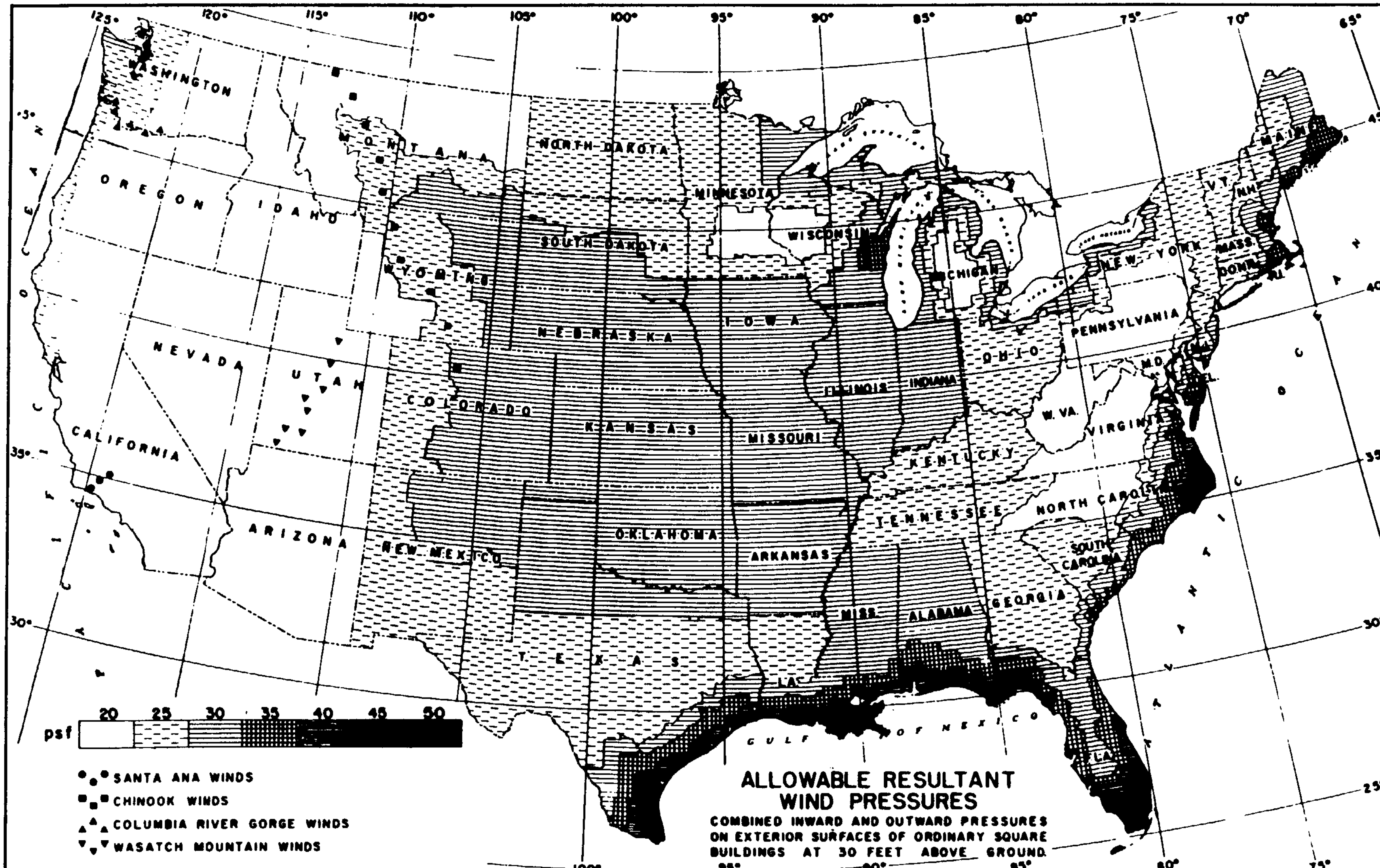
where P_w = wind pressure lb. per sq. ft.
V_w = wind velocity mph

EXAMPLE

Wind of 100 mph velocity exerts a pressure:
$P_w = 0.0025 \times V_w^2 = 25$ pounds per square foot pressure on the projected area of a cylindrical vessel at a height of 30 feet above ground.

The total wind pressure on a tower is the product of the unit pressure and the projected area of the tower. With good arrangement of the equipment the exposed area of the wind can be reduced considerably. For example, by locating the ladder 90 degrees from the vapor line.

MAP OF WIND PRESSURE



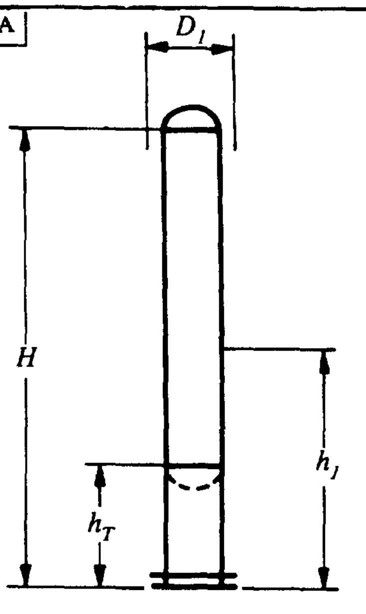
The map based on the records of the United States Weather Bureau and developed by the National Bureau of Standards.

DESIGN OF TALL TOWERS

WIND LOAD

(Continuation)

A



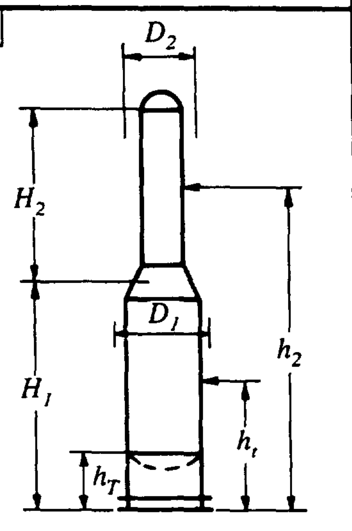
FORMULAS

SHEAR	MOMENT	STRESS	REQUIRED THICKNESS
$V = P_w D_{1,2} H_{1,2}$	$M = P_w D_{1,2} H_{1,2} h_{1,2}$ $M_T = M - h_T(V - 0.5\,P_w D_1 h_T)$	$S = \dfrac{12M}{R^2 \pi t}$	$t = \dfrac{12M}{R^2 \pi S E}$

NOTATION

$D_1 D_2$ = Width of the vessel with insulation etc., ft.
E = Efficiency of the welded joints.
$h_1 h_2$ = Lever arm, ft.
h_T = Distance from base to section under consideration, ft.
$H, H_1 H_2$ = Length of vessel or vessel section, ft.
M = Maximum moment (at the base) ft. lb.
M_T = Moment at height h_T, ft. lb.
P_w = Wind pressure, lb. per sq. ft.
R = Mean radius of vessel, in.
S = Stress value of material or actual stress psi.
V = Total shear, lb.
t = Required thickness, corrosion excluded, in.

B



EXAMPLE:

Given: $D_1 = 4'\text{-}0''$ $D_2 = 3'\text{-}0''$ $H_1 = 56'\text{-}0''$ $H_2 = 44'\text{-}0''$
$h_T = 4'\text{-}0''$ $P_w = 30$ psf

Determine the wind moment

$h_1 = H_1/2 = 28'\text{-}0''$ $h_2 = H_1 + (H_2/2) = 78'\text{-}0''$

$P_w \times D \times H = V \times h = M$

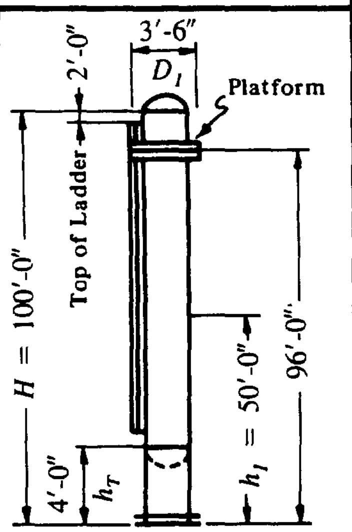
Lower Section	30 × 4 × 56 =	6720 × 28 =	188,160
Upper Section	30 × 3 × 44 =	3,960 × 78 =	308,880
Total	V =	10,680	M 497,040 ft. lb.

Moment at the bottom tangent line

$M_T = M - h_T (V - 0.5\,P_w D_1 h_T) =$

497,040 − 4 (10,680 − 0.5 × 30 × 4 × 4) = 455,280 ft. lb.

C



EXAMPLE:

Given: $D_1 = 3$ ft. 6 in. $H = 100$ ft. 0 in. $h_T = 4$ ft. 0 in.
$P_w = 30$ psf

Determine the wind moment

$h_1 = H/2 = 50$ ft. 0 in.

	$P_w \times D_1 \times H =$	$V \times h_1 =$	M
Vessel	30 × 3.5 × 100	= 10,500 × 50 =	525,000
Ladder	30 × 98 lin. ft.	= 2,940 = 49 =	144,060
Platform	30 × 8 lin. ft.	= 240 × 96 =	23,040
Total		V = 13,680	M = 692,100 ft. lb.

Moment at the bottom tangent line

$M_T = M - h_T (V - 0.5\,P_w D_1 h_T) =$

692,100 − 4 (13,680 − 0.5 × 30 × 3.5 × 4) = 638,220 ft. lb.

SEE EXAMPLES FOR COMBINED LOADS ON PAGE: 67.

DESIGN OF TALL TOWERS

WEIGHT OF THE VESSEL

The weight of the vessel results compressive stress only when eccentricity does not exist and the resultant force coincides with the axis of the vessel. Usually the compression due to the weight is insignificant and is not controlling.

The weight shall be calculated for the various conditions of the tower as follows:

A. Erection weight, which includes the weight of the:

1. shell
2. heads
3. internal plate work
4. tray supports
5. insulation rings
6. openings
7. skirt
8. base ring
9. anchor ring
10. anchor lugs
11. miscellaneous
12. + 6% of the weight of items 1 through 11 for overweight of the plates and weight added by the weldings

Equipments:

13. insulation
14. fireproofing
15. platform
16. ladder
17. piping
18. miscellaneous

Erection weight: the sum of items 1 through 18.

B. Operating weight, which includes the weight of the:

1. vessel in erection condition
2. trays
3. operating liquid

C. Test weight, which includes the weight of the:

1. vessel in erection condition
2. test water

The compressive stress due to the weight given by:

$$S = \frac{W}{ct}$$

where
S = unit stress, psi
W = weight of vessel above the section under consideration, lb.
c = circumference of shell or skirt on the mean diameter, in.
t = thickness of the shell or skirt, in.

The weight of different vessel elements are given in tables beginning on page 374

DESIGN OF TALL TOWERS

VIBRATION

As a result of wind tall towers develop vibration. The period of the vibration should be limited, since large natural periods of vibration can lead to fatigue failure. The allowable period has been computed from the maximum permissible deflection.

The so called harmonic vibration is not discussed in this Handbook since the trays as usually applied and their supports prevent the arising of this problem.

FORMULAS

Period of Vibration, T sec.	$T = 0.0000265\left(\frac{H}{D}\right)^2\sqrt{\frac{wD}{t}}$
Maximum Allowable Period of Vibration, T_a sec.	$T_a = 0.80\sqrt{\frac{WH}{Vg}}$

NOTATION

D = Outside diameter of vessel, ft.
H = Length of vessel including skirt, ft.
g = 32.2 ft. per sec. squared, acceleration
t = Thickness of skirt at the base, in.
V = Total shear, lb., CW, see page **61**
W = Weight of tower, lb.
w = Weight of tower per foot of height, lb.

EXAMPLE

Given:

D = 3.125 ft. 0 in.
H = 100 ft. 0 in.
g = 32.2 ft/sec^2
t = 0.75 in.
V = 1440 lb.
W = 36,000 lb. in operating condition
w = 360

Determine the actual and maximum allowable period of vibration

$$T = 0.0000265\left(\frac{100}{3.125}\right)^2\sqrt{\frac{360 \times 3.125}{0.75}} = 1.05 \text{ sec.}$$

$$T_a = 0.80\sqrt{\frac{36000 \times 100}{1440 \times 32.2}} = 7.05 \text{ sec.}$$

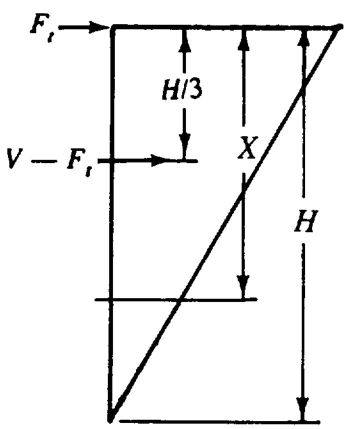
The actual vibration does not exceed the allowable vibration

Reference: Freese, C. E.: Vibration of Vertical Pressure Vessel ASME Paper 1959

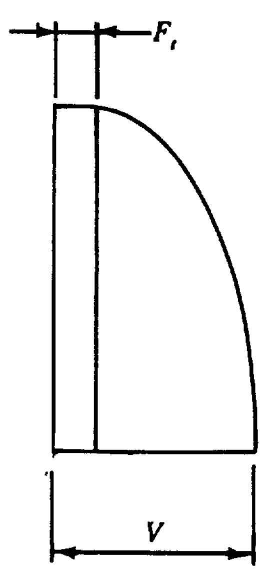
DESIGN OF TALL TOWERS

SEISMIC LOAD (EARTHQUAKE)

The loading condition of a tower under seismic forces is similar to that of a cantilever beam when the load increases uniformly toward the free end. The design method below is based on Uniform Building Code, 1991 (UBC).



(a) Seismic Loading Diagram



(b) Seismic Shear Diagram

Base Shear

FORMULAS

SHEAR	MOMENT
$V = \dfrac{ZIC}{R_w} W$	$M = [F_t \times H + (V - F_t) \times (2H/3)]$ $M_x = [F_t \times X]$ for $X \leq H/3$ $M_x = [F_t \times X + (V - F_t) \times (X - H/3)]$ for $X > H/3$

Base Shear

The base shear is the total horizontal seismic shear at the base of a tower. The triangular loading pattern and the shape of the tower shear diagram due to that loading are shown in Fig. (a) and (b). A portion F_t of total horizontal seismic force V is assumed to be applied at the top of the tower. The remainder of the base shear is distributed throughout the length of the tower, including the top.

Overturning Moment

The overturning moment at any level is the algebraic sum of the moments of all the forces above that level.

NOTATION

C = Numerical coefficient $= \dfrac{1.25S}{T^{2/3}}$ (need not exceed 2.75)

C_t = Numerical coefficient = 0.035

D = Outside diameter of vessel, ft.

E = Efficiency of welded joints

F_t = Total horizontal seismic force at top of the vessel, lb. determined from the following formula:

$F_t = 0.07\,TV$ (F_t need not exceed $0.25V$)

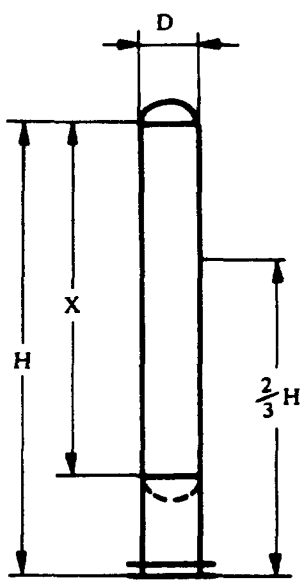
$= 0$, for $T \leq 0.7$

H = Length of vessel including skirt, ft.

DESIGN OF TALL TOWERS

SEISMIC LOAD (EARTHQUAKE)

(Continuation)



NOTATION

I = Occupancy importance coefficient (use 1.0 for vessels)

M = Maximum moment (at the base), ft-lb.

M_x = Moment at distance X, ft-lb.

R = Mean radius of vessel, in.

R_w = Numerical coefficient (use 4 for vessels)

S = Site coefficient for soil characteristics

A soil profile with either:

(a) A rock-like material characterized by a shear-wave velocity greater than 2,500 feet per second or by other suitable means of classification.

(b) Stiff or dense soil condition where the soil depth is less than 200 feet. **S = 1**

A soil profile with dense or stiff soil conditions, where the soil depth exceeds 200 feet. **S = 1.2**

A soil profile 40 feet or more in depth and containing more than 20 feet of soft to medium stiff clay but not more than 40 feet of soft clay. **S = 1.5**

A soil profile containing more than 40 feet of soft clay. **S = 2.0**

S_t = Allowable tensile stress of vessel plate material, psi

T = Fundamental period of vibration, seconds

$= C_t \times H^{3/4}$

t = Required corroded vessel thickness, in.

$$= \frac{12\,M}{\pi\,R^2 S_t\,E} \text{ or } \frac{12\,M_x}{\pi R^2 S_t\,E}$$

V = Total seismic shear at base, lb.

W = Total weight of tower, lb.

X = Distance from top tangent line to the level under consideration, ft.

Z = Seismic zone factor,
0.075 for zone 1, 0.15 for zone 2A,
0.2 for zone 2B, 0.3 for zone 3,
0.4 for zone 4,
(see map on the following pages for zoning)

DESIGN OF TALL TOWERS

SEISMIC LOAD (EARTHQUAKE)

EXAMPLE

Given:

Seismic zone: 2B $\quad Z = 0.2$

$D = 37.5$ in. $= 3.125$ ft. $\quad X = 96$ ft. 0 in.

$H = 100$ ft., 0 in. $\quad W = 35{,}400$ lb.

Determine: The overturning moment due to earthquake at the base and at a distance X from top tangent line

First, fundamental period of vibration shall be calculated

$T = C_t \times H^{3/4} = 0.035 \times 100^{3/4} = 1.1$ sec.

and

$I = 1, \quad S = 1.5 \quad R_w = 4,$

$$C = \frac{1.25S}{T^{2/3}} = \frac{1.25 \times 1.5}{1.1^{2/3}} = 1.76 < 2.75$$

$$V = \frac{ZIC}{R_w} \times W = \frac{0.2 \times 1 \times 1.76}{4} \times 35{,}400 = 3115 \text{ lb.}$$

$F_t = 0.07\,TV = 0.07 \times 1.1 \times 3115 = 240$ lb.

$M = [F_t H + (V - F_t)\,(2H/3)\,] =$

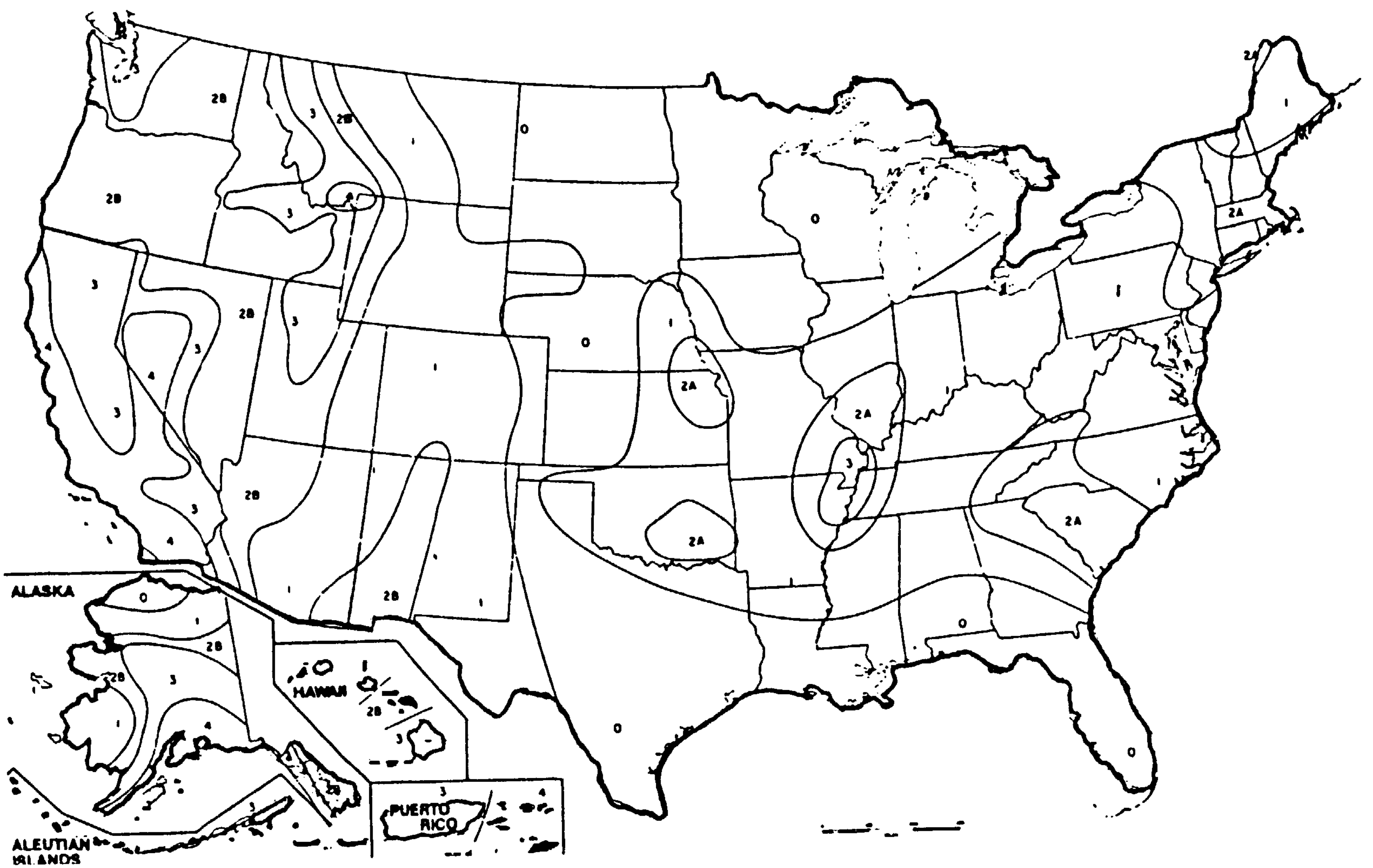
$=[240 \times 100 + 3115 - 240)\,(2 \times 100/3)] = 216{,}625$ ft. lb.

$$\text{X} > \frac{H}{3} \text{ thus}$$

$M_x = [F_t X + (V - F_t)\,(X - H/3)] =$

$= [240 \times 100 + 3115 - 240)\,(96 - 100/3)] = 205{,}125$ ft. -lb.

SEISMIC ZONE MAP OF THE UNITED STATES

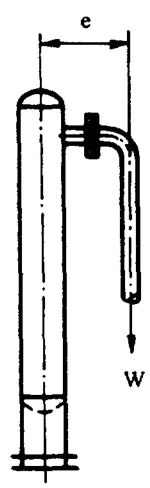


For areas outside of the United States, see Appendix Chapter 23 of UBC :1991

DESIGN OF TALL TOWERS

ECCENTRIC LOAD

Towers and their internal equipment are usually symmetrical around the vertical axis and thus the weight of the vessel sets up compressive stress only. Equipment attached to the vessel on the outside can cause unsymmetrical distribution of the loading due to the weight and result in bending stress. This unsymmetrical arrangement of small equipment, pipes and openings may be neglected, but the bending stresses exerted by heavy equipment are additional to the bending stresses resulting from wind or seismic load.



FORMULAS

MOMENT	STRESS	REQUIRED THICKNESS
$M = We$	$S = \frac{12We}{\pi R^2 t}$	$t = \frac{12We}{R^2 \pi SE}$

NOTATION

- e = Eccentricity, the distance from the tower axis to center of eccentric load, ft.
- E = Efficiency of welded joints.
- M = Moment of eccentric load, ft. lb.
- R = Mean radius of vessel, in.
- S = Stress value of material, or actual bending stress, psi
- t = Thickness of vessel, excluding corrosion allowance, in.
- W = Eccentric load, lb.

EXAMPLE

Given:
- e = 4 ft. 0 in.
- R = 15 in.
- t = 0.25 in.
- W = 1000 lb.

Determine moment, M, and stress, S.

Moment, $M = We = 1000 \times 4 = 4000$ ft. lb.

$$S = \frac{12\ We}{\pi\ R^2 t} = \frac{12 \times 1000 \times 4}{3.14 \times 15^2 \times 0.25} = 272 \text{ psi}$$

When there is more than one eccentric load, the moments shall be summarized, taking the resultant of all eccentric loads.

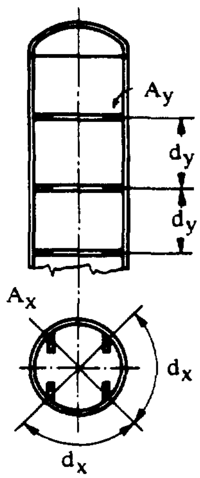
Design of Tall Towers

ELASTIC STABILITY

A tower under axial compression may fail in two ways because of instability:

1. By buckling of the whole vessel (Euler buckling)
2. By local buckling

In thin-walled vessels (when the thickness of the shell is less than one-tenth of the inside radius) local buckling may occur at a unit load less than that required to cause failure of the whole vessel. The out of roundness of the shell is a very significant factor in the resulting instability. The formulas for investigation of elastic stability are given in this Handbook, developed by Wilson and Newmark. Elements of the vessel which are primarily used for other purposes (tray supports, downcomer bars) may be considered also as stiffeners against buckling if closely spaced. Longitudinal stiffeners increase the rigidity of the tower more effectively than circumferential stiffeners. If the rings are not continuous around the shell, its stiffening effect shall be calculated with the restrictions outlined in the Code UG-29 (c).



FORMULAS

ALLOWABLE STRESS (S)

Without Stiffener	With Stiffener
$S = 1{,}500{,}000\frac{t}{R}$ ($\not> \frac{1}{3}$ yield point)	$S = \frac{1{,}500{,}000}{R}\sqrt{t_y t_x}$ ($\not> \frac{1}{3}$ yield p.)

NOTATIONS:

A_x = Cross sectional area of one logitudinal stiffener, sq. in.
A_y = Cross sectional area of one circumferential stiffener, sq. in.
d_x = Distance between logitudinal stiffeners, in.
d_y = Distance between circumferential stiffeners, in.
R = Mean radius of the vessel, in.
S = Allowable compressive stress, psi
t = Thickness of shell, in.

$t_x = t + \frac{A_x}{d_x}$ The equivalent thickness of the shell when longitudinally stiffened, in.

$t_y = t + \frac{A_y}{d_y}$ The equivalent thickness of the shell when circumferentially stiffened, in.

EXAMPLE

Given: R = 18 in.
t = 0.25 in.

Given: A_y = 1 sq. in.
d_y = 24 in.

Longitudinal stiffener is not used, then:

$t_x = t = 0.25$ in.

$t_y = t + \frac{1}{24} =$

$= 0.25 + 0.04 = 0.29$

Determine the allowable compressive stress *(S)*

$$S = \frac{1{,}500{,}000 \times t}{R} = \frac{1{,}500{,}000 \times 0.25}{18} = 20{,}833 \text{ psi}$$

Determine the allowable compressive stress *(S)* using stiffener rings

$$S = \frac{1{,}500{,}000}{R}\sqrt{t_y t_x} =$$

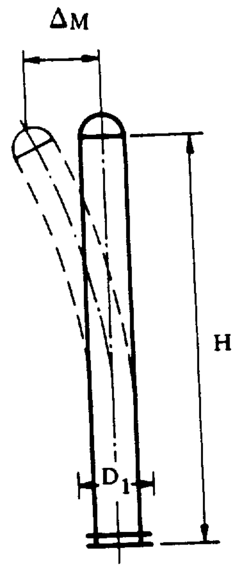
$$\frac{1{,}500{,}000}{18}\sqrt{0.25 \times 0.29} = 22.438 \text{ PSI}$$

Reference: Wilson, W. M., and Newmark N. M.: The Strength of Thin Cylindrical Shells as Columns, Eng. Exp. Sta. Univ. Ill. bull. 255, 1933.

DESIGN OF TALL TOWERS

DEFLECTION

Towers should be designed to deflect no more than 6 inches per 100 feet of height. The deflection due to the wind load may be calculated by using the formula for uniformly loaded cantilever beam.



FORMULA

$$\Delta_M = \frac{P_w D_1 H (12H)^3}{8EI}$$

NOTATIONS

Δ_M = Maximum deflection (at the top), in.
D_I = Width of the tower with insulation, etc. ft.
E = Modulus of elasticity, psi
H = Length of vessel, included skirt, ft.
I = $R^3 \pi\, t$, moment of inertia for thin cylindrical shell (when $R > 10t$)
R = Mean radius of the tower, in.
t = Thickness of skirt, in.
P_w = Wind pressure, psf

EXAMPLE

Given:

D_I = 2 ft., 6 in.
E = 30,000,000
H = 48 ft., 0 in.
I = $R^3\ \pi\ 0.3125$
P_w = 30 psf
R = 12 in.
t = 0.3125 in.

Determine the maximum deflection: Δ_M

$$\Delta_M = \frac{P_w D_I H\ (12H)^3}{8EI}$$

$$\Delta_M = \frac{30 \times 2.5 \times 48\ (12 \times 48)^3}{8 \times 30{,}000{,}000 \times 12^3 \times 3.14 \times 0.3125} = 1.69 \text{ in.}$$

The maximum allowable deflection 6 inches per 100 ft. of height:

$$\text{for } 48'\text{-}0'' = \frac{48 \times 6}{100} = 2.88 \text{ in.}$$

Since the actual deflection does not exceed this limit, the designed thickness of the skirt is satisfactory.

A method for calculating deflection, when the thickness of the tower is not constant, given by S. S. Tang: "Short Cut Method for Calculating Tower Deflection". Hydrocarbon Processing November 1968.

COMBINATION OF STRESSES

The stresses induced by the previously described loadings shall be investigated in combination to establish the governing stresses.

Combination of wind load (or earthquake load), internal pressure and weight of the vessel:

Stress Condition

At windward side	At leeward side
+ Stress due to wind	– Stress due to wind
+ Stress due to int. press.	+ Stress due to int. press.
– Stress due to weight	– Stress due to weight

Combination of wind load (or earthquake load), external pressure and weight of the vessel:

Stress Condition

At windward side	At leeward side
+ Stress due to wind	– Stress due to wind
– Stress due to ext. press.	– Stress due to ext. press.
– Stress due to weight	– Stress due to weight

The positive signs denote tension and the negative signs denote compression. The summation of the stresses indicate whether tension or compression is governing.

It is assumed that wind and earthquake loads do not occur simultaneously, thus the tower should be designed for either wind or earthquake load whichever is greater.

Bending stress caused by excentricity shall be summarized with the stresses resulting from wind or earthquake load.

The stresses shall be calculated at the following locations:

1. At the bottom of the tower
2. At the joint of the skirt to the head
3. At the bottom head to the shell joint
4. At changes of diameter or thickness of the vessel

The stresses furthermore shall be examined in the following conditions:

1. During erection or dismantling
2. During test
3. During operation

Under these different conditions, the weight of the vessel and consequently, the stress conditions are also different. Besides, during erection or dismantling the vessel is not under internal or external pressure.

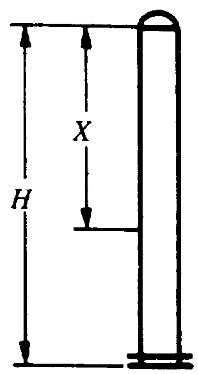
For analyzing the strength of tall towers under various loadings by this Handbook, the maximum stress theory has been applied.

COMBINATION OF STRESSES (cont.)

The bending moment due to wind is decreasing from the bottom to the top of the tower, thus the plate thickness can also be decreased accordingly.
Table A and Figure B are convenient aids to find the distance down from the top of the tower for which a certain thickness is adequate.

t_w/t_p	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7
m	1.0	0.91	0.84	0.79	0.74	0.71	0.67	0.64	0.62	0.60	0.58	0.56	0.54
t_w/t_p	1.8	1.9	2.0	2.2	2.4	2.6	2.8	3.0	3.3	3.6	4.0	4.5	5.0
m	0.53	0.51	0.50	0.48	0.46	0.44	0.42	0.41	0.39	0.37	0.35	0.33	0.32

TABLE A, VALUES OF FACTOR m



Since the longitudinal stress due to internal pressure is one half of the circumferential stress, one half of the required wall thickness for internal pressure is available to resist the bending force of the wind. From Table A, using factor m can be found the distance X down from the top tangent line within which the thickness calculated for internal pressure satisfactory also to resist the wind pressure.

$X = H \times m$

t_p = The required thickness for internal pressure (Hoop Tension) in.

t_w = The required thickness for wind pressure at the bottom head joint to shell, in.

EXAMPLE:

t_p = 0.233 in., t_w = 0.644 in. t_w/t_p = 0.644/0.233 = 2.7

H = 100 ft.

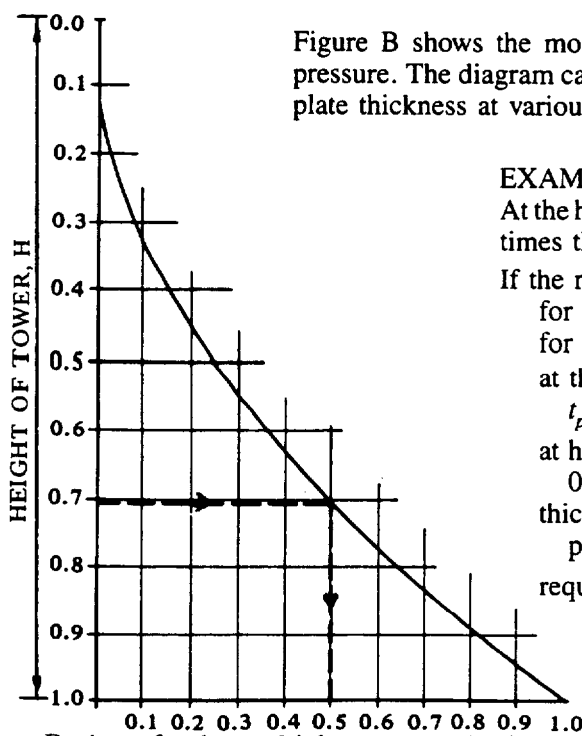
From Table m = 0.43 and $X = mH = 0.43 \times 100 = 43$ ft.

Figure B shows the moment diagram of a tower under wind pressure. The diagram can also be used to select the appropriate plate thickness at various heights.

EXAMPLE:
At the height of 0.71 H the required thickness is 0.5 times the thickness required at the bottom.

If the required thickness is:

for internal pressure, t_p	= 0.250 in.
for wind load, t_w	= 0.625 in.
at the bottom required $t_p/2 + t_w$	= 0.750 in.
at height 0.71 H; 0.5 × 0.750	= 0.375 in.
thickness for internal pressure $t_p/2$	= 0.125 in.
required thickness at 0.71 H	= 0.500 in.



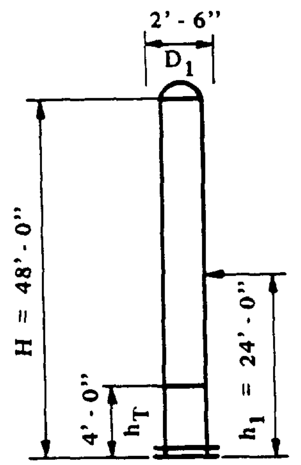
Ratio of plate thickness required at the bottom ($t_r/2 + t_w$) to thickness required at the considered height.

Fig. B

DESIGN OF TALL TOWERS

EXAMPLE - A

Required thickness of cylindrical shell under internal pressure and wind load.



DESIGN CONDITIONS

D = 2 ft. 0 in. inside diameter of vessel
D_1 = 2 ft. 6 in. width of tower with insulation, etc.
E = 0.85 efficiency of welded joints
H = 48 ft. 0 in. length of tower
h_T = 4 ft. 0 in. distance from the base to the bottom head to shell joint
P = 250 psi internal pressure
P_w = 30 psf wind pressure
R = 12 in. inside radius of vessel
S = 13750 psi stress value of SA 285 C material at 200°F temperature
V = Total shear lb.

No allowance for corrosion.

Minimum required thickness for internal pressure considering the strength of the long seams:

$$t = \frac{PR}{SE - 0.6P} = \frac{250 \times 12}{13{,}750 \times 0.85 - 0.6 \times 250} = \frac{3{,}000}{11{,}538} = 0.260 \text{ in.}$$

Minimum required thickness for internal pressure considering the strength of the girth seams:

$$t = \frac{PR}{2SE + 0.4P} = \frac{250 \times 12}{2 \times 13{,}750 \times 0.85 + 0.4 \times 250} = \frac{3{,}000}{23{,}475} = 0.128 \text{ in.}$$

Required thickness for longitudinal bending due to wind pressure. Moment at the base (M):

$$P_w \times D_1 \times H = V \times h_1 = M$$
$$30 \times 2.5 \times 48 = 3{,}600 \times 24 = 86{,}400 \text{ ft. lb.}$$

Moment at the bottom seam (M_T)

$$M_T = M - h_T (V - 0.5\, P_w\, D_1\, h_T) = 86{,}400 - 4\,(3{,}600 - 0.5 \times 30 \times 2.5 \times 4)$$
$$= 86{,}400 - 13{,}800 = 72{,}600 \text{ ft. lb.} = 72{,}600 \times 12 = 871{,}200 \text{ in. lb.}$$

Required thickness:

$$t = \frac{M_T}{R^2 \pi SE} = \frac{871{,}200}{12^2 \times 3.14 \times 13{,}750 \times 0.85} = \frac{871{,}200}{5{,}287{,}523} = 0.165 \text{ in.}$$

The required thickness calculated with the strength of the bottom girth seam:

For wind pressure	0.165 in.
For int. pressure	0.128 in.
TOTAL	0.293

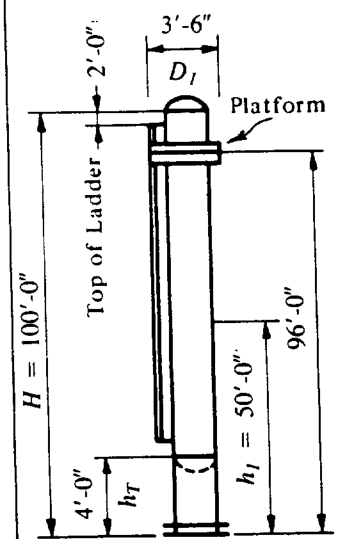
This is greater than the thickness calculated with the strength of the longitudinal seam therefore, this minimum thickness 0.293 in. shall be used.

For simple vessels where the moment due to wind is small, the above calculation is satisfactory. Vessels which are subject to larger loadings may need closer investigation with respect also to economical viewpoints. **See page 77–84 for skirt, base and anchor bolt design.**

DESIGN OF TALL TOWERS

EXAMPLE B

Required thickness of cylindrical shell under combined loadings of internal pressure, wind and weight of tower.



DESIGN DATA

D = 3 ft. 0 in. inside diameter
D_l = 3 ft. 6 in. width of vessel with insulation, allowance for piping, etc.
E = 0.85 efficiency of welded seams
h_T = 4 ft. 0 in. distance from the base to the bottom head to shell joint.
H = 100 ft. 0 in. length of tower
P = 150 psi internal pressure
P_w = 30 psf wind pressure
R = 18 in. inside radius of vessel
S = 13750 psi stress value of SA-285C material at 200°F temperature
V = Total shear, lb.
Head: 2:1 seamless elliptical
C_m = Circumference of shell on the mean diameter, in.
(corrosion allowance not required)

Minimum required thickness for internal pressure considering the strength of the longitudinal seam of shell.

$$t = \frac{PR}{SE - 0.6P} = \frac{150 \times 18}{13{,}750 \times 0.85 - 0.6 \times 150} = 0.233 \text{ in. Use } 0.25 \text{ in. plate}$$

Minimum required thickness for internal pressure considering the strength of the circumferential seam of shell.

$$t = \frac{PR}{2SE + 0.4P} = \frac{150 \times 18}{2 \times 13{,}750 \times 0.85 + 0.4 \times 150} = 0.115 \text{ in.}$$

Minimum required thickness for head

$$t = \frac{PD}{2SE - 0.2P} = \frac{150 \times 36}{2 \times 13{,}750 \times 0.85 - 0.2 \times 150} = 0.231 \text{ in.}$$

Wind Load	$P_w \times D_l \times H$	$= V$	$\times h_l$	$= M$
Vessel	$30 \times 3.5 \times 100$	= 10,500	× 50	= 525,040
Platform	30 × 8 lin. ft.	= 240	× 96	= 23,040
Ladder	30 × 98 lin. ft.	= 2,940	× 49	= 144,060
	Total shear	V = 13,680	M	= 692,100 ft. lb. moment at base

Moment at the bottom head seam (M_T)

$$M_T = M - h_T(V - 0.5\, P_w D_l h_T) =$$

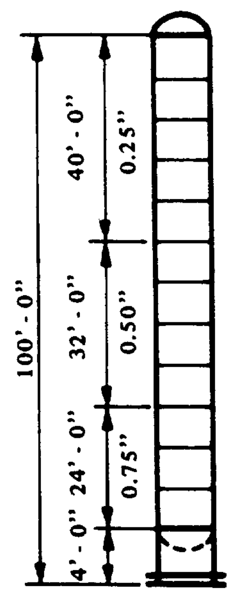
$$692{,}100 - 4\,(13680 - 0.5 \times 30 \times 3.5 \times 4) = 638{,}220 \text{ ft. lb.}$$

$$t = \frac{12\, M_t}{R^2\, \pi\, SE} = \frac{12 \times 638{,}220}{18^2 \times 3.14 \times 13{,}750 \times 0.85} = \frac{7{,}658{,}640}{11{,}896{,}425} = 0.644$$

For int. pressure 0.115

Try 0.750 in. plate for the lower courses 0.759 in.

EXAMPLE B (CONT.)



The preliminary calculation of the required wall thickness shows that at the bottom approximately 0.75 in. plate is required, to withstand the wind load and internal pressure, while at the top the wind load is not factor and for internal pressure (hoop tension) only 0.25 plate is satisfactory. For economical reasons it is advisable to use different plate thicknesses at various heights of the tower.

The thickness required for hoop tension (0.25 in.) serves to resist also the wind load to a certain distance down from the top.

Find this distance (X) from table A, Page 70

tw/tp = 0.233/0.644 = 2.7 then X = 0.43 x H = 43 ft.

From diagram B, Page 70 can be found the required thickness and length of the intermediate shell sections.

Using 8 ft. wide plates, the vessel shall be constructed from:

(5) 0.25 thick 8 ft. wide courses	40 ft.
(4) 0.50 thick 8 ft. wide courses	32 ft.
(3) 0.75 thick 8 ft. wide courses	24 ft.
Total	96 ft.

WEIGHT OF THE TOWER
(See tables beginning on page 374)

Shell 40 × 97	3880	Skirt 4 × 195	780
32 × 195	6240	Base ring	720
24 × 294	7056	Anchor ring	260
Head top 0.3125 nom.	160	Anchor lugs	120
bot. 0.8125 nom.	393		1880
Int. plate work	800	+ 6%	113
Tray supports	110		1993
Insulation rings	220	Say	2000 lb.
Opening	900		
	19759	Insulation	4600
+ 6%	1184	Platform	1160
	20943 lb.	Ladder	2800
Say	21,000	Piping	1400
			9960
		Say	10,000 lb.

TOTAL ERECTION WEIGHT: 33,000 lb.

Trays	600
Operating liquid	2400
	3000 lb.
+ Erection Wt.	33,000 lb.

TOTAL OPERATING WEIGHT: 36.000 lb.

Test water	42,000 lb.
+ Erection Wt.	33,000 lb.

TOTAL TEST WEIGHT: 75,000 lb.

For weight of water content, see Page 416

EXAMPLE B (CONT.)

Checking the stresses with the preliminary calculated plate thicknesses:

Stress in the shell at the bottom head to shell joint:

Plate thickness 0.75 in.

Stress due to internal pressure $S = \frac{PD}{4t} = \frac{150 \times 36.75}{4 \times 0.75} = 1837$ psi

Stress due to wind $S = \frac{12\ M_T}{R^2\ \pi\ t} = \frac{12 \times 638{,}220}{18.375^2 \times 3.14 \times 0.75} = 9{,}632$ psi

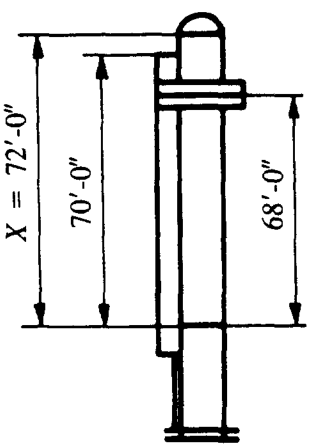
Stress due to weight, in erection condition $S = \frac{W}{C_m t} = \frac{31{,}000}{115.5 \times 0.75} = 358$ psi

in operating condition $S = \frac{W}{C_m t} = \frac{34{,}000}{115.5 \times 0.75} = 392$ psi

COMBINATION OF STRESSES			
WINDWARD SIDE		**LEEWARD SIDE**	
IN EMPTY (ERECTION) CONDITION			
Stress due to wind	+ 9,640	Stress due to wind	− 9,640
Stress due to weight	− 358	Stress due to weight	− 358
	+ 9,282 psi		− 9,998 psi
(No int. pressure during erection)			
IN OPERATING CONDITION			
Stress due to int. press.	+ 1,837	Stress due to wind	− 9,640
Stress due to wind	+ 9,640	Stress due to weight	− 392
	+ 11,477		−10,032
Stress due to weight	− 392	Stress due to int. press.	+ 1,837
	+ 11,085 psi		− 8,195 psi

The tensile stress 11,085 psi in operating condition on the windward side governs. The allowable stress for the plate material with 0.85 joint efficiency is 11687.5 psi. Thus the selected 0.75 in. thick plate at the bottom of the vessel is satisfactory.

Stress in the shell at 72 ft. down from the top of tower. Plate thickness 0.50 in.



Stress due to wind.

$$P_w \times D_l \times X = V \times \frac{X}{2} = M_x$$

Shell	30 × 3.5 × 72 = 7,560 × 36	=	272,160
Platform	30 × 8 lin.-ft. = 240 × 68	=	16,320
Ladder	30 × 70 lin.-ft. = 2,100 × 35	=	73,500
	Total Moment M_x	=	361,980 ft.-lb.

$$S = \frac{12\ M_x}{R^2\ \pi\ t} = \frac{12 \times 361{,}980}{18.25^2 \times 3.14 \times 0.50} = 8{,}303 \text{ psi}$$

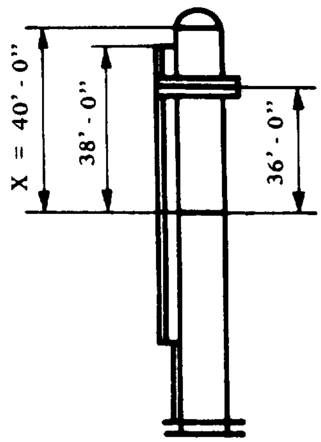
Stress due to internal pressure (As calculated previously) 1,837

Total 10,140 psi

The calculation of stresses at the bottom head has shown that the stresses on the windward side in operating condition govern and the effect of the weight is insignificant. Therefore without further calculation it can be seen that the tensile stress 10,142 psi does not exceed the allowable stress 11,687.5 psi. Thus the selected 0.50 in. thick plate is satisfactory.

EXAMPLE B (CONT.)

Stress in the shell at 40 ft. down from the top of the tower. Plate thickness 0.25 in.



Stress due to wind.

$$P_w \times D_l \times X = V \times \frac{X}{2} = M_x$$

Shell	30 × 3.5 × 40 = 4,200 × 20 =		84,000
Platform	30 × 8 lin. ft. = 240 × 36 =		8,640
Ladder	30 × 38 lin. ft. = 1,140 × 19 =		21,660
	Total Moment M_x	=	114,300 ft.-lb.

$$S = \frac{12\ M_x}{R^2\ \pi\ t} = \frac{12 \times 114,300}{18.125^2 \times 3.14 \times 0.25} = 5,316 \text{ psi}$$

Stress due to internal pressure
(As calculated previously) 1,837 psi

Total 7,153 psi

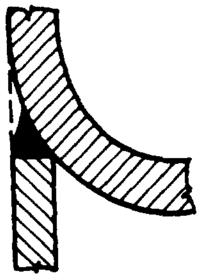
The 0.25 in. thick plate for shell at 40 ft. distance from top of the tower is satisfactory. No further calculation is required on the same reason mentioned above.

DESIGN OF SKIRT SUPPORT

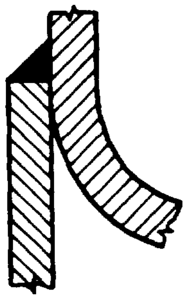
A skirt is the most frequently used and the most satisfactory support for vertical vessels. It is attached by continuous welding to the head and usually the required size of this welding determines the thickness of the skirt.

Figures A and B show the most common type of skirt to head attachment. In calculation of the required weld size, the values of joint efficiency given by the Code (UW 12) may be used.

A



B



FORMULA

$$t = \frac{12\,M_T}{R^2 \pi SE} + \frac{W}{D \pi SE}$$

NOTATIONS

D = Outside diameter of skirt, in.
E = Efficiency of skirt to head joint.
(0.6 for butt weld, Fig. A, 0.45 for lap weld, Fig. B
M_T = Moment at the skirt to head joint, ft. lb.
R = Outside radius of skirt, in.
S = Stress value of the head or skirt material whichever is smaller, psi.
t = Required thickness of skirt, in.
W = Weight of the tower above the skirt to the head joint, in operating condition.

NOTE: Using extremely high skirt, the stresses at the base may govern. To calculate the required thickness of the skirt, in this case the above formula can be used. The moment and weight shall be taken into consideration at the base and the joint efficiency will be 1.0.

EXAMPLE

Given the same vessel considered in Example B.

D = 37.5 in.
E = 0.60 for butt joint
M_T = 638,220 ft. lb.
R = 18.75 in.

S = 18,000* stress value of SA-285-C plate
W = 31,000 lb.

*For structural purpose.

Determine the required skirt thickness.

For wind $t = \dfrac{12\,M_T}{R^2 \pi SE} = \dfrac{12 \times 638{,}220}{18.75^2 \times 3.14 \times 18{,}000 \times 0.6} = 0.642$ in.

For Weight $t = \dfrac{W}{D \times 3.14 \times SE} = \dfrac{31{,}000}{37.5 \times 3.14 \times 18{,}000 \times 0.6} = \underline{0.024 \text{ in.}}$

TOTAL = 0.666 in.

Use 11/16" thick plate for skirt.

REFERENCES: Thermal stresses are discussed in these works:
Brownell, Lloyd E., and Young, Edwin, H., "Process Equipment Design", John Wiley and Sons, Inc., 1959. Weil, N. A., and J. J. Murphy Design and Analysis of Welded Pressure Vessel Skirt Supports. Asme. Trans. Industrial Engineering for Industry, Vol. 82, Ser. B., Feb., 1960.

DESIGN OF ANCHOR BOLT

Vertical vessels, stacks and towers must be fastened to the concrete foundation, skid or other structural frame by means of anchor bolts and the base (bearing) ring.

The number of anchor bolts. The anchor bolts must be in multiple of four and for tall towers it is preferred to use minimum eight bolts.

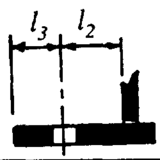
Spacing of anchor bolts. The strength of too closely spaced anchor bolts is not fully developed in concrete foundation. It is advisable to set the anchor bolts not closer than about 18 inches. To hold this minimum spacing, in the case of small diameter vessel the enlarging of the bolt circle may be necessary by using conical skirt or wider base ring with gussets.

Diameter of anchor bolts. Computing the required size of bolts the area within the root of the threads only can be taken into consideration. The root areas of bolts are shown below in Table A. For corrosion allowance one eighth of an inch should be added to the calculated diameter of anchor bolts.

For anchor bolts and base design on the following pages are described:

1. An approximate method which may be satisfactory in a number of cases.
2. A method which offers closer investigation when the loading conditions and other circumstances make it necessary.

TABLE A



Bolt Size	Bolt * Root Area sq. in.	Dimension in. l_2	Dimension in. l_3
½	0.126	7/8	5/8
⅝	0.202	1	3/4
¾	0.302	1-1/8	13/16
⅞	0.419	1-1/4	15/16
1	0.551	1-3/8	1-1/16
1⅛	0.693	1-1/2	1-1/8
1¼	0.890	1-3/4	1-1/4
1⅜	1.054	1-7/8	1-3/8
1½	1.294	2	1-1/2
1⅝	1.515	2-1/8	1-5/8
1¾	1.744	2-1/4	1-3/4
1⅞	2.049	2-3/8	1-7/8
2	2.300	2-1/2	2
2¼	3.020	2-3/4	2-1/4
2½	3.715	3-1/16	2-3/8
2¾	4.618	3-3/8	2-5/8
3	5.621	3-5/8	2-7/8

* For bolts with standard threads.

TABLE B
NUMBER OF ANCHOR BOLTS

Diameter of Bolt circle in.	Minimum	Maximum
24 to 36	4	4
42 to 54	8	8
60 to 78	12	12
84 to 102	12	16
108 to 126	16	20
132 to 144	20	24

TABLE C
MAXIMUM ALLOWABLE STRESSES FOR BOLTS USED AS ANCHOR BOLT

Specification Number	Diameter in.	Max. allow. Stress psi.
SA 325	All diameters	15,000
SA 193 B 7	2½ and under	18,000
SA 193 B16	2½ and under	18,000
SA 193 B 7	Over 2½ to 4 incl.	16,000
SA 193 B16	Over 2½ to 4 incl.	15,700

DESIGN OF ANCHOR BOLT
(Approximate Method)

A simple method for the design of anchor bolts is to assume the bolts replaced by a continuous ring whose diameter is equal to the bolt circle.

The required area of bolts shall be calculated for empty condition of tower.

FORMULAS

Maximum Tension lb./lin. in. T	$T = \frac{12M}{A_B} - \frac{W}{C_B}$
Required Area of One Bolt Sq. - in. B_A	$B_A = \frac{T C_B}{S_B N}$
Stress in Anchor Bolt psi. S_B	$S_B = \frac{T C_B}{B_A N}$

NOTATION

A_B = Area within the bolt circle, sq. in.
C_B = Circumference of bolt circle in.
M = Moment at the base due to wind or earthquake, ft. lb.
N = Number of anchor bolts
S_B = Maximum allowable stress value of bolt material psi.
W = Weight of the vessel during erection, lb.

EXAMPLE

Given bolt circle = 30 in.; then:

A_B = 707 sq. in.
C_B = 94 in.
M = 86400 ft. lb.
W = 6000 lb. during erection.
S_B = 15000 psi. the maximum allowable stress value of the anchor bolt material.
N = 4 number of bolts. (See Table B on the Preceding Page)

Determine the size and number of required anchor bolts.

$$T = \frac{12 \times 86,400}{707} - \frac{6,000}{94} = 1,402 \text{ lb./lin. in.}$$

$$B_A = \frac{1,402 \times 94}{15,000 \times 4} = 2.196 \text{ sq. in.}$$

From Table A. Page 77 the root area of 2" bolt is 2.300 sq. in.
Adding 0.125 in. for corrosion, use:
(4) 2¼" bolts.

Checking stress in anchor bolt:

$$S_B = \frac{1,402 \times 94}{2.300 \times 4} = 14,324 \text{ psi}$$

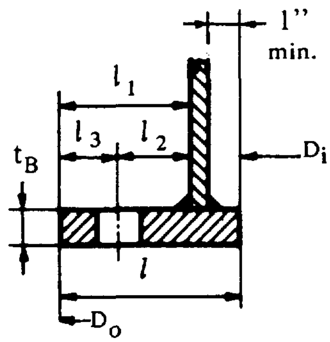
Since the maximum allowable stress is 15,000 psi, the selected number and size of bolts are satisfactory.

DESIGN OF BASE RING
(Approximate Method)

The formulas below are based on the following considerations:

1. The bearing surface of the base ring shall be large enough to distribute the load uniformly on the concrete foundation and thus not to exceed the allowable bearing load of the foundation.
2. The thickness of the base ring shall resist the bending stress induced by wind or earthquake.

FORMULAS



Maximum Compression lb./lin. in.	$P_c = \frac{12M}{A_s} + \frac{W}{C_s}$
Approximate Width of Base Ring in.	$l = \frac{P_c}{f_b}$
Approximate Thickness of Base Ring in.	$t_B = 0.32 l_1$
Bearing Stress psi	$S_1 = \frac{P_c C_s}{A_R}$
Bending Stress psi	$S_2 = \frac{3 \times S_1 l_1^2}{t_B^2}$

NOTATION

A_R = Area of base ring = 0.7854 $(D^2_o - D^2_i)$ sq. in.
A_S = Area within the skirt, sq. in.
C_S = Circumference on O.D. of skirt, in.
f_b = Safe bearing load on concrete, psi. See Table E, on Page 80
l_1 = Cantilever inside or outside, whichever is greater, in.
l_2 l_3 = Dimensions, as shown on sketch above. (For minimum dimensions see Table A on page 77)
M = Moment at the base due to wind or earthquake, ft. lb.
W = Weight of vessel during operation or test, lb.

EXAMPLE

Given:
M = 86,400 ft. lb.
f_b = 500 psi from Table E Page 80
W = 7,500 lb. operating
18,000 lb. test
Anchor bolts: (4) 2¼ in.
O.D. of skirt 24.625 in.
Then A_s = 476 sq. in.
C_s = 77 in.

Determine the minimum width and thickness of base ring for operating condition.

$$P_c = \frac{12 \times 86{,}400}{476} + \frac{7{,}500}{77} = 2{,}275 \text{ lb./lin.-in.}$$

$$l = \frac{2{,}275}{500} = 4.55 \text{ in.},$$ but from Table A, page 77 the minimum dimension for l_2 = 2¾ in. and for l_3 = 2¼ in., use 6½ in. wide base ring.

t_B = 0.32 × 5 = 1.60 in.
Use 1⅝ in. thick base ring.

Checking stresses:

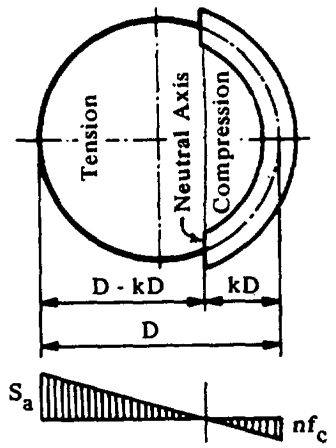
$$S_1 = \frac{2{,}273 \times 77}{574} = 305 \text{ psi}$$ Bearing stress

$$S_2 = \frac{3 \times 305 \times 5^2}{1.5^2} = 10{,}167 \text{ psi}$$ Bending stress

Using SA 285 C plate for base ring, 18,000 psi allowable stress can be taken for structural purposes. Thus the width and thickness of the base ring are satisfactory.
The stresses should be checked also for test condition.

DESIGN OF ANCHOR BOLT AND BASE RING

When a tower is under wind or earthquake load, on the windward side tensional stress arises in the steel and on the opposite side compressive stress in the concrete foundation. It is obvious then that the area of the bolting and the area of the base ring are related. As the anchor bolt area increased, the base ring area can be decreased. With the design method given here, the minimum required anchor bolt area for a practical size of base ring can be found. The strength of the steel and the concrete is different, therefore, the neutral axis does not coincide with the centerline of the skirt.



Design procedure:

1. Determine the value of k
2. Calculate the required size and number of anchor bolts. See page 77 Table B
3. Determine the inside and outside diameter of the base ring
4. Check the stresses in the anchor bolts and foundation
5. If the deviation between the allowable and actual stresses are too large, repeat the calculation
6. Calculate the base ring thickness
7. Use gusset plates, anchor chairs or compression ring if it is necessary for better stress distribution in the base ring or skirt

TABLE D
Values of Constants as Functions of K

k	C_c	C_t	j	z
0.00	0.000	3.142	0.750	0.500
.05	0.600	3.008	.760	.490
.10	0.852	2.887	.766	.480
.15	1.049	2.772	.771	.469
.20	1.218	2.661	.776	.459
.25	1.370	2.551	.779	.448
.30	1.510	2.442	.781	.438
.35	1.640	2.333	.783	.427
.40	1.765	2.224	.784	.416
.45	1.884	2.113	.785	.404
.50	2.000	2.000	.785	.393
.55	2.113	1.884	.785	.381
.60	2.224	1.765	.784	.369
.65	2.333	1.640	.783	.357
.70	2.442	1.510	.781	.344
.75	2.551	1.370	.779	.331
.80	2.661	1.218	.776	.316
.85	2.772	1.049	.771	.302
.90	2.887	0.852	.766	.286
.95	3.008	0.600	.760	.270
1.00	3.142	0.000	.750	.250

TABLE F
Bending moment per unit length of section of a plate perpendicular to X and Y axes respectively. Use greater value, M_x or M_y.

l_1/b	Mx	My
0.000	0.000	$-0.500 f_c l_1^2$
0.333	$0.0078 f_c b^2$	$-0.428 f_c l_1^2$
0.500	$0.0293 f_c b^2$	$-0.319 f_c l_1^2$
0.667	$0.0558 f_c b^2$	$-0.227 f_c l_1^2$
1.000	$0.0972 f_c b^2$	$-0.119 f_c l_1^2$
1.500	$0.123 f_c b^2$	$-0.124 f_c b^2$
2.000	$0.131 f_c b^2$	$-0.125 f_c b^2$
3.000	$0.133 f_c b^2$	$-0.125 f_c b^2$
∞	$0.133 f_c b^2$	$-0.125 f_c b^2$

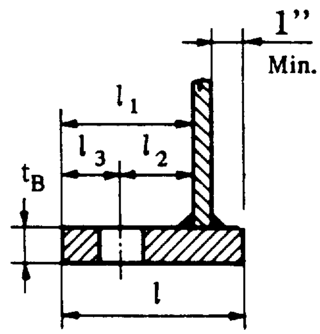
TABLE E
Properties of Concrete Four Mixtures

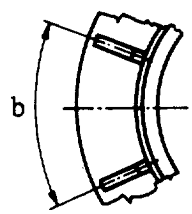
Ultimate 28 day Strength psi	2000	2500	3000	3750
Allowable compr. Strength f_c psi	800	1000	1200	1500
Safe bearing load f_b psi	500	625	750	938
Factor n	15	12	10	8

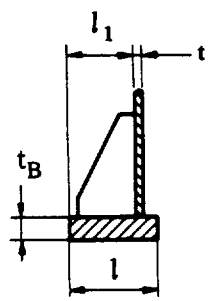
NOTE:
See notation on facing page.

DESIGN OF ANCHOR BOLT AND BASE RING

FORMULAS







Value of constant, k dimensionless	$k = \frac{1}{1 + (S_a/nf_{cb})}$
Total required area of anchor bolts B_t sq. - in.	$B_t = 2\pi \frac{12M - Wzd}{C_t S_a jd}$
Relationship between max. allowable compressive stress at the outside edge of base ring and at the bolt circle.	$f_c = f_{cb} \frac{2kd + l}{2kd}$ $f_{cb} = f_c \frac{2kd}{2kd + l}$
Tensile load on anchor bolts, F_t lb.	$F_t = \frac{M - WzD}{jD}$
Tensile stress in anchor bolts, S_a, psi.	$S_a = \frac{F_t}{t_s r C_t}$
Thickness of a ring which has an area equal to the area of anchor bolts, t_s, in.	$t_s = \frac{B_t}{\pi d}$
Compression load on the concrete, F_c, lb.	$F_c = F_t + W$
Compressive stress in the concrete at the bolt circle. f_{cb} psi.	$f_{cb} = \frac{F_c}{(l_4 + nt_s) r C_c}$
Relationship between tension in steel and compression in concrete.	$S_a = nf_c$
Base ring thickness without gusset plate, t_B, in.	$t_B = l_1 \sqrt{3f_c/S}$
Base ring thickness with gusset plate, t_B, in.	$t_B = \sqrt{\frac{6Mmax}{S}}$

NOTATION

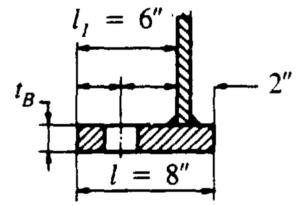
b = The distance between gusset plates, measured on arc of bolt circle in.
B_t = Total area required for anchor bolt sq. in.
C_c, C_t = Constants, see Table D on the preceding page.
d = Diameter of anchor bolt circle, in.
D = Diameter of anchor bolt circle, ft.
f_c = Compressive stress in the concrete at the outer edge of the base ring, psi.
f_{cb} = Compressive stress in the concrete at the bolt circle, psi.
j = Constant, see Table D on the preceding page.
l_4 = $l - t_s$ in. = width of the base ring, in.
M = Moment at the base due to wind or earthquake ft. lb.
M_{max} = M_x or M_y, whichever is greater. See Table F on the preceding page.
n = Ratio of modulus of elasticity of steel and concrete Es/Ec. See Table E.
r = Radius of bolt circle, in.
S_a = Tensile stress in anchor bolts, psi.
S = Maximum allowable stress value of base plate, psi.
W = Weight of the tower at the base, lb.
z = Constant. See Table D on the preceding page.

DESIGN OF ANCHOR BOLT AND BASE RING
EXAMPLE

DESIGN DATA:

D = 5 ft., 0 in. diameter of anchor bolt circle.
d = 60 in. diameter of anchor bolt circle.
n = 10, ratio of modulus of elasticity of steel and concrete (Table E. Page 80)
f_c = 1,200 psi allowable compr. strength of concrete (Table E, Page 80)
S = 15,000 psi allowable stress value of base ring.
S_a = 18,000 psi allowable tensile stress in bolts.
W = 36,000 lb. weight of the tower.
M = 692,100 ft. lb. moment at the base.

DETERMINE:
The size and number of anchor bolts;
The width and thickness of base ring.



SOLUTION:
Assume 8 in. wide base ring and a compressive stress at the bolt circle, f_{cb} = 1,000 psi.

$$k = \frac{1}{1 + \dfrac{S_a}{nf_{cb}}} = \frac{1}{1 + \dfrac{18{,}000}{10 \times 1{,}000}} = 0.35$$

Then the constants from Table D are:
C_c = 1.640
C_t = 2.333
j = 0.783
z = 0.427

$$f_{cb} = f_c \frac{2kd}{2kd + l} = 1{,}200 \frac{2 \times 0.35 \times 60}{2 \times 0.35 \times 60 \times 8} = 1{,}008 \text{ psi}$$

This is in sufficient agreement with the assumed value of f_{cb} = 1,000 psi

Required area of anchor bolts

$$B_t = 2\pi \frac{12M - Wzd}{C_t S_a jd} = 6.28 \frac{12 \times 692{,}100 - 36{,}000 \times 0.427 \times 60}{2.333 \times 18{,}000 \times 0.783 \times 60} = 23.50 \text{ sq. in.}$$

Using 12 anchor bolts, the required root area for one bolt
23.50/12 = 1.958 in.

From Table A 1⅞ in. diameter bolt would be satisfactory but adding ⅛ in. for corrosion, use (12) -2 in. diameter anchor bolts.
Tensile load on the anchor bolts

$$F_t = \frac{M - Wz D}{jD} = \frac{692{,}100 - 36{,}000 \times 0.427 \times 5}{0.783 \times 5} = 157{,}150 \text{ lb.}$$

Tensile stress in the anchor bolts

$$S_a = \frac{F_t}{t_s r C_t} = \frac{157{,}150}{0.125 \times 30 \times 2.333} = 17{,}960 \text{ psi}$$

$$t_s = \frac{B_t}{\pi d} = \frac{23.50}{3.14 \times 60} = 0.125 \text{ in.}$$

Compressive load on the concrete: $l_4 = l - t_s = 8.0 - 0.125 = 7.875$ in.

$$f_{cb} = \frac{F_c}{(l_4 + nt_s)\, r\, C_e} = \frac{193{,}150}{(7.875 + 10 \times 0.125)\, 30 \times 1.640} = 430 \text{ psi}$$

DESIGN OF ANCHOR BOLT AND BASE RING

EXAMPLE (CONT.)

Checking value of k which was calculated with assumed values of f_{cb} = 1,000 psi and S_a = 18,000

$$k = \frac{1}{1 + \frac{S_a}{nf_{cb}}} = \frac{1}{1 + \frac{17,960}{10 \times 430}} = 0.19$$

Then the constants from Table D are:

C_c = 1.184
C_t = 2.683
j = 0.775
z = 0.461

$$F_t = \frac{M - WzD}{jD} = \frac{692,100 - 36,000 \times 0.461 \times 5}{0.775 \times 5} = 157,192 \text{ lb.}$$

$$S_a = \frac{F_t}{t_s r\, C_t} = \frac{157,192}{0.125 \times 30 \times 2.683} = 15,624 \text{ psi}$$

$$F_c = F_t + W = 157,192 + 36,000 = 193,192 \text{ lb.}$$

$$f_{cb} = \frac{F_c}{(l_4 + n\, ts)r\, C_c} = \frac{193,192}{(7.875 + 10 \times 0.125)\, 30 \times 1.184} = 596 \text{ psi}$$

Compressive stress in the anchor bolts:
$S_a = nf_{cb} = 10 \times 596 = 5,960$ psi

Compressive stress in the concrete at the outer edge of the base ring:

$$f_c = f_{cb} \times \frac{2\,kd + l}{2kd} = 596 \times \frac{2 \times 0.19 \times 60 + 8}{2 \times 0.19 \times 60} = 805 \text{ psi}$$

Required thickness of base ring l_l = 6 in.

$$t_B = l_l \sqrt{3 f_c / S} = 6 \sqrt{\frac{3 \times 805}{15,000}} = 2.406 \text{ in.}$$

To decrease the thickness of the base ring, use gusset plates.
Using (24) gusset plates, the distance between the gussets,

$$b = \frac{\pi\, d}{24} = 7.85'' ; \frac{l_l}{b} = \frac{6}{7.85} = 0.764$$

from Table F:

$$M_{max} = M_y = 0.196 f_c\, l_l^2 = 0.196 \times 805 \times 6^2 = 5680 \text{ in. lb.}$$

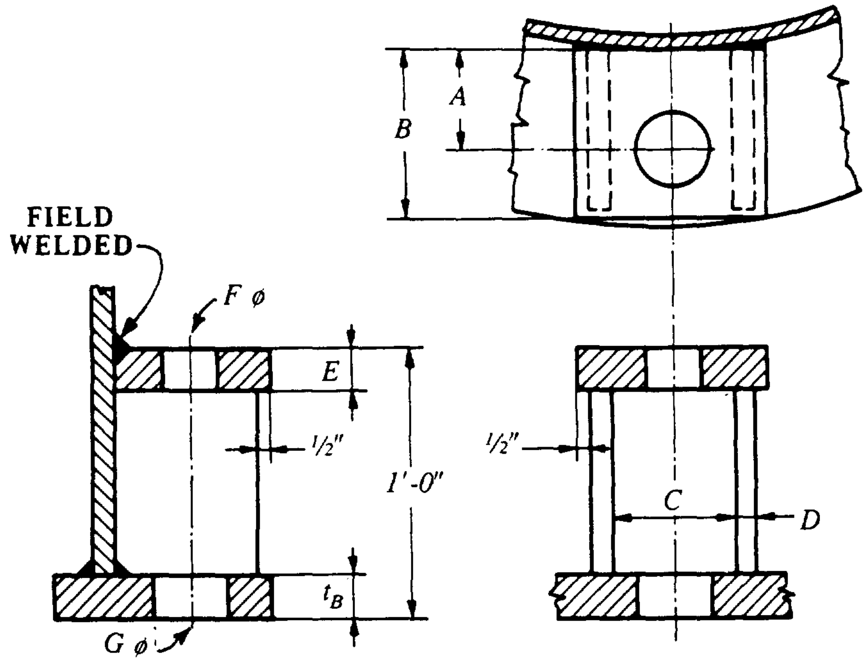
$$t_B = \sqrt{\frac{6 \times 5680}{15,000}} = 1.5076 \text{ in.}$$ Use 1½" in. thick base plate.

ANCHOR BOLT CHAIR FOR TALL TOWERS

The chairs are designed for the maximum load which the bolt can transmit to them.

The anchor bolt size and base plate shall be calculated as described on the foregoing pages.

All contacting edges of the plates shall be welded with continuous fillet weld. The leg size of the fillet weld shall be one half of the thinner joining plate thickness.



DIMENSIONS inches							
Anchor bolt diam.	A	B	C	D	E	F	G
1	1 3/4	3	2 1/2	1/2	3/4	1 1/4	1 1/2
1 1/8	1 7/8	3	2 1/2	1/2	3/4	1 3/8	1 5/8
1 1/4	2	3	2 1/2	1/2	1	1 1/2	1 3/4
1 3/8	2 1/8	4	3	5/8	1	1 5/8	1 7/8
1 1/2	2 1/4	4	3	5/8	1 1/4	1 3/4	2
1 5/8	2 3/8	4	3	5/8	1 1/4	1 7/8	2 1/8
1 3/4	2 1/2	5	3 1/2	3/4	1 1/2	2	2 1/4
1 7/8	2 5/8	5	3 1/2	3/4	1 1/2	2 1/8	2 3/8
2	2 3/4	5	3 1/2	3/4	1 3/4	2 1/4	2 1/2
2 1/4	3	6	4	1	1 3/4	2 1/2	2 3/4
2 1/2	3 1/4	6	4	1	2	2 3/4	3
2 3/4	3 1/2	7	5	1 1/4	2 1/2	3	3 1/4
3	3 3/4	7	5	1 1/4	2 1/2	3 1/4	3 1/2

The above table is taken from Scheiman A.D. Short Cuts to Anchor Bolting and Base Ring Sizing. Petroleum Refiner, June 1963.

STRESSES IN LARGE
HORIZONTAL VESSELS
SUPPORTED BY SADDLES

The design methods of supports for horizontal vessels are based on L. P. Zick's analysis presented in 1951. The ASME published Zick's work (Pressure Vessel and Piping Design) as recommended practice. The API Standard 2510 also refers to the analysis of Zick. The British Standard 1515 adopted this method with slight modification and further refinement. Zick's work has also been used in different studies published in books and various technical periodicals.

The design method of this Handbook is based on the revised analysis mentioned above. (Pressure Vessel and Piping; Design and Analysis, ASME, 1972)

A horizontal vessel on saddle support acts as a beam with the following deviations:

1. The loading conditions are different for a full or partially filled vessel.

2. The stresses in the vessel vary according to the angle included by the saddles.

3. The load due to the weight of the vessel is combined with other loads.

LOADINGS:

1. Reaction of the saddles. It is a recommended practice to design the vessel for at least a full waterload.

2. Internal Pressure. Since the longitudinal stress in the vessel is only one half of the circumferential stress, about one half of the actually used plate thickness is available to resist the load of the weight.

3. External pressure. If the vessel is not designed for full vacuum because vacuum occurs incidentally only, a vacuum relief valve should be provided especially when the vessel outlet is connected to a pump.

4. Wind load. Long vessels with very small t/r values are subject to distortion from wind pressure. According to Zick "experience indicates that a vessel designed to 1 psi. external pressure can successfully resist external loads encountered in normal service."

5. Impact Loads. Experience shows, that during shipping, hardly calculable impact loads can damage the vessels. When designing the width of the saddles and the weld sizes, this circumstance is to be considered.

LOCATION OF SADDLES.

The use of only two saddles is preferred both statically and economically over the multiple support system, this is true even if the use of stiffener rings is necessary. The location of the saddles is sometimes determined by the location of openings, sumps, etc., in the bottom of the vessel. If this is not the case, then the saddles can be placed at the statically optimal point. Thin walled vessels with a large diameter are best supported near the heads, so as to utilize the stiffening effect of the heads. Long thick walled vessels are best supported where the maximal longitudinal bending stress at the saddles is nearly equal to the stress at the midspan. This point varies with the contact angle of the saddles. The distance between the head tangent line and the saddle shall in no case be more than 0.2 times the length of the vessel. (L)

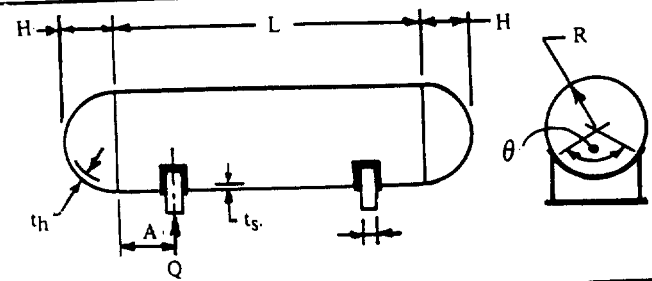
Contact Angle θ

The minimum contact angle suggested by the ASME Code is 120°, except for very small vessels. (Code Appendix G-6). For unstiffened cylinders under external pressure the contact angle is mandatorily limited to 120° by the ASME Code. (UG-29).

Vessels supported by saddles are subject to:

1. Longitudinal bending stress
2. Tangential shear stress
3. Circumferential stress

STRESSES IN VESSELS ON TWO SADDLES



NOTATION:
All dimensions in inches
Q = Load on one saddle lbs.
R = Radius of shell
S = Stress pound per sq. inch
t_s = Wall thickness of shell
t_h = Wall thickness of head
(Excluding corrosion allow.)
K = Constant, see page 90
θ = Contact angle of saddle degree

Stress	Conditions	Max. Stress Occurs	FORMULAS	Max. Allow. Stress
LONGITUDINAL BENDING	SHELL STIFFENED BY HEADS OR RINGS OR SHELL UNSTIFFENED	AT THE SADDLES (Tension at the Top. Compression at the Bottom)	$S_1 = \pm \dfrac{QA\left(1 - \dfrac{1 - \dfrac{A}{L} + \dfrac{R^2 - H^2}{2AL}}{1 + \dfrac{4H}{3L}}\right)}{{}^{*}KR^2 t_s}$ *See note on facing page	In tension S_1 plus the stress due to internal pressure $(PR/2t_s)$ shall not exceed the allowable stress value of shell material times the efficiency of girth seam. In compression the stress due to internal pressure minus S_1 shall not exceed one half of the compression yield point of the material or the value given by: $S_1 \leqq \left(\dfrac{E}{29}\right)(t/R)[2 - (2/3)(100)(t/R)]$
		AT MIDSPAN (Tension at the Bottom Compression at the Top)	$S_1 = \pm \dfrac{\dfrac{QL}{4}\left(\dfrac{1 + 2\dfrac{R^2 - H^2}{L^2}}{1 + \dfrac{4H}{3L}} - \dfrac{4A}{L}\right)}{\pi R^2 t_s}$	
TANGENTIAL SHEAR	Saddles Away From Head A > R/2 See Note	IN SHELL	$S_2 = \dfrac{K_2 Q}{Rt_s}\left(\dfrac{L - 2A}{L + 4/3\ H}\right)$	S_2 shall not exceed 0.8 times the allowable stress value of vessel material. S_3 plus stress due to internal pressure shall not exceed 1.25 times the allowable tensile stress value of head material. NOTE: Use formula with factor K_2 if ring not used or rings are adjacent to the saddle. Use formula with factor K_3 if ring used in plane of saddle.
		IN SHELL	$S_2 = \dfrac{K_3 Q}{Rt_s}\left(\dfrac{L - 2A}{L + 4/3\ H}\right)$	
	SADDLES CLOSE TO HEAD A ≦ R/2	IN SHELL	$S_2 = \dfrac{K_4 Q}{Rt_s}$	
		IN HEAD	$S_2 = \dfrac{K_4 Q}{Rt_h}$	
		ADDITIONAL STRESS IN HEAD	$S_3 = \dfrac{K_5 Q}{Rt_h}$	
CIRCUMFERENTIAL	UNSTIFFENED, L ≧ 8R	AT HORN OF SADDLE	$S_4 = -\dfrac{Q}{4t_s(b + 1.56\sqrt{Rt_s})} - \dfrac{3K_6 Q}{2t_s^2}$	S_4 shall not exceed 1.50 times the allowable tensile stress value of shell material. S_5 shall not exceed 0.5 times the compression yield point of shell material.
	UNSTIFFENED, L < 8R	AT HORN OF SADDLE	$S_4 = -\dfrac{Q}{4t_s(b + 1.56\sqrt{Rt_s})} - \dfrac{12K_6 QR}{Lt_s^2}$	
	Stiffened or Unstiffened	AT BOTTOM OF SHELL	$S_5 = -\dfrac{K_7 Q}{t_s(b + 1.56\sqrt{Rt_s})}$	

STRESSES IN VESSELS ON TWO SADDLES

STRESS	NOTES: Positive values denote tensile stresses and negative values denote compression. E = Modulus of elasticity of shell or stiffener ring material,pound per square inch.
LONGITUDINAL BENDING	The maximum bending stress S_1 may be either tension or compression. Computing the tension stress in the formula for S_1, for factor K the values of K_1 shall be used. Computing the compression stress in the formula for S_1, for factor K the values of K_8 shall be used. When the shell is stiffened, the value of factor K = 3.14 in the formula for S_1. The compression stress is not factor in a steel vessel where $t/R \geqq 0.005$ and the vessel is designed to be fully stressed under internal pressure. Use stiffener ring if stress S_1 exceeds the maximum allowable stress.
TANGENTIAL SHEAR	If wear plate is used, in formulas for S_2 for the thickness t_s may be taken the sum of the shell and wear plate thickness, provided the wear plate extends R/10 inches above the horn of the saddle near the head and extends between the saddle and an adjacent stiffener ring. In unstiffened shell the maximum shear occurs at the horn of the saddle. When the head stiffness is utilized by locating the saddle close to the heads, the tangential shear stress can cause an additional stress (S3) in the heads. This stress shall be added to the stress in the heads due to internal pressure. When stiffener rings are used, the maximum shear occurs at the equator.
CIRCUMFERENTIAL	If wear plate is used, in formulas for S_4 for the thickness t_s may be taken the sum of the shell and wear plate thickness and for t_s^2 may be taken the shell thickness squared plus the wear plate thickness squared, provided the wear plate extends R/10 inches above the horn of the saddle , and $A \leqslant R/2$. The combined circumferential stress at the top edge of the wear plate should also be checked. When checking at this point: t_s = shell thickness, b = width of saddle θ = central angle of the wear plate but not more than the included angle of the saddle plus 12° If wear plate is used, in formulas for S_5 for the thickness t_s may be taken the sum of the shell and wear plate thickness, provided the width of the wear plate equals at least $b + 1.56\sqrt{Rt_s}$. If the shell is not stiffened, the maximum stress occurs at the horn of the saddle. This stress is not be to added to the internal pressure-stress. In a stiffened shell the maximum ring-compression is at the bottom of shell. Use stiffener ring if the circumferential bending stress exceeds the maximum allowable stress.

STRESSES IN LARGE HORIZONTAL VESSELS SUPPORTED BY TWO SADDLES

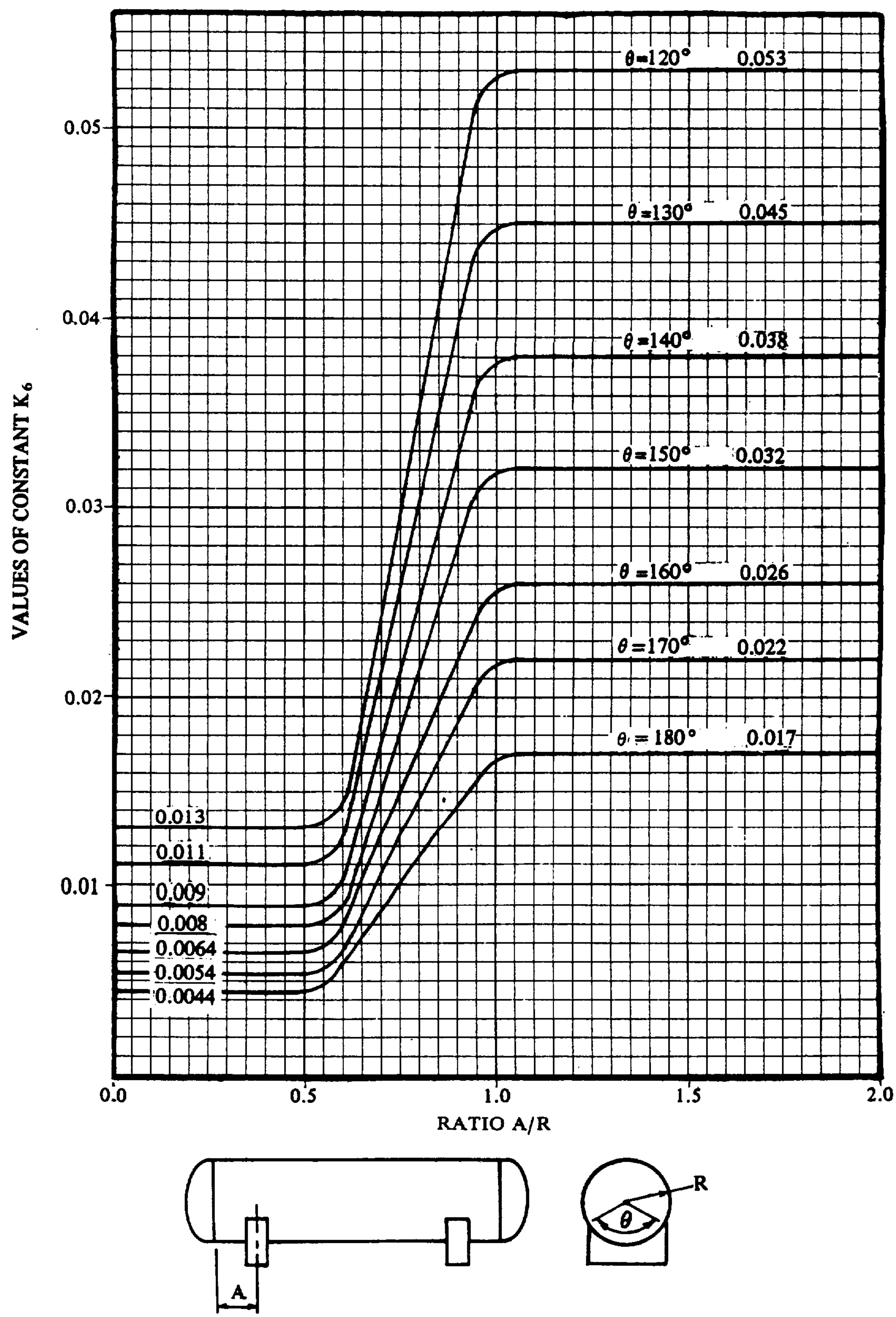
VALUES OF CONSTANT K
(Interpolate for Intermediate Values)

*K_1 = 3.14 if the shell is stiffened by ring or head ($A < R/2$)

CONTACT ANGLE θ	K_1*	K_2	K_3	K_4	K_5	K_6	K_7	K_8
120	0.335	1.171	0.319 For Any Con-Tact Angles θ	0.880	0.401	See chart on facing page	0.760	0.603
122	0.345	1.139		0.846	0.393		0.753	0.618
124	0.355	1.108		0.813	0.385		0.746	0.634
126	0.366	1.078		0.781	0.377		0.739	0.651
128	0.376	1.050		0.751	0.369		0.732	0.669
130	0.387	1.022		0.722	0.362		0.726	0.689
132	0.398	0.996		0.694	0.355		0.720	0.705
134	0.409	0.971		0.667	0.347		0.714	0.722
136	0.420	0.946		0.641	0.340		0.708	0.740
138	0.432	0.923		0.616	0.334		0.702	0.759
140	0.443	0.900		0.592	0.327		0.697	0.780
142	0.455	0.879		0.569	0.320		0.692	0.796
144	0.467	0.858		0.547	0.314		0.687	0.813
146	0.480	0.837		0.526	0.308		0.682	0.831
148	0.492	0.818		0.505	0.301		0.678	0.853
150	0.505	0.799		0.485	0.295		0.673	0.876
152	0.518	0.781		0.466	0.289		0.669	0.894
154	0.531	0.763		0.448	0.283		0.665	0.913
156	0.544	0.746		0.430	0.278		0.661	0.933
158	0.557	0.729		0.413	0.272		0.657	0.954
160	0.571	0.713		0.396	0.266		0.654	0.976
162	0.585	0.698		0.380	0.261		0.650	0.994
164	0.599	0.683		0.365	0.256		0.647	1.013
166	0.613	0.668		0.350	0.250		0.643	1.033
168	0.627	0.654		0.336	0.245		0.640	1.054
170	0.642	0.640		0.322	0.240		0.637	1.079
172	0.657	0.627		0.309	0.235		0.635	1.097
174	0.672	0.614		0.296	0.230		0.632	1.116
176	0.687	0.601		0.283	0.225		0.629	1.137
178	0.702	0.589		0.271	0.220		0.627	1.158
180	0.718	0.577		0.260	0.216		0.624	1.183

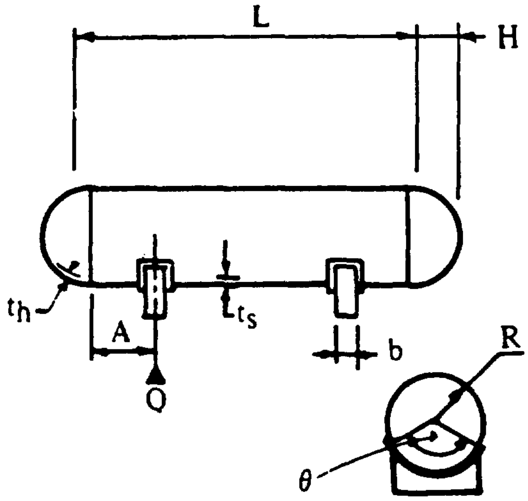
STRESSES IN LARGE HORIZONTAL VESSELS SUPPORTED BY TWO SADDLES

VALUES OF CONSTANT K_6



STRESSES IN LARGE HORIZONTAL VESSELS SUPPORTED BY TWO SADDLES

EXAMPLE CALCULATIONS



Design Data

A = 48 in. distance from tangent line of head to the center of saddle
b = 24 in. width of saddle
H = 21 in. depth of dish of head
L = 960 in. length of vessel tan.-tan.
P = 250 psi. internal design pressure
Q = 300,000 lb. load on one saddle
R = 60 in. outside radius of shell
t_s = 1.00 in. thickness of shell
θ = 120 deg. contact angle
Shell material: SA 515-70 plate
Allowable stress value 17,500 psi.
Yield point 38,000 psi.
Joint Efficiency: 0.85

LONGITUDINAL BENDING STRESS (S_1)

Stress at the saddles

$$S_1 = \frac{QA\left(1 - \dfrac{1 - \dfrac{A}{L} + \dfrac{R^2 - H^2}{2AL}}{1 + \dfrac{4H}{3L}}\right)}{K_1 R^2 t_s} = \frac{300{,}000 \times 48 \left(1 - \dfrac{1 - \dfrac{48}{960} + \dfrac{60^2 - 21^2}{2 \times 48 \times 960}}{1 + \dfrac{4 \times 21}{3 \times 960}}\right)}{0.335 \times 60^2 \times 1} = 522 \text{ psi.}$$

Stress at midspan

$$S_1 = \frac{\dfrac{QL}{4}\left(\dfrac{1 + 2\dfrac{R^2 - H^2}{L^2}}{1 + \dfrac{4H}{3L}} - \dfrac{4A}{L}\right)}{\pi R^2 t_s} = \frac{\dfrac{300{,}000 \times 960}{4}\left(\dfrac{1 + 2\dfrac{60^2 - 21^2}{960^2}}{1 + \dfrac{4 \times 21}{3 \times 960}} - \dfrac{4 \times 48}{960}\right)}{3.14 \times 60^2 \times 1} = 4959 \text{ psi}$$

Stress due to internal pressure: $\dfrac{PR}{2t_s} = \dfrac{250 \times 60}{2 \times 1} = 7500$ psi

The sum of tensional stresses: 4959 + 7500 = 12,459 psi
It does not exceed the stress value of the girth seam: 17,500 × .085 = 14,875 psi

Compression stress is not factor since t/R > 0.005; 1/60 = 0.017

STRESSES IN LARGE HORIZONTAL VESSELS SUPPORTED BY TWO SADDLES

EXAMPLE CALCULATIONS (cont.)

TANGENTIAL SHEAR STRESS (S_2)

Since A (48)>R/2 (60/2), the applicable formula:

$$S_2 = \frac{K_2 Q}{R t_s}\left(\frac{L-2A}{L+4/3H}\right) = \frac{1.171 \times 300{,}000}{60 \times 1}\left(\frac{960 - 2 \times 48}{960 + 4/3 \times 21}\right) = 5{,}120 \text{ psi}$$

S_2 does not exceed the stress value of shell material multiplied by 0.8; 17,500 × 0.8 = 14,000 psi.

CIRCUMFERENTIAL STRESS

Stress at the horn of saddle (S_4)
Since L (960) > 8R(480), A(48) > R/2 (60/2), the applicable formula:

$$S_4 = -\frac{Q}{4t_s(b+1.56\sqrt{Rt_s})} - \frac{3K_6 Q}{2t_s^2}$$

A/R = 48/60 = 0.8; K = 0.036 (from chart)

$$S_4 = -\frac{300{,}000}{4 \times 1\ (24 + 1.56\sqrt{60 \times 1})} - \frac{3 \times 0.036 \times 300{,}000}{2t} = -18{,}279 \text{ psi}$$

S_4 does not exceed the stress value of shell material multiplied by 1.5; 17,500 × 1.5 = 26,250 psi

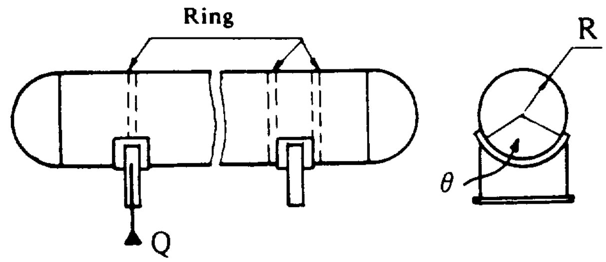
Stress at bottom of shell (S_5)

$$S_5 = -\frac{K_7 Q}{t_s(b + 1.56\sqrt{Rt_s})}$$

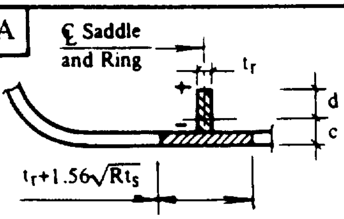
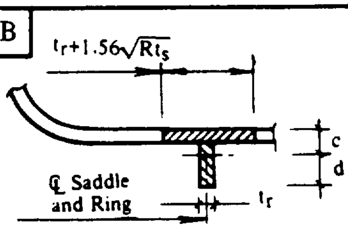
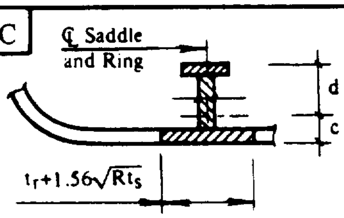
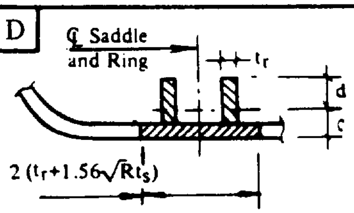
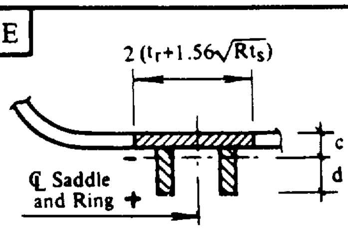
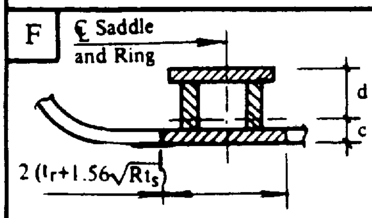
$$S_5 = -\frac{0.760 \times 300{,}000}{1(24 + 1.56\sqrt{60 \times 1})} = -6{,}319 \text{ psi}$$

S_5 does not exceed the compression yield point multiplied by 0.5; 38,000 × 0.5 = 19,000 psi

STIFFENER RING FOR LARGE HORIZONTAL VESSELS SUPPORTED BY SADDLES



NOTATION.
A = Cross sectional area of ring plus the effective area of shell, in^2
I = Moment of inertia, in^4
K = Constant, see next page
Q = Load on one saddle, lbs.
R = Radius of shell, in.
S_6 = Max. combined stress, psi.
θ = Contact angle, degree

TYPE OF RING		MAX. STRESS	FORMULAS	Max. Allow Stress
A		Ring Inside. Compression at the Shell Governs	$S_6=-\frac{K_9Q}{A}-\frac{K_{10}QR}{I/c}$	In tension the allowable stress value of shell or ring material whichever is smaller. In compression 0.5 times the yield point of shell or ring material whichever is smaller.
B		Ring Outside. Stress at the Shell	$S_6=-\frac{K_9Q}{A}+\frac{K_{10}QR}{I/c}$	
		Ring Outside. Stress at the Tip of the Ring	$S_6=-\frac{K_9Q}{A}-\frac{K_{10}QR}{I/d}$	
C		Ring Inside. Compression at the Shell Governs	$S_6=-\frac{K_9Q}{A}-\frac{K_{10}QR}{I/c}$	
		Ring Outside. Stress at the Shell	$S_6=-\frac{K_9Q}{A}+\frac{K_{10}QR}{I/c}$	
D		Ring Inside. Stress at the Shell	$S_6=-\frac{K_9Q}{A}+\frac{K_{10}QR}{I/c}$	
		Ring Inside. Stress at the Tip of the Ring	$S_6=-\frac{K_9Q}{A}-\frac{K_{10}QR}{I/d}$	
E		Ring Outside. Compression at the Shell Governs	$S_6=-\frac{K_9Q}{A}-\frac{K_{10}QR}{I/c}$	
F		Ring Inside. Stress at the Shell	$S_6=-\frac{K_9Q}{A}+\frac{K_{10}QR}{I/c}$	
		Ring Inside. Stress at the Tip of the Ring	$S_6=-\frac{K_9Q}{A}-\frac{K_{10}QR}{I/d}$	

STIFFENER RING
FOR LARGE HORIZONTAL VESSELS SUPPORTED BY SADDLES

VALUES OF CONSTANT,K
(Interpolate for Intermediate Values)

Contact Angle θ	120°	130°	140°	150°	160°	170°	180°
K_9	.34	.33	.32	.30	.29	.27	.25
K_{10}	.053	.045	.037	.032	.026	.022	.017

NOTES:

1. In figures & formulas A-F positive signs denote tensile stresses and negative signs denote compression.
2. The first part of the formulas for S_6 gives the direct stress and the second part gives the circumferential bending stress.
3. If the governing combined stress is tensional, the stress due to internal pressure, $\frac{PR}{t_s}$ shall be added.

CALCULATION OF MOMENT OF INERTIA (I)

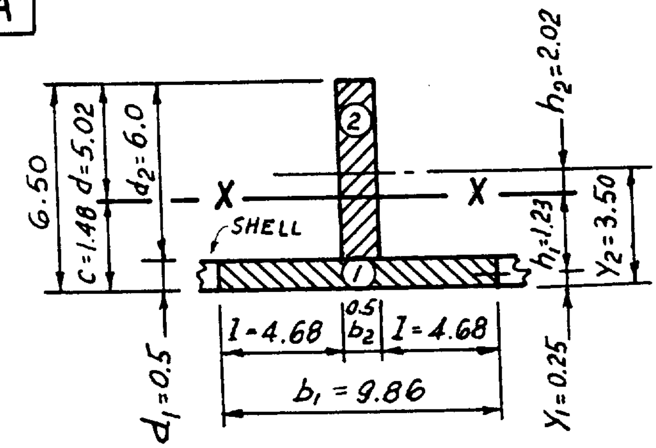
1. Determine the width of shell that is effective to resist the circumferential bending moment. The effective width = $1.56\sqrt{R\,t_s}$; $0.78\sqrt{R\,t_s}$ on both sides of the stiffener ring.
2. Divide the stiffener ring into rectangles and calculate the areas (a) of each rectangles, including the area of shell section within the effective width. Add the areas (a) total area = A.
3. Multiply the areas (a) with the distances (Y) from the shell to the center of gravity of the rectangles. Summarize the results and denote it AY.
4. Determine the neutral axis of the stiffener ring,the distance (C) from the shell to the neutral axis $C = \frac{AY}{A}$
5. Determine the distances (h) from the neutral axis to the center of gravity of each rectangle of the stiffener.
6. Multiply the square of distances (h^2) by the areas (a) and summarize the results to obtain AH^2
7. Calculate the moment of inertia I_g of each rectangles $I_g = \frac{b\,d^3}{12}$,where b = the width and d = the depth of the rectangles.
8. The sum of AH^2 and ΣI_g gives the moment of inertia of the stiffener ring and the effective area of the shell.

See example calculations on the following pages.

MOMENT OF INERTIA (I) OF STIFFENER RINGS
EXAMPLE CALCULATIONS

ALL DIMENSIONS IN INCHES
R = 72 in. OUTSIDE RADIUS OF SHELL

A



$l = 0.78\sqrt{Rd_1} =$

$0.78\sqrt{72 \times 0.5} = 4.68$

AREA ① Ig

$\frac{b_1 d_1^3}{12} = \frac{9.86 \times 0.5^3}{12} = 0.103 \text{ in.}^4$

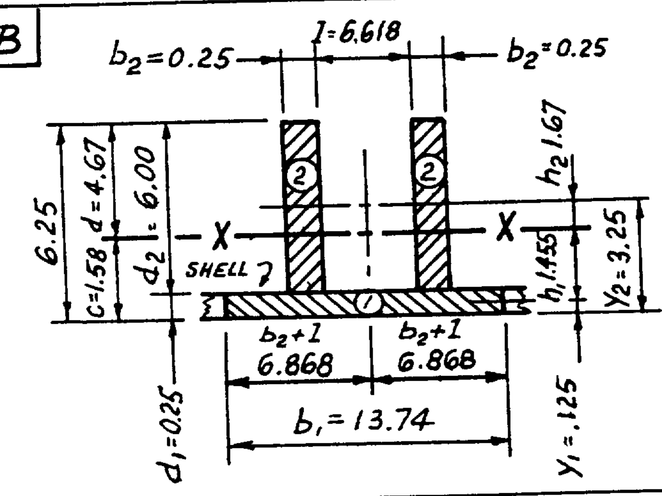
AREA ② Ig

$\frac{b_2 d_2^3}{12} = \frac{0.5 \times 6^3}{12} = 9.00 \text{ in.}^4$

MARK OF AREAS	AREA a	y	a x y	h	h^2	a x h^2	$\frac{b\,d^3}{12}$
①	4.93	0.25	1.23	1.23	1.51	7.44	0.10
②	3.00	3.50	10.50	2.02	4.08	12.24	9.00
TOTAL	A = 7.93	–	AY = 11.73	–	–	AH^2 = 19.68	Ig = 9.10

$C = \frac{AY}{A} = \frac{11.73}{7.93} = 1.48 \qquad I = AH^2 + I_g = 19.68 + 9.10 = 28.78 \text{ in.}^4$

B



$l = 1.56\sqrt{Rd_1} =$

$1.56\sqrt{72 \times 0.25} = 6.618$

AREA ① Ig

$\frac{b_1 d_1^3}{12} = \frac{13.74 \times 0.25^3}{12} = 0.02 \text{ in}^4$

AREA ②

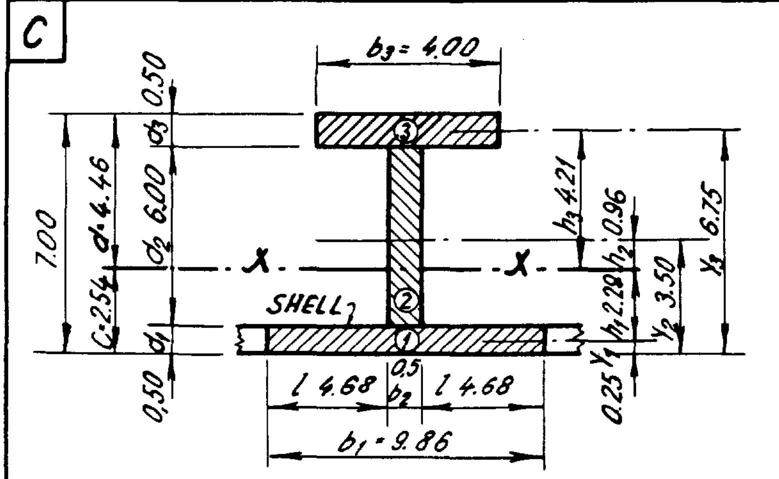
$\frac{2b_2 d_2^3}{12} = \frac{0.50 \times 6^3}{12} = 9.00 \text{ in}^4$

MARK OF AREAS	AREA a	y	a x y	h	h^2	a x h^2	$\frac{b\,d^3}{12}$
①	3.43	0.125	0.43	1.455	2.12	7.27	0.02
②	3.00	3.250	9.75	1.670	2.79	8.37	9.00
TOTAL	A = 6.43	–	AY = 10.18	–	–	AH^2 = 15.64	Ig = 9.02

$C = \frac{AY}{A} = \frac{10.18}{6.43} = 1.58 \qquad I = AH^2 + I_g = 15.64 + 9.02 = 24.66 \text{ in.}^4$

MOMENT OF INERTIA (I) OF STIFFENER RINGS
EXAMPLE CALCULATIONS
ALL DIMENSIONS IN INCHES
R = 72 in. OUTSIDE RADIUS OF SHELL

C



$l = 0.78\sqrt{Rd_1}$

$0.78\sqrt{72 \times 0.5} = 4.68$

AREA ① Ig

$\frac{b_1 d_1^3}{12} = \frac{9.86 \times 0.5^3}{12} = 0.103 \text{ in.}^4$

AREA ② Ig

$\frac{b_2 d_2^3}{12} = \frac{0.5 \times 6^3}{12} = 9.00 \text{ in.}^4$

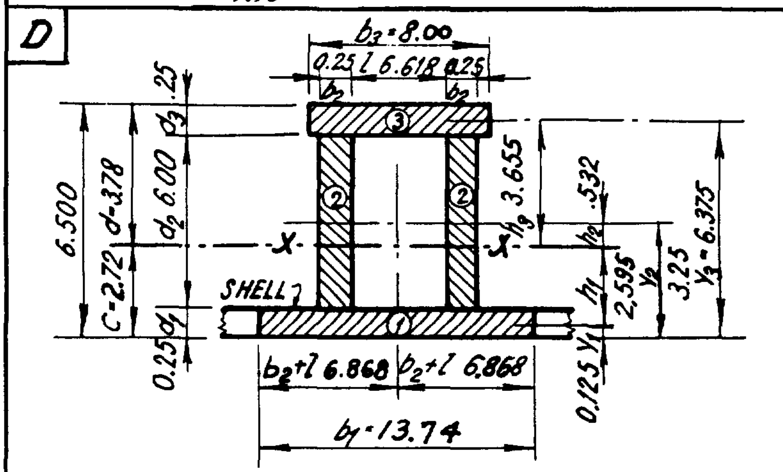
AREA ③ Ig

$\frac{b_3 d^3}{12} = \frac{4 \times 0.5^3}{12} = 0.04 \text{ in.}^4$

MARK OF AREAS	AREA a	y	a x y	h	h^2	a x h^2	$\frac{bd^3}{12}$
1	4.93	0.25	1.23	2.29	5.24	25.83	0.10
2	3.00	3.50	10.50	0.96	0.92	2.76	9.00
3	2.00	6.75	13.50	4.21	17.72	35.44	0.04
TOTAL	A = 9.93	–	AY = 25.23	–	–	AH = 64.03	Ig = 9.14

$C = \frac{AY}{A} = \frac{25.23}{9.93} = 2.54$ $I = AH^2 + I_g = 64.03 + 9.14 = 73.17 \text{ in.}^4$

D



$l = 1.56\sqrt{Rd_1}$

$1.56\sqrt{72 \times 0.25} = 6.618$

AREA ① Ig

$\frac{b_1 d_1^3}{12} = \frac{13.74 \times 0.25^3}{12} = 0.02 \text{ in.}^4$

AREA ② Ig

$\frac{2b_2 d_2^3}{12} = \frac{0.50 \times 6^3}{12} = 9.00 \text{ in.}^4$

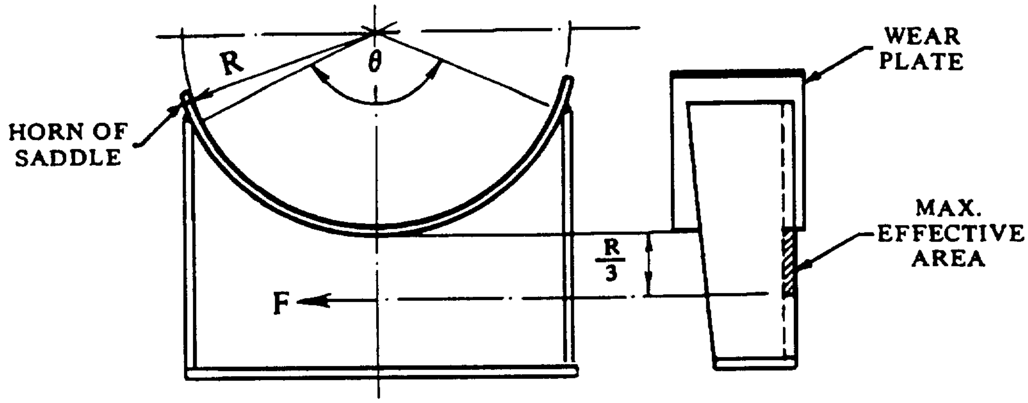
AREA 3

$\frac{b_3 d^3}{12} = \frac{8 \times 0.25^3}{12} = 0.01 \text{ in.}^4$

MARK OF AREAS	AREA a	y	a x y	h	h^2	a x h^2	$\frac{bd^3}{12}$
1	3.43	0.125	0.43	2.59	6.72	23.09	0.02
2	3.00	3.250	9.75	0.53	0.28	0.84	9.00
3	2.00	6.375	12.75	3.66	13.40	26.80	0.01
TOTAL	A = 8.43	–	AY = 22.93	–	–	AH^2 = 50.73	Ig = 9.03

$C = \frac{AY}{A} = \frac{22.93}{8.43} = 2.72$ $I = AH^2 + I_g = 50.73 + 9.03 = 59.76 \text{ in.}^4$

DESIGN OF SADDLES



1. The saddle at the lowest section must resist the horizontal force *(F)*. The effective cross section of the saddle to resist this load is one third of the vessel radius *(R)*.

   $F=K_{11}Q$, Where Q= the load on one saddle, lbs.
   K_{11} = constant as tabulated.

   The average stress shall not exceed two thirds of the compression yield point of the material. (See example below.)

VALUES OF CONSTANT K_{11}							
Contact Angle	120°	130°	140°	150°	160°	170°	180°
K_{11}	.204	.222	.241	.259	.279	.298	.318

EXAMPLE:
Diameter of vessel = 8' - 6"
Weight of vessel = 375,000 lbs.
Q = 187,500 lbs.
Saddle material: SA 285 C
Web plate thickness = 0.25 in.
Contact angle = 120°
K_{11} = 0.204 from table above
$R/3$ = 51/3 = 17 inches
Force, $F = K_{11} \times Q = 0.204 \times 187{,}500 = 38{,}250$ lb.

To resist this force the effective area of web plate = $R/3 \times 0.25 = 4.25$ in.²
38,250/4.25 = 9,000 lbs. per square inch.

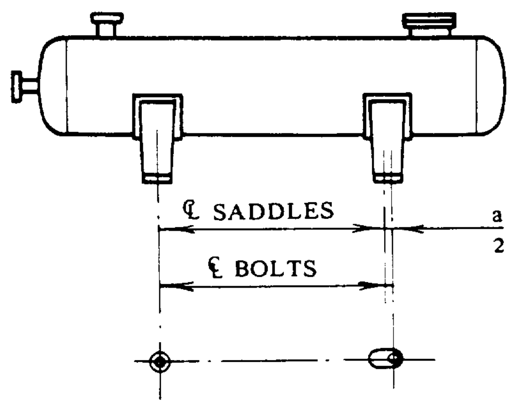
The allowable stress = ⅔ × 30,000 = 20,000 psi.

The thickness of the web plate is satisfactory for horizontal force *(F)*.

2. The base plate and wear plate should be thick enough to resist longitudinal bending over the web.
3. The web plate should be stiffened with ribs against the buckling.

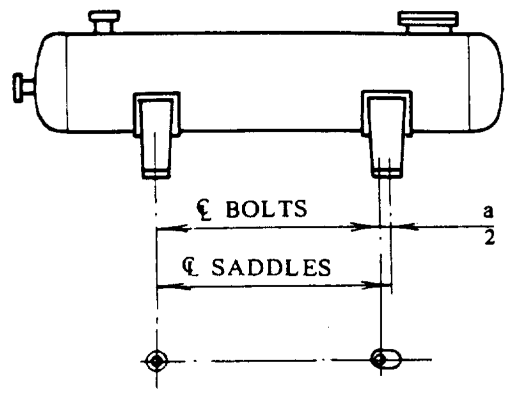
EXPANSION AND CONTRACTION OF HORIZONTAL VESSELS

A



EXPANDING VESSEL

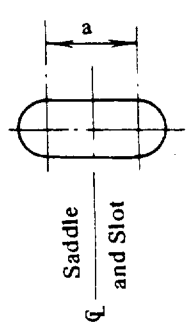
B



CONTRACTING VESSEL

For thermal expansion and contraction, one of the saddles, preferably the one on the opposite side of the pipe connections, must be allowed to move. In this saddle for the anchor bolts slots are to be used instead of holes. The length of the slots shall be determined by the expected magnitude of the movement. The coefficient of linear expansion for carbon steel per unit length and per degree F = 0.0000067. The table below shows the minimum length of the slot. Dimension "a" calculated for the linear expansion of carbon steel material between 70°F and the indicated temperature. When the change in the distance between the saddles is more than 3/8" inch long, a slide (bearing) plate should be used. When the vessel is supported by concrete saddles, an elastic, waterproof sheet at least 1/4" thick is to be applied between the shell and the saddle.

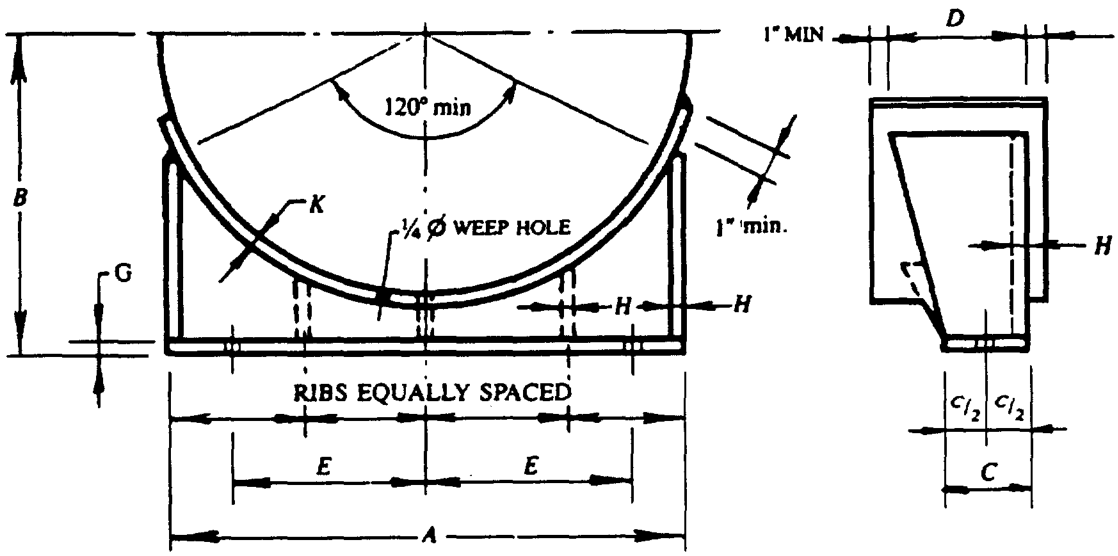
MINIMUM LENGTH OF SLOT (DIM. "a")



The width of the slot equals the diam. of anchor bolt + ¼".

DISTANCE BETWEEN SADDLES Ft.	FOR TEMPERATURE °F									
	-50	100	200	300	400	500	600	700	800	900
10	0	0	0	1/4	3/8	3/8	1/2	5/8	3/4	3/4
20	0	0	1/4	3/8	5/8	3/4	1	1-1/8	1-1/4	1-3/8
30	1/4	1/8	3/8	5/8	7/8	1-1/8	1-3/8	1-5/8	1-5/8	2
40	1/4	1/8	3/8	3/4	1-1/8	1-1/2	1-7/8	2-1/8	2-3/8	2-1/2
50	3/8	1/4	1/2	1	1-3/8	1-5/8	2-1/4	2-5/8	3	3-3/8
60	3/8	1/4	5/8	1-1/4	1-5/8	2-1/8	2-3/4	3-1/8	3-5/8	4-1/8
70	1/2	1/4	3/4	1-3/8	1-7/8	2-1/2	3-1/8	3-5/8	4-1/4	4-5/8
80	1/2	3/8	3/4	1-1/2	2-1/8	2-7/8	3-5/8	4-1/8	4-7/8	5-3/8
90	5/8	3/8	7/8	1-3/4	2-3/8	3-1/4	4	4-5/8	5-3/8	6
100	5/8	3/8	1	1-7/8	2-5/8	3-5/8	4-1/2	5-1/8	6	6-5/8

SADDLE
FOR SUPPORT OF HORIZONTAL VESSELS



The design based on:

1. the vessel supported by two saddles
2. to resist horizontal force *(F)* due to the maximum operating weight of vessel as tabulated.
3. the maximum allowable stress is ⅔ of the compression yield point: ⅔ of 30,000 = 20,000 psi.
4. the maximum allowable load on concrete foundation 500 psi.
5. the minimum contact angle of shell and saddle 120°.

Weld: ¼" continuous fillet weld all contacting plate edges.

Drill and tap ¼" weep holes in wear plate.

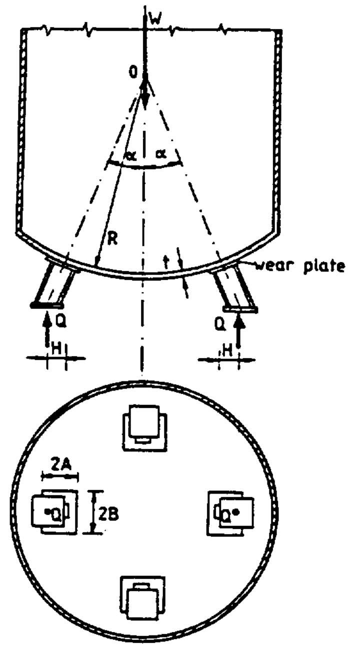
At the sliding saddle the nuts of the anchor bolts shall be hand-tight and secured by tack welding.

SEE FACING PAGE FOR DIMENSIONS

SADDLE

NOMINAL DIAMETER OF VESSEL FT.-IN.	DIMENSIONS						NO. OF RIBS	PLATE THICKNESS IN.			MAXIMUM WEIGHT OF VESSEL LB.
	A FT.-IN.	B FT.-IN.	C IN.	D IN.	E FT.-IN.	BOLT DIAM IN.		BASE G	WEB FLANGE, RIBS H	WEAR K	
1-0	0-10½	1-0	4	4	0-3½	½	0	¼	¼	-	42,000
1-2	1-½	1-1	4	4	0-4	½	0	¼	¼	-	50,000
1-4	1-2	1-2	4	4	0-5	½	0	¼	¼	-	56,000
1-6	1-3½	1-3	4	4	0-6	½	0	¼	¼	-	62,000
1-8	1-5½	1-4	4	4	0-6½	½	0	¼	¼	-	70,000
1-10	1-7	1-5	4	6	0-7	½	0	¼	¼	-	76,000
2-0	1-9	1-6	4	6	0-7½	½	0	¼	¼	-	84,000
2-2	1-10½	1-7	4	6	0-8	½	0	¼	¼	¼	90,000
2-4	2-2½	1-8	4	6	0-8½	½	0	½	¼	¼	98,000
2-6	2-2	1-9	4	6	0-9	½	0	½	¼	¼	104,000
2-8	2-4	1-10	4	6	0-9½	½	0	½	¼	¼	112,000
2-10	2-5	1-11	6	11	0-10	½	0	½	¼	¼	128,000
3-0	2-6½	2-0	6	11	0-11	½	0	½	¼	¼	134,000
3-2	2-9	2-1	6	11	1-0	¾	0	½	¼	¼	144,000
3-4	2-11	2-2	6	11	1-1	¾	0	½	⅜	⅜	210,000
3-6	3-½	2-3	6	11	1-2	¾	0	½	⅜	⅜	220,000
4-0	3-6	2-6	6	11	1-4	¾	0	¾	⅜	⅜	252,000
4-6	3-11	3-0	6	11	1-6	¾	0	¾	⅜	⅜	282,000
5-0	4-4	3-3	6	11	1-8	¾	1	¾	⅜	⅜	312,000
5-6	4-9½	3-6	6	11	1-10	¾	1	¾	⅜	⅜	344,000
6-0	5-2½	3-9	9	18	2-0	¾	1	¾	⅜	⅜	402,000
6-6	5-8	4-0	9	18	2-2	¾	1	¾	½	⅜	436,000
7-0	6-1	4-3	9	18	2-4	1	1	¾	½	⅜	470,000
7-6	6-6	4-6	9	18	2-6	1	1	1	½	⅜	502,000
8-0	6-11½	4-9	9	18	2-8	1	1	1	½	⅜	536,000
8-6	7-4½	5-0	9	18	2-10	1	2	1	½	½	760,000
9-0	7-9½	5-3	9	18	3-0	1	2	1	½	½	806,000
9-6	8-3½	5-6	9	24	3-2	1	2	1	¾	½	852,000
10-0	8-8	5-9	9	24	3-4	1¼	2	1	¾	½	896,000
10-6	9-1½	6-0	9	24	3-6	1¼	2	1	¾	½	940,000
11-0	9-6½	6-3	9	24	3-8	1¼	2	1	¾	½	986,000
11-6	10-0	6-6	9	24	3-10	1¼	3	1	¾	½	1,030,000
12-0	10-5	6-9	9	24	4-0	1¼	3	1	¾	½	1,076,000

STRESSES IN VESSELS ON
LEG SUPPORT



NOTATION:

W = Weight of vessel, lbs.

n = number of legs

$Q = \frac{W}{n}$ Load on one leg, lbs.

R = Radius of head, inch

H = Leverarm of load, inch.

$2A$, $2B$ = Dimensions of wear plate

S = Stress, pound per sq. inch

t = Wall thickness of head, inch

K = Factors, see charts

$C = \sqrt{AB}$, inch

C = radius of circular wear plate, in

$$D = 1.82 \frac{C}{R} \sqrt{\frac{R}{t}}$$

LONGITUDINAL STRESS:

$$S_l = \frac{Q}{t^2} \left[\cos \alpha (K_1 + 6 K_2) + \frac{H}{R} \sqrt{\frac{R}{t}} (K_3 + 6 K_4) \right]$$

CIRCUMFERENTIAL STRESS:

$$S_2 = \frac{Q}{t^2} \left[\cos \alpha (K_5 + 6 K_6) + \frac{H}{R} \sqrt{\frac{R}{t}} (K_7 + 6 K_8) \right]$$

NOTES:

Positive values denote tensile stresses and negative values denote compression.

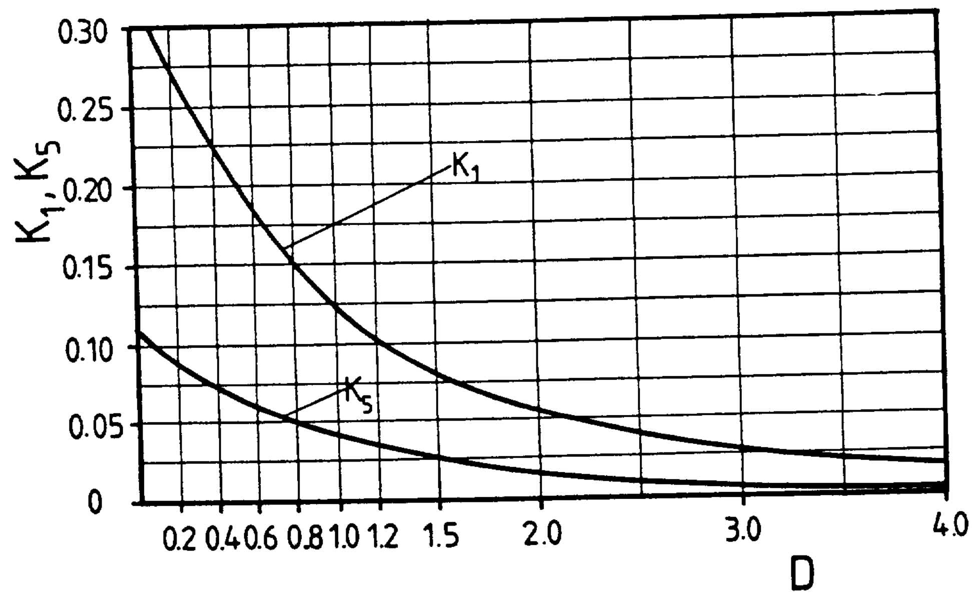
Computing the maximum tensile stresses, in formulas for S_1 and S_2, K_1, K_3, K_5 and K_7 denote negative factors and K_2, K_4, K_6 and K_8 denote positive factors.

Computing the maximum compression stresses, in formulas for S_1 and S_2, K_1, K_2, K_3, K_4, K_5, K_6, K_7 and K_8 denote negative factors.

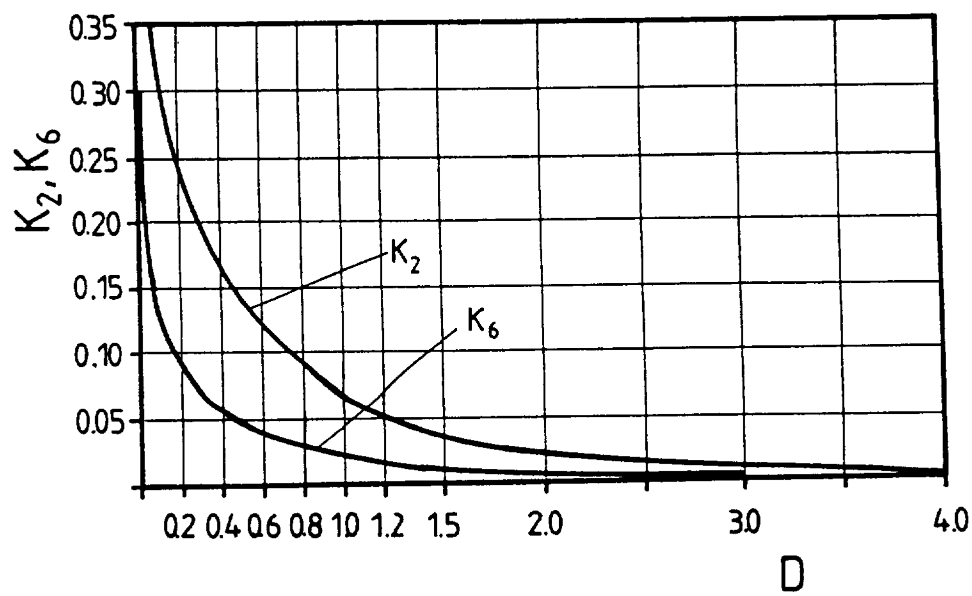
The maximum tensile stresses S_1 and S_2, respectively, plus the tensile stress due to internal pressure shall not exceed the allowable tensile stress value of head material.

The maximum compression stresses S_1 and S_2, respectively, plus the tensile stress due to internal pressure shall not exceed the allowable compression stress value of head material.

STRESSES IN VESSELS ON LEG SUPPORT

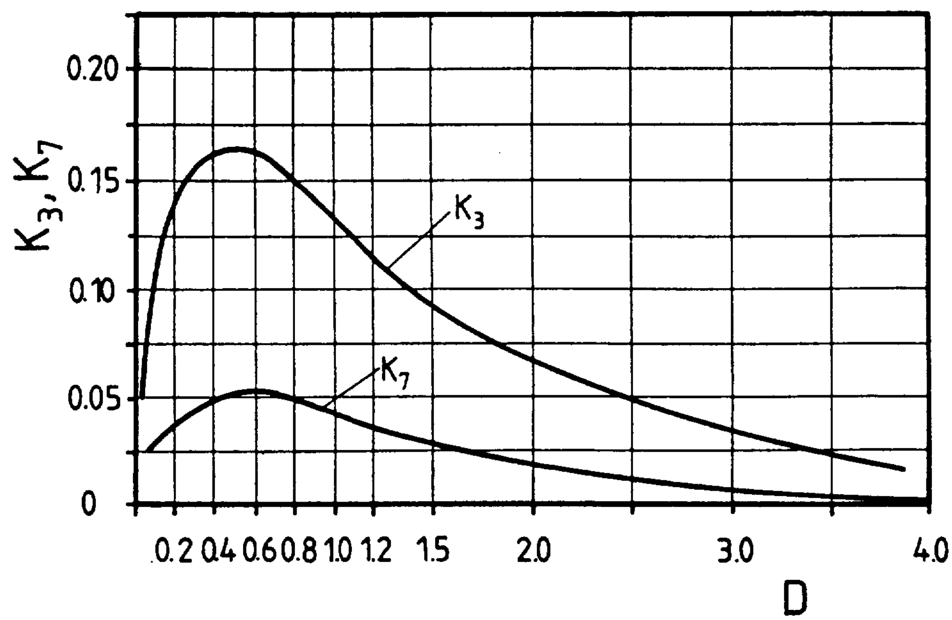


VALUE OF K_1 & K_5

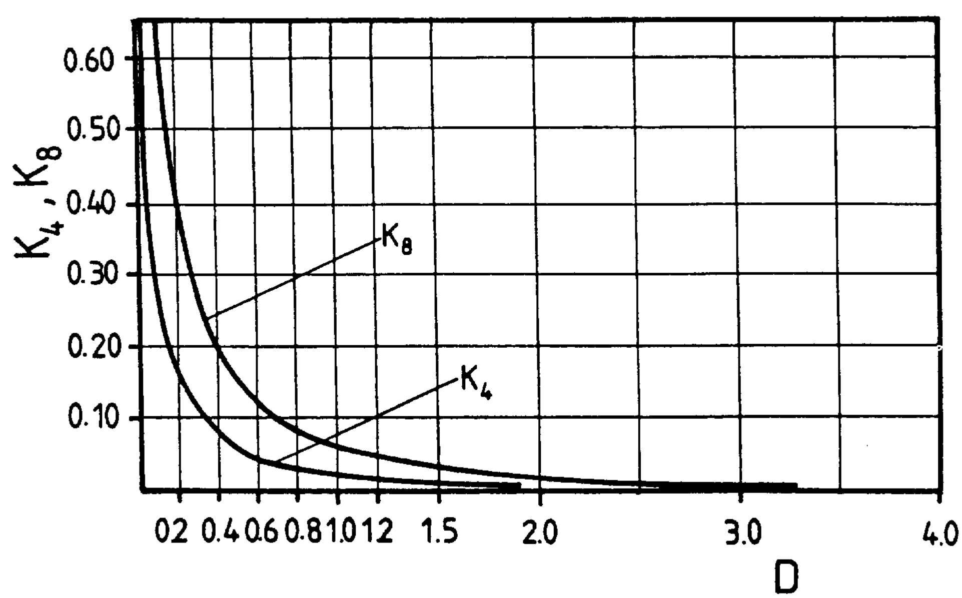


VALUE OF K_2 & K_6

STRESSES IN VESSELS ON LEG SUPPORT



VALUE OF K_3 & K_7



VALUE OF K_4 & K_8

STRESSES IN VESSELS ON LEG SUPPORT

EXAMPLE CALCULATIONS

DESIGN DATA

W = 800,000 lb, weight of vessel

n = 4, number of legs

$Q = \frac{W}{n} = \frac{800{,}000}{4}$ = 200,000 lb, load on one leg

R = 100 inch, radius of head

H = 5 inch, leverarm of load

$2A$ = 30 inch, $2B$ = 30 inch, dimensions of wear plate

t = 1.8 inch thickness of head

$\cos \propto = 0.800$

P = 100 psi, internal pressure

Head material: SA — 515−70

Allowable stress value: 17,500 psi

Joint Efficiency: 0.85

Yield point: 38,000 psi.

Factors K (see charts):

$$C = \sqrt{AB} = \sqrt{15 \times 15} = 15 \text{ inch}$$

$$D = 1.82 \frac{C}{R} \sqrt{\frac{R}{t}} = 1.82 \frac{15}{100} \sqrt{\frac{100}{1.8}} = 2.03$$

$K_1 = 0.065$, $K_2 = 0.030$, $K_3 = 0.065$, $K_4 = 0.025$,
$K_5 = 0.020$, K_6 0.010, $K_7 = 0.022$, $K_8 = 0.010$.

LONGITUDINAL STRESS:

1.) Maximum tensile stress:

$$S_l = \frac{Q}{t^2} \left[\cos \propto (-K_1 + 6K_2) + \frac{H}{R} \sqrt{\frac{R}{t}} (-K_3 + 6K_4) \right]$$

$$S_l = \frac{200{,}000}{1.8^2} \left[0.800\,(-0.065 + 6 \times 0.030) + \frac{5}{100} \sqrt{\frac{100}{1.8}} (-0.065 + 6 \times 0.025) \right] = +7{,}634 \text{ psi}$$

The stress due to internal pressure:

$$\frac{PR}{2t} = \frac{100 \times 100}{2 \times 1.8} = +2778 \text{ psi}$$

The sum of tensional stresses:

7.634 + 2.778 = 10,412 psi

It does not exceed the stress value of the girth seam:

17,500 × 0.85 = 14,875 psi

2.) Maximum compressional stress:

$$S_1 = \frac{Q}{t^2}\left[\cos\alpha\,(-K_1 - 6K_2) + \frac{H}{R}\sqrt{\frac{R}{t}}(-K_3 - 6K_4)\right]$$

$$S_1 = \frac{200{,}000}{1.8^2}\left[0.800\,(-0.065 - 6 \times 0.030) + \frac{5}{100}\sqrt{\frac{100}{1.8}}\,(-0.065 - 6 \times 0.025)\right] = -17{,}044 \text{ psi}$$

The stress due to internal pressure:

$$\frac{PR}{2t} = \frac{100 \times 100}{2 \times 1.8} = +2778 \text{ psi}$$

The sum of stresses:
$-\ 17{,}044 + 2{,}778 = -\ 14{,}266$ psi
It does not exceed the stress value of the girth seam:
$17{,}500 \times 0{,}85 = 14{,}875$ psi

Circumferential stress:

1.) Maximum tensile stress:

$$S_2 = \frac{Q}{t^2}\left[\cos\alpha\,(-K_5 + 6K_6) + \frac{H}{R}\sqrt{\frac{R}{t}}(-K_7 + 6K_8)\right]$$

$$S_2 = \frac{200{,}000}{1.8^2}\left[0.800\,(-0.020 + 6 \times 0.010) + \frac{5}{100}\sqrt{\frac{100}{1.8}}\,(-0.022 + 6 \times 0.010)\right] = +2{,}849 \text{ psi}$$

The stress due to internal pressure:

$$\frac{PR}{2t} = \frac{100 \times 100}{2 \times 1.8} = +2778 \text{ psi}$$

The sum of tensile stresses:
$2{,}849 + 2{,}778 = 5{,}627$ psi

It does not exceed the stress value of the girth seam:
$17{,}500 \times 0.85 = 14{,}875$ psi

2.) Maximum compressional stress:

$$S_2 = \frac{Q}{t^2}\left[\cos\alpha\,(-K_5 - 6K_6) + \frac{H}{R}\sqrt{\frac{R}{t}}(-K_7 - 6K_8)\right]$$

$$S_2 = \frac{200{,}000}{1.8^2}\left[0.800\,(-0.020 - 6 \times 0.010) + \frac{5}{100}\sqrt{\frac{100}{1.8}}\,(-0.022 - 6 \times 0.010)\right] = -\,5{,}837 \text{ psi}$$

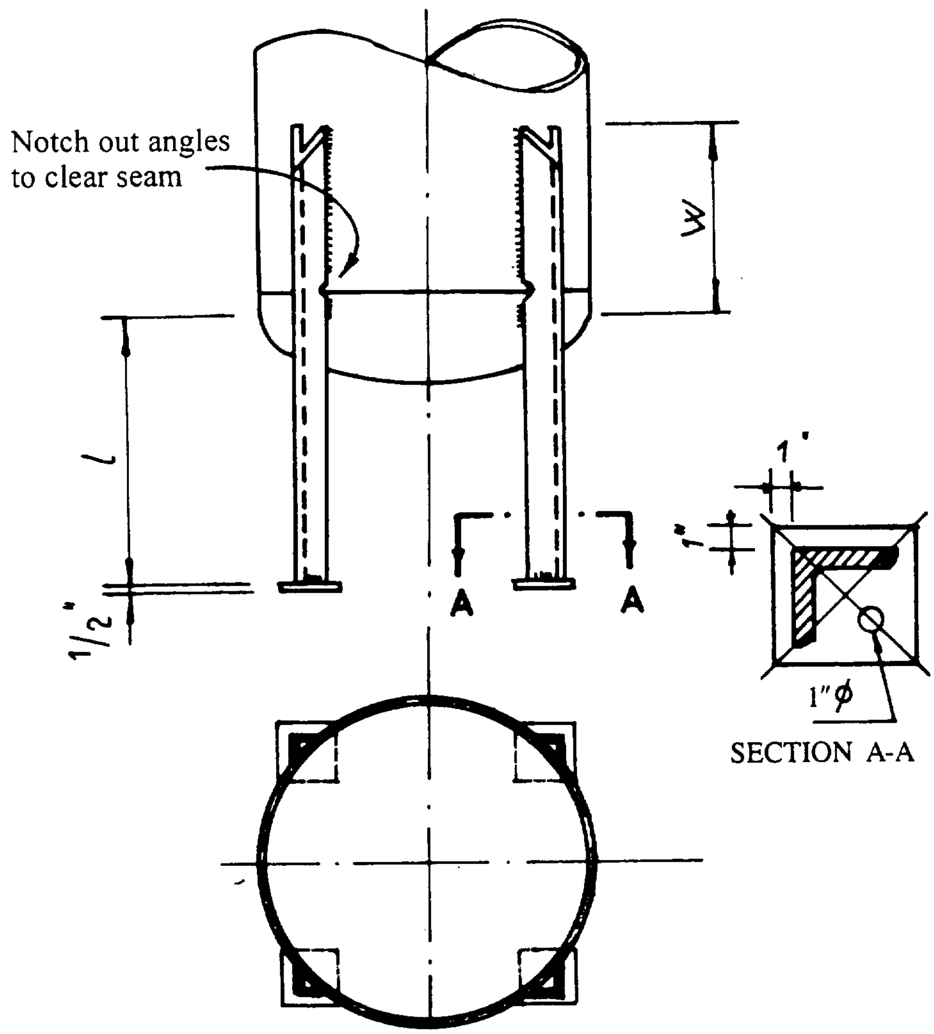
The stress due to internal pressure:

$$\frac{PR}{2t} = \frac{100 \times 100}{2 \times 1.8} = +\ 2778 \text{ psi}$$

The sum of stresses:
$-\ 5837 + 2778 = -\ 3{,}059$ psi.

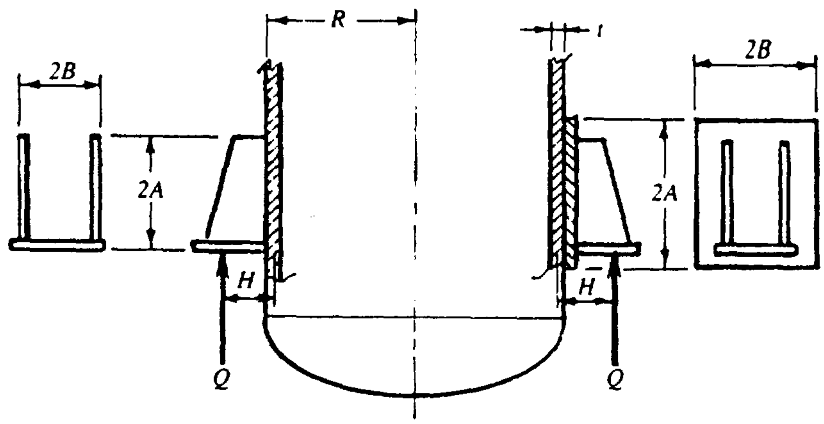
It does not exceed the stress value of the girth seam:
$17{,}500 \times 0.85 = 14{,}875$ psi

LEG SUPPORT



VESSEL DIA	VESSEL HEIGHT MAX	ANGLE SIZE	l max	W
2'-6"	8'-0"	3" × 3" × 3/8"	5'-0"	4"
3'-0"				
3'-6"				
4'-0"	10'-0"	3.5" × 3.5" × 3/8"		6"
4'-6"				
5'-0"	14'-0"	4" × 4" × 1/2"	7'-0"	7"
5'-6"				
6'-0"	16'-0"	5" × 5" × 1/2"		10"
6'-6"				
7'-0"	18'-0"	6" × 6" × 5/8"		1'-0"
7'-6"				

STRESSES IN VESSELS DUE TO
LUG SUPPORT



NOTATION:

W = Weight of vessel, lb
n = Number of lugs
$Q = \dfrac{W}{n}$ = Load on one lug, lb
R = Radius of shell, in
H = Lever arm of load, in

$2A$, $2B$ = Dimensions of wear plate
S = Stress, pound per sq. in
t = Wall thickness of shell, in
C = shape factor, see table
K = Factors, see charts
$D = \dfrac{A}{R}\sqrt[3]{\dfrac{B}{A}}$

LONGITUDINAL STRESS:

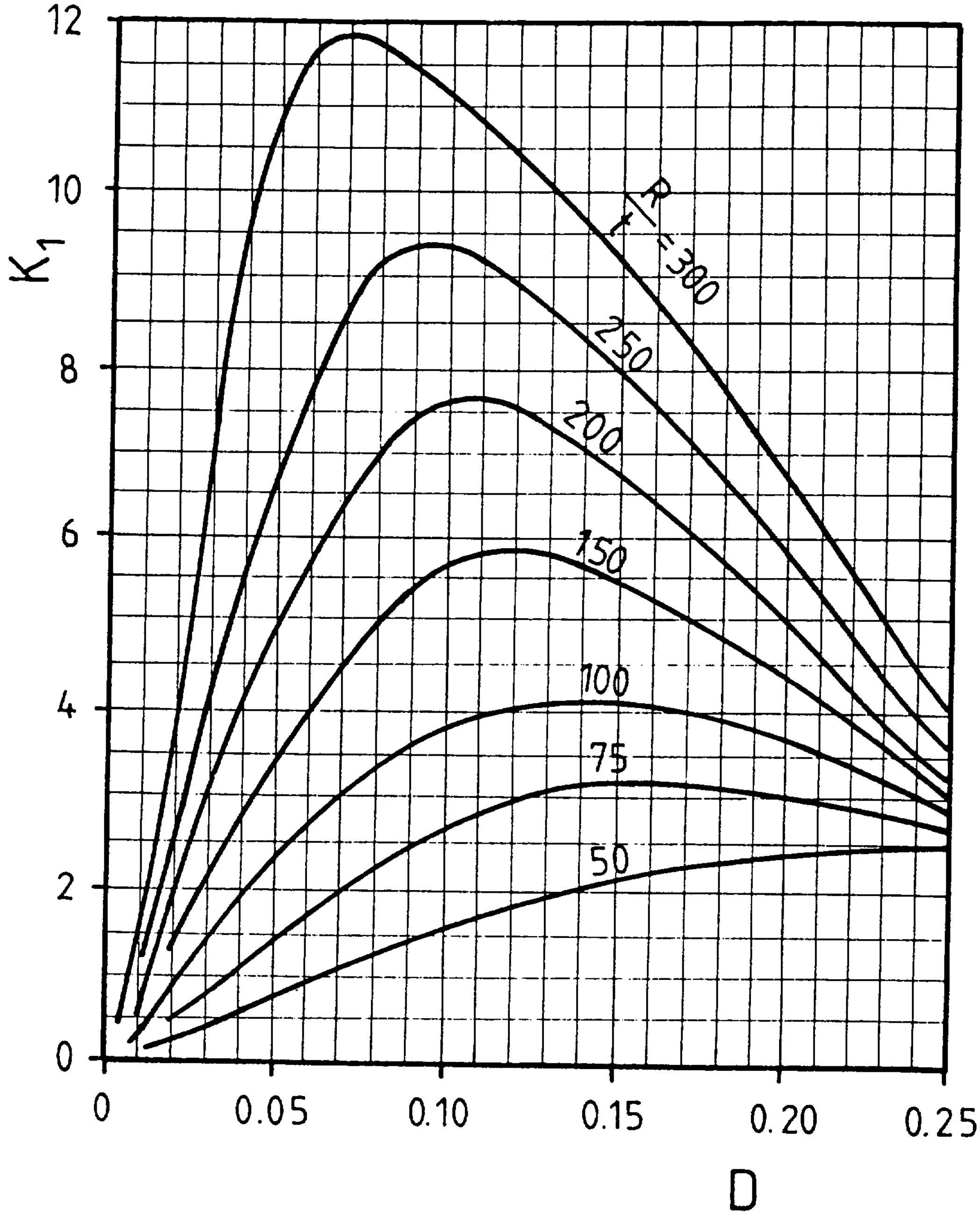
$$S_1 = \pm \frac{QH}{DR^2t}\left(C_1K_1 + 6\frac{K_2R}{C_2t} + \frac{D}{2\,(1.17 + B/A)} \times \frac{R^2}{HA} \right)$$

NOTE: In tension S_1 plus the stress due to internal pressure $PR/2t$ shall not exceed the stress value of shell material times the efficiency of girth seam.

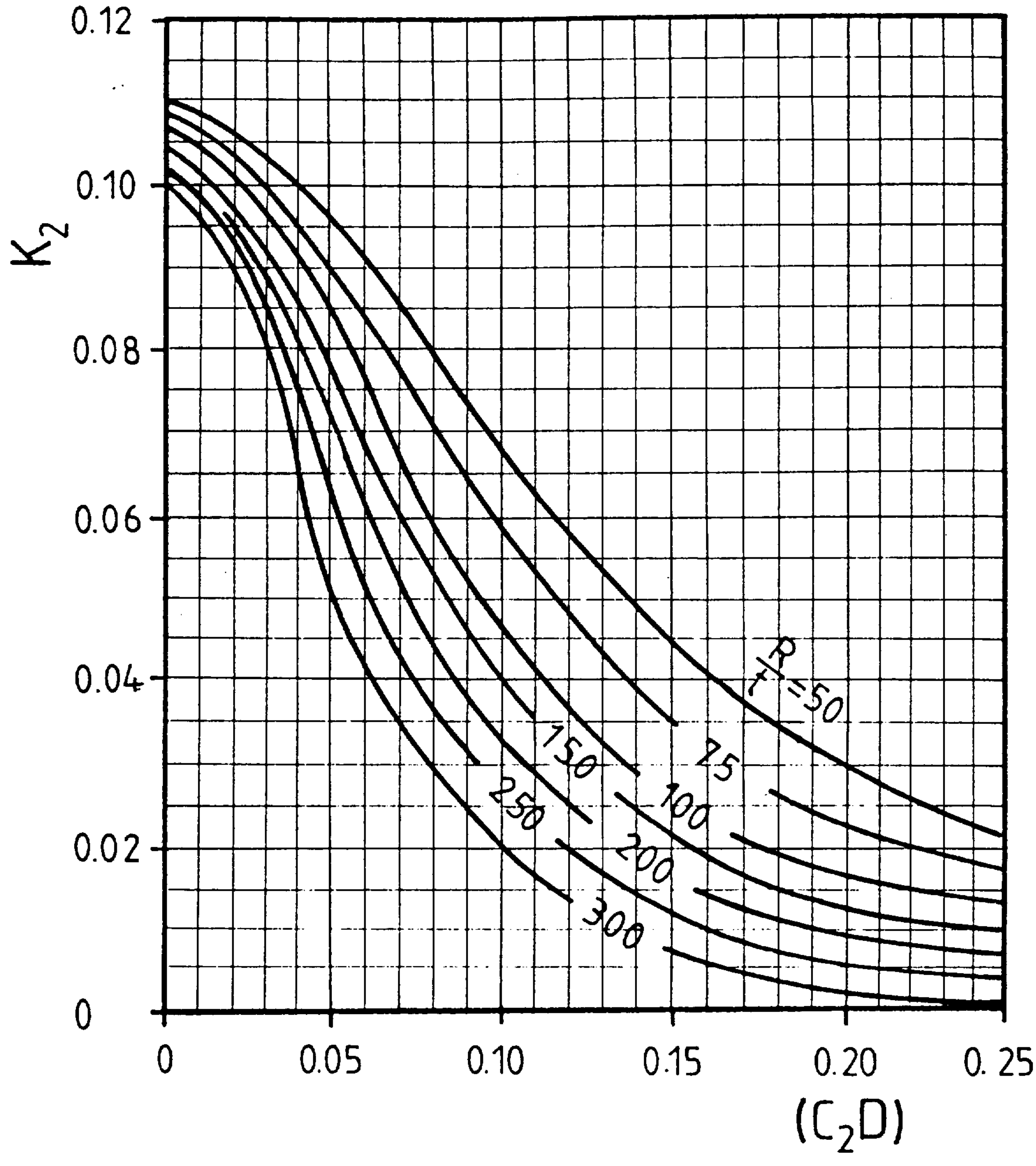
CIRCUMFERENTIAL STRESS:

$$S_2 = \pm \frac{QH}{DR^2t}\left(C_3K_3 + 6\frac{K_4R}{C_4t} \right)$$

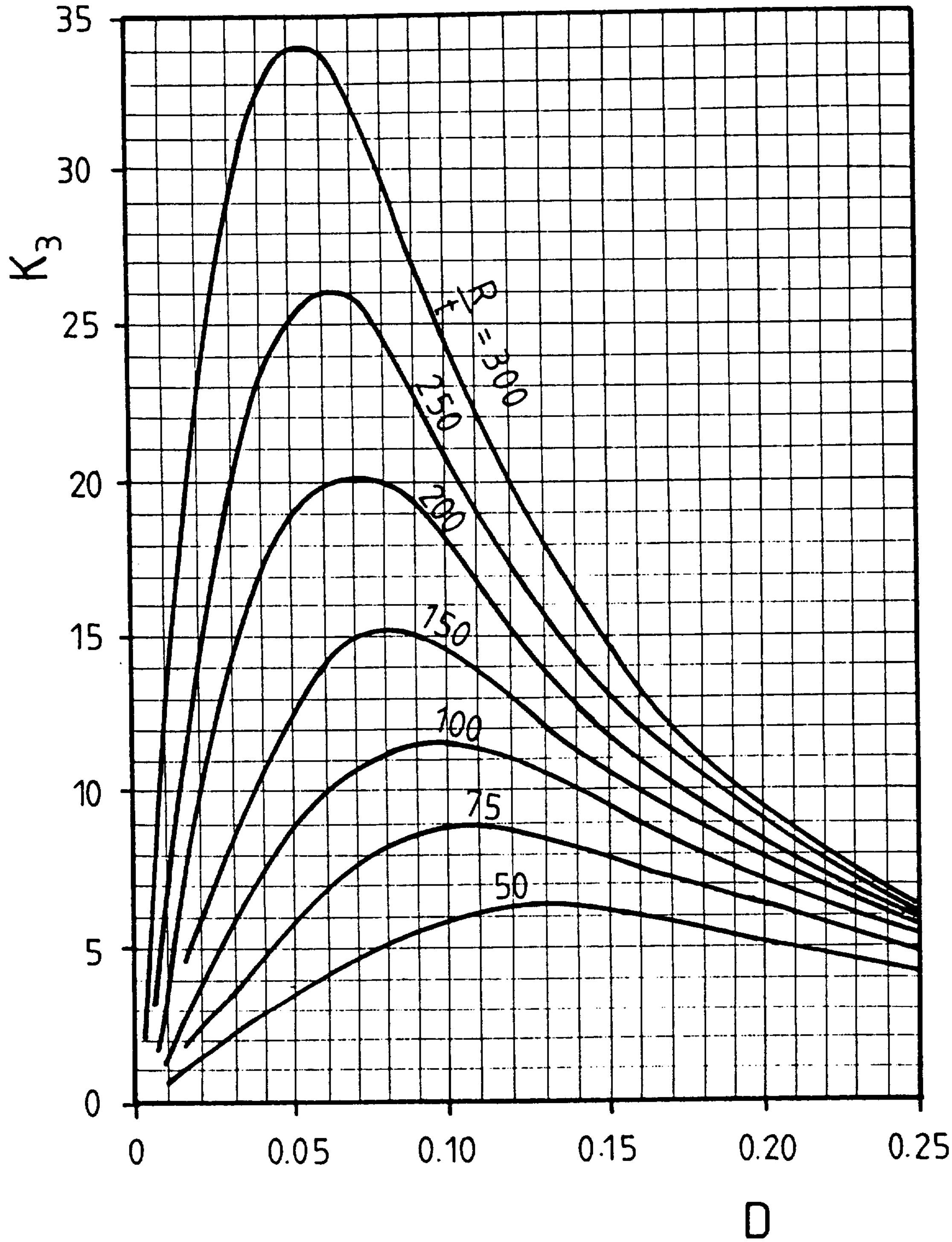
NOTE: In tension S_2 plus the stress due to internal pressure PR/t shall not exceed the stress value of shell material multiplied by 1.5.



VALUE OF K_1

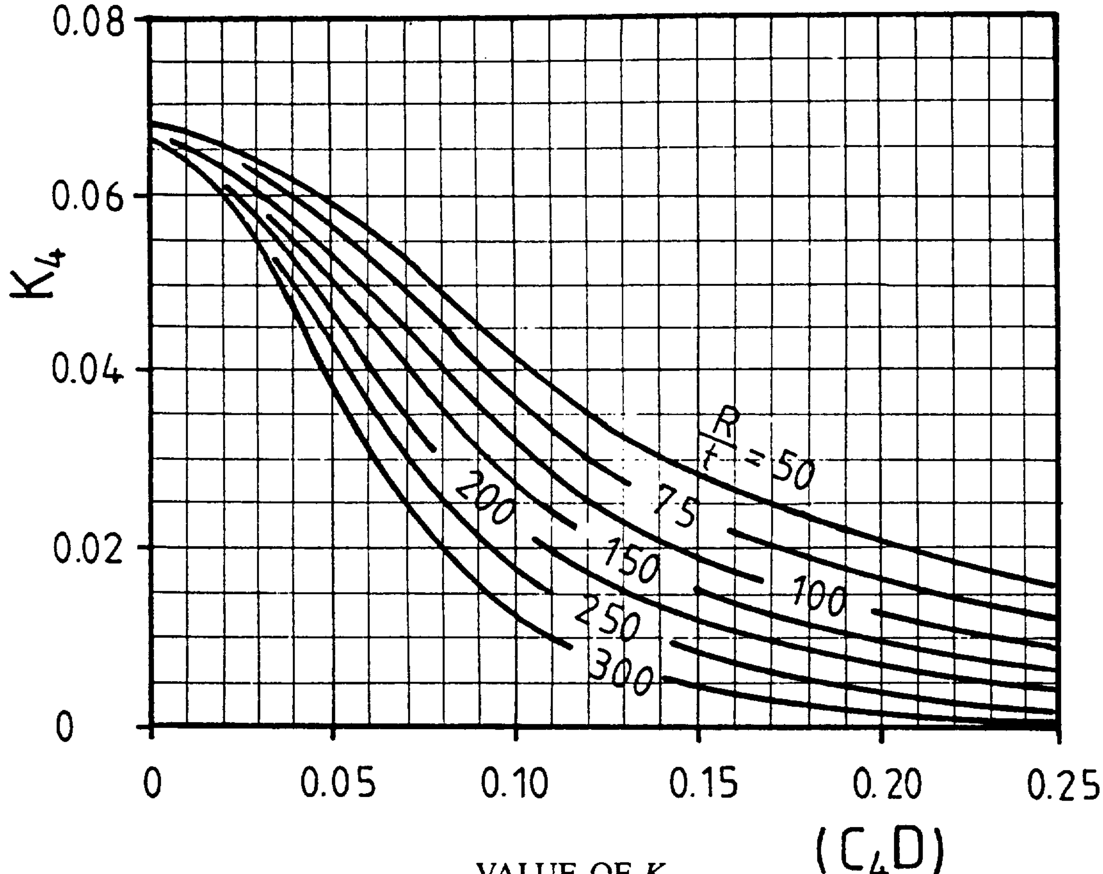

0.12
0.10
0.08
0.06
0.04
0.02
0
K_2
0
0.05
0.10
0.15
0.20
0.25
(C_2D)
R/t = 50
75
100
150
200
250
300

VALUE OF K_2


35
30
25
20
15
10
5
0
K3
R/t = 300
250
200
150
100
75
50
0
0.05
0.10
0.15
0.20
0.25
D

VALUE OF K_3

STRESSES IN VESSELS DUE TO LUG SUPPORT



VALUE OF K_4

B/A	*R/t*	C_1	C_2	C_3	C_4
1/2	50	0.72	1.03	0.95	1.07
	100	0.68	1.02	0.97	1.06
	200	0.64	1.02	1.04	1.05
	300	0.60	1.02	1.10	1.04
1	50	1	1	1	1
	100	1	1	1	1
	200	1	1	1	1
	300	1	1	1	1
2	50	0.85	1.10	0.85	0.92
	100	1.15	1.07	0.81	0.89
	200	1.32	0.98	0.80	0.84
	300	1.50	0.90	0.79	0.79

VALUE OF *C*

EXAMPLE CALCULATIONS

DESIGN DATA

W = 1,200,000 lb. weight of vessel
n = 4 number of lugs

$$Q = \frac{W}{n} = \frac{1{,}200{,}000}{4} = 300{,}000 \text{ lb. load on one lug}$$

R = 90 in, radius of shell
H = 5 in, leverarm of load
$2A$ = 30 in, $2B$ = 30 in, dimensions of wear plate
t = 1.5 in, thickness of shell
p = 100 psi internal pressure

Shell material: SA - 515-70
Allowable stress value 17,500 psi
Yield point 38,000 psi
Joint Efficiency: 0.85

Shape factors C, (see table):

$$R/t = \frac{90}{1.5} = 60, \quad B/A = 15/15) = 1{,}0$$

$$C_1 = C_2 = C_3 = C_4 = 1.0$$

The factors K, (see charts)

$$D = \frac{A}{R}\sqrt[3]{\frac{B}{A}} = \frac{15}{90}\sqrt[3]{\frac{15}{15}} = 0.167, \quad R/t = \frac{90}{1.5} = 60$$

$$K_1 = 2.8, \quad K_2 = 0.025, \quad K_3 = 6.8 \quad K_4 = 0.021$$

Longitudinal Stress:

$$S_1 = \pm \frac{Q\,H}{D\,R^2 t}\left(C_1 K_1 + 6\,\frac{K_2 R}{C_2 t} + \frac{D}{2\,(1.17 + B/A)} \times \frac{R^2}{HA} \right)$$

$$S_1 = \frac{300{,}000 \times 5}{0.167 \times 90^2 \times 1.5}\left(1 \times 2.8 + 6\,\frac{0.025 \times 90}{1 \times 1.5} + \frac{0.167}{2\,(1.17 + 15/15)} \times \frac{90^2}{5 \times 15} \right) = 11{,}795 \text{ psi}$$

Stress due to internal pressure:

$$\frac{PR}{2t} = \frac{100 \times 90}{2 \times 1.5} = 3000 \text{ psi}$$

The sum of tensional stresses:
11,795 + 3000 = 14,795 psi

It does not exceed the stress value of the girth seam:
17,500 × 0.85 = 14,875 psi

STRESSES IN VESSELS DUE TO LUG SUPPORT

Circumferential Stress:

$$S_2 = \pm \frac{QH}{DR^2t} \left(C_3K_3 + 6 \frac{K_4R}{C_4 t} \right)$$

$$S_2 = \frac{300{,}000 \times 5}{0.167 \times 90^2 \times 1.5} \left(1 \times 6.8 + 6 \frac{0.021 \times 90}{1 \times 1.5} \right) = 10{,}616 \text{ psi}$$

Stress due to internal pressure:

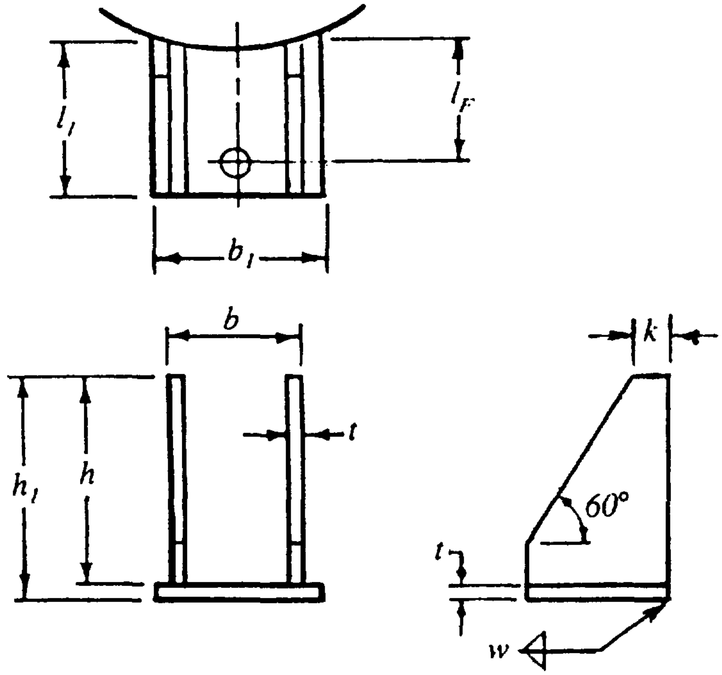
$$\frac{PR}{t} = \frac{100 \times 90}{1.5} = 6000 \text{ psi}$$

The sum of tensional stresses:
10,616 + 6000 = 16,616 psi

It does not exceed the stress value of shell material multiplied by 1.5:
$17,500 \times 1.5 = 26,250$

LUG SUPPORT

FOR INSULATED VESSELS

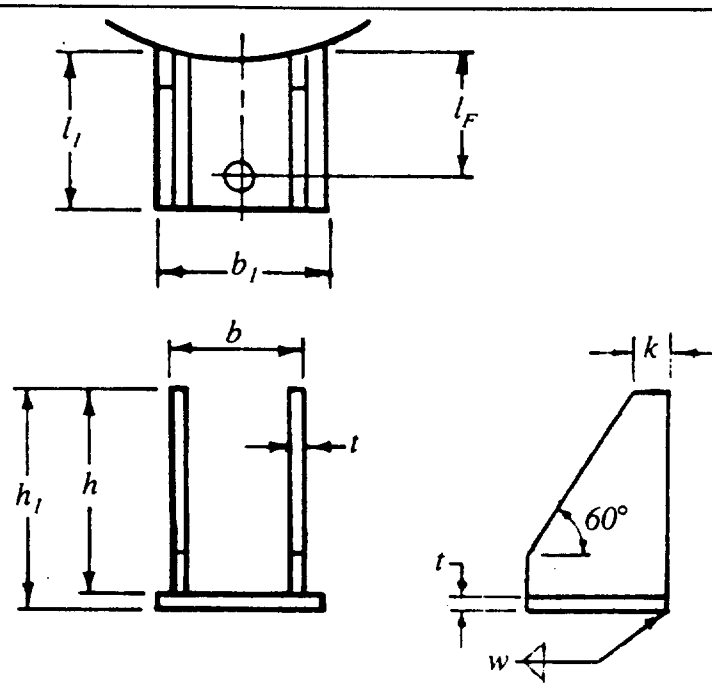


Maximum Allowable Load on One Lug, Lbs.	DIMENSIONS									Weight of One Lug, Lbs.
	l_l	b	b_l	h	h_l	k	l_F	t	w	
1,400	6½	5	5½	3¾	4	⅜	5¼	¼	¼	7
2,200	6¾	5½	6	5	5¼	⅝	5½	¼	¼	9
3,600	8¼	6¾	7¼	6¾	7	¾	6¾	¼	¼	16
5,600	10¼	8¾	9¼	9⅝	9⅞	1	8½	¼	¼	24
9,000	12½	10¾	11½	14¼	14⅝	1	10½	⅜	⅜	58
14,000	13¾	11½	12¼	17	17⅜	1	11½	⅜	⅜	72
22,000	15½	13	13¾	18⅛	18⅝	1¼	12½	½	⅜	126
36,000	17½	14¾	15½	22	22⅝	1⅜	14	⅝	½	165
56,000	20½	17½	18½	28⅜	29	1⅝	16½	⅝	½	235
90,000	22¾	18½	19½	31½	32¼	1¾	18	¾	½	388
140,000	25¼	20½	21½	34⅝	35⅜	2	20	¾	½	482

All dimensions are in inches
Stresses in vessel shall be checked.
Use wear plate if necessary

LUG SUPPORT

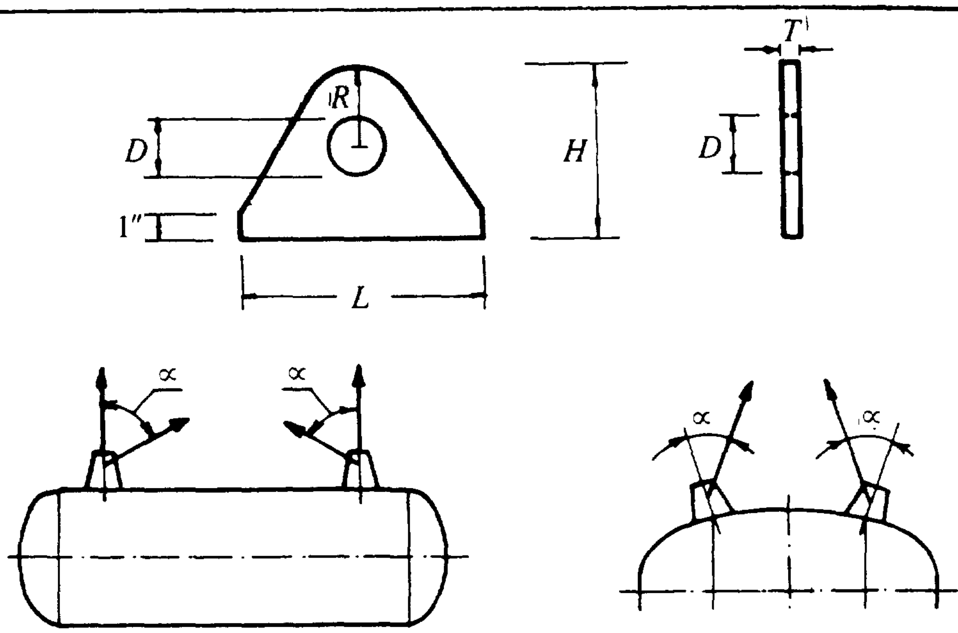
FOR UNINSULATED VESSELS



Maximum Allowable Load on One Lug, Lbs.	DIMENSIONS									Weight of One Lug, Lbs.
	l_1	b	b_1	h	h_1	k	l_F	t	w	
1,400	2½	2	2½	4	4³⁄₁₆	¾	1½	³⁄₁₆	full	1
2,200	3¼	2½	3	5¼	5⁷⁄₁₆	¾	2	³⁄₁₆	full	2
3,600	4	3¼	3¾	6¾	6¹⁵⁄₁₆	¾	2½	³⁄₁₆	full	4
5,600	5¾	5¾	6¼	9¾	10	1	4	¼	¼	9
9,000	7¾	7	7¾	14¼	14⁹⁄₁₆	1	5½	⁵⁄₁₆	¼	21
14,000	9½	8½	9¼	17	17⁵⁄₁₆	1	6½	⁵⁄₁₆	¼	28
22,000	10	9½	10¼	18	18⅜	1¼	7	⅜	¼	45
36,000	12	11½	2½	22	22½	1¼	9	½	⅜	80
56,000	15	15	6¼	28½	29¹⁄₁₆	1½	12	⁹⁄₁₆	⅜	148
90,000	16½	15¾	7	31½	32⅛	1¾	13	⅝	⅜	218
140,000	18	17½	8¾	34½	35⅛	2	14	⅝	⅜	260

All dimensions are in inches
Stresses in vessel shall be checked.
Use wear plate if necessary

LIFTING LUG

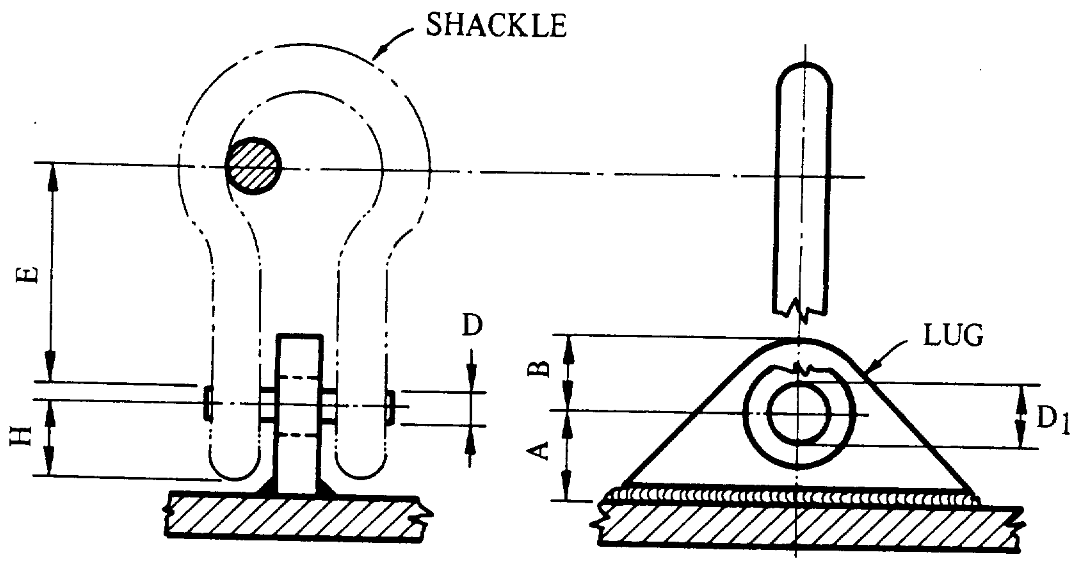


VESSEL WEIGHT (LBS)	D (IN)	T (IN)	R (IN)	H (IN)	L (IN)	WELD (Min)
12,000	1	½	1½	5	10	Full Penetration with ½ Fillet
20,000	1⅛	¾	2	6	10	
30,000	1⅜	1	2⅛	6	10	
50,000	1⅝	1¼	2½	7	12	
70,000	2⅛	1¼	3½	8	12	Full Penetration with ¾ Fillet
100,000	2½	1½	4½	9	16	
150,000	3	1¾	5	10	16	
200,000	4	2	6	12	18	
250,000	4¼	2	6½	13	18	
300,000	4½	2½	7	14	20	

Notes:

1. All dimensions are in inches
2. The design is based on conditions:
   a. $\propto = 45°$ maximum
   b. Minimum tensile strength of lug material 70,000 psi.
   c. Direction of force is in the plane of lugs.
3. Use wear plate if necessary to eliminate buckling due to normal or sudden loading.

LIFTING ATTACHMENTS



MINIMUM DIMENSIONS OF LIFTING LUGS USING SHACKLE

Load Lbs.	Shackle Pin Diam. D	Hole Diam. in Lug D_1	H	A	Sheared Edge	Rolled Gas-cut	Arm of Moment E
					B		
710	5/16	3/8	.50	.65			.84
1060	3/8	7/16	.56	.73			.97
1600	7/16	1/2	.63	.82	7/8	3/4	1.16
2170	1/2	5/8	.69	.90	1-1/8	7/8	1.44
2820	5/8	3/4	.94	1.22	1-1/4	1	1.75
4420	3/4	7/8	1.13	1.47	1-1/2	1-1/8	2.12
6375	7/8	1	1.19	1.55	1-3/4	1-1/4	2.25
8650	1	1-1/8	1.31	1.70	2	1-1/2	2.59
11300	1-1/8	1-1/4	1.50	1.95	2-1/4	1-5/8	2.94
13400	1-1/4	1-3/8	1.63	2.12	2-7/16	1-3/4	3.06
16500	1-3/8	1-1/2	1.75	2.28	2-5/8	1-7/8	3.62
20000	1-1/2	1-5/8	1.88	2.45	2-7/8	2	4.06
23750	1-5/8	1-3/4			3-1/16	2-3/16	4.19
32350	2	2-1/8	2.25	2.93	3-3/4	2-5/8	4.75
42500	2-1/4	2-3/8	2.56	3.33	4-1/8	3	5.25
54000	2-1/2	2-5/8	2.81	3.66	4-9/16	3-1/4	6.00
67600	2 3/4	2-7/8	2.94	3.82	5	3-9/16	7.00
81000	3	3-1/8			5-7/16	3-7/8	8.61
97000	3-1/4	3-3/8			5-7/8	4-1/4	9.74

All dimensions in inches.

LIFTING ATTACHMENTS (cont.)

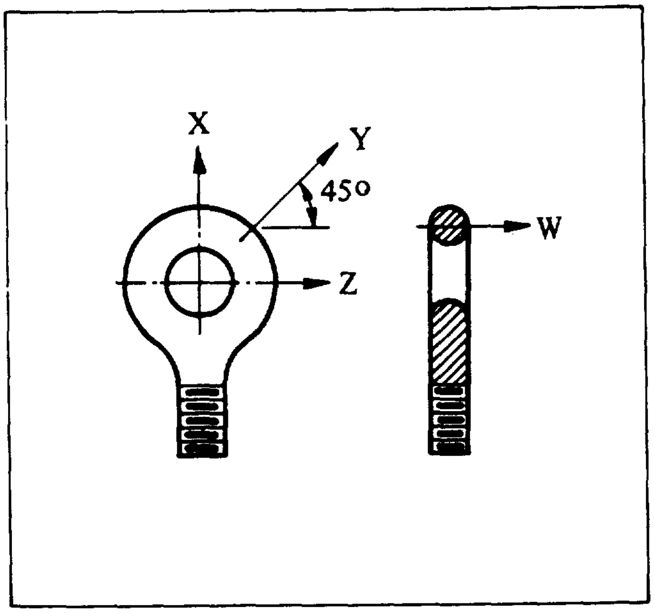
RECOMMENDED MATERIAL: A 515-70, A 302 or equivalent. The thickness, and length of the lifting lug shall be determined by calculation.*

WELD: When fillet welds are used, it is recommended that throat areas be at least 50 per cent greater than the cross sectional area of the lug.

To design the lugs the entire load should be assumed to act on one lug.

All possible directions of loading should be considered (during shipment, storage, erection, handling.) When two or more lugs are used for multileg sling, the angle between each leg of the sling and the horizontal should be assumed to be 30 degrees.

EYE - BOLT



Threaded fasteners smaller than 5/8" diameter should not be used for lifting because of the danger of overtorquing during assembly.

Commercial eyebolts are supplied with a rated breaking strength in the X direction.

For loadings other than along the axis of the eyebolt, the following ratings are recommended. These are expressed as percentage of the rating in the axial direction.

X = 100% Y = 33%
Z = 20% W = 10%

EXAMPLE:

An eyebolt of 1 in. diameter which is good for 4960 lb. load in tension (direction x) can carry only 4960 x 0.33 = 1637 lb. load if it acts in direction y.

The above dimensions and recommendations are taken from C. V. Moore: Designing Lifting Attachments, Machine Design, March 18, 1965.

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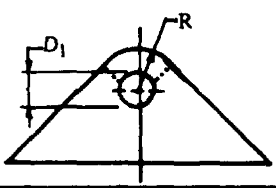
*Assuming shear load only thru the minimum section, the required thickness may be calculated by the formula:



$$t = \frac{P}{2S\ (R - D_1/2)}$$

where t = required thickness of lug, in.
P = load, lbs.
S = allowable shear stress, psi.

See page 459 for design of weld and length of lug.

SAFE LOADS FOR ROPES AND CHAINS

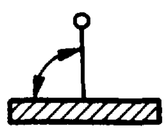
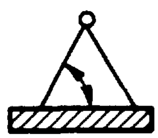
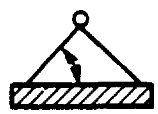
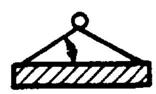
The stress in ropes and chains under load is increasing with the reduction of the angle between the sling and the horizontal. Thus the maximum allowable safe load shall be reduced proportionally to the increased stress.

If the allowable load for a single vertical rope is divided by the cosecant of the angle between one side of the rope and the horizontal, the result will indicate the allowable load on one side of the inclined sling.

Example:

The allowable load for a rope in vertical position is 8000 lb. If the rope applied to an angle of 30 degrees, in this position the allowable load on one side will be 8000/cosecant 30 deg. = 8000/2 = 4000 lb. For the two-rope sling the total allowable load 2 times 4000 = 8000 lb. The table shows the load-bearing capacity of ropes and chains in different positions. Multiplying with the factors shown in the table the allowable load for a certain rope or chain, the product will indicate the allowable load in inclined position.

FACTORS TO CALCULATE SAFE LOADS FOR ROPES AND CHAINS

					
Angle of Inclination	90°	60°	45°	30°	10°
On One End	1.00	0.85	0.70	0.50	0.17
On Two Ends	–	1.70	1.40	1.00	0.34

OPENINGS

Where external piping is connected to the vessel, the scope of the Code includes:

(a) the welding end connection for the first circumferential joint for welded connections

(b) the first threaded joint for screwed connections

(c) the face of the first flange for bolted, flanged connections

(d) the first sealing surface for proprietary connections or fittings
Code U-1(e)(1)

SHAPE OF OPENINGS:

Openings in pressure vessels shall preferably be circular, elliptical or obround. An obround opening is one which is formed by two parallel sides and semicircular ends. The opening made by a pipe or a circular nozzle, the axis of which is not perpendicular to the vessel wall or head, may be considered an elliptical opening for design purposes.

Openings may be of shapes other than the above. (See Code UG-36.)

SIZE OF OPENINGS:

Properly reinforced openings are not limited as to size, but, when the opening in the head of a cylinder shell is larger than one half the inside diameter of the head, it is recommended to use in place of heads, shell reducer sections as shown in the Code Figure UG-36,

NOZZLE NECK THICKNESS (Code UG-45)

For vessels under internal pressure the wall thickness of opening necks shall not be less than:

(1) the thickness computed for the applicable loadings in UG-22 on the neck (pressure, reaction of piping, etc.), plus corrosion allowance.

(2) for other than access and inspection openings shall not be less than required for the applicable loadings and not less than the smallest of the following:

(a) the thickness of the shell or head (to which the opening is attached), required for internal pressure (assuming $E = 1$), plus corrosion allowance, but for welded vessel in no case less than 1/16 in.

(b) the minimum thickness of standard wall pipe plus corrosion allowance. The minimum thickness of a pipe (ANSI/A B36.10M) is the nominal thickness less 12.5 percent allowable tolerance (see page 140).

INSPECTION OPENINGS

All pressure vessels for use with compressed air and those subject to internal corrosion, erosion or mechanical abrasion, shall be provided with suitable manhole, handhole, or other inspection openings for examination and cleaning. The required inspection openings shown in the table below are selected from the alternatives allowed by the Code, UG-46, as they are considered to be the most economical.

INSIDE DIAMETER OF VESSEL	INSPECTION OPENING REQUIRED
over 12 in. less than 18 in. I.D.	two - 1½ in. pipe size threaded opening
18 in. to 36 in. inclusive I.D.	min. 15 in. I.D. manhole or two - 2 in. pipe size threaded opening
over 36 in. I.D.	min. 15 in. I.D. manhole or two - 6 in. pipe size nozzle

INSPECTION OPENINGS ARE NOT REQUIRED:

1. for vessels 12 in. or less inside diameter if there are at least two minimum ¾ in. pipe size removable connections.
2. for vessels over 12 in. but less than 16 in. inside diameter, that are to be installed so that they must be disconnected from an assembly to permit inspection, if there are at least two removable connections not less than 1½ in. pipe size. UG-46(e).
3. for vessels over 12 in. inside diameter under air pressure which also contain other substances which will prevent corrosion, providing the vessel contains suitable openings through which inspection can be made conveniently, and providing such openings are equivalent in size and number to the requirement of the table. UG-46(c).
4. for vessels (not over 36 in. I.D.) which are provided with teltale holes (one hole min. per 10 sq. ft.) complying with the provisions of the Code UG-25, which are subject only to corrosion and are not in compressed air service. UG-46(b).

The preferable location of small inspection openings is in each head or near each head.

In place of two smaller openings a single opening may be used, provided it is of such size and location as to afford at least an equal view of the interior.

Compressed air as used here is not intended to include air which has had moisture removed to the degree that it has an atmospheric dew point of -50 F or less. The manufacturer's Data Report shall include a statement "for non-corrosive service" and Code paragraph number when inspection openings are not provided.

NOZZLE NECK THICKNESS

The wall thickness of a nozzle neck or other connection used as access or inspection opening only shall not be less than the thickness computed for the applicable loadings plus corrosion allowance.

OPENINGS WITHOUT REINFORCING PAD

Below the most commonly used types of welded attachments are shown. For other types see Code, Fig. UW-16.1.

NOTATIONS:

a = Min. weld size = t or t_n or 0.375 in. whichever is the smallest, in.

$a_1 + a_2$ = 1¼ × the smallest of t, t_n or 1 in.

a_1 or a_2 = the smallest of t, t_n or 0.375 in.

b = No minimum size requirement

α = The angle of beveling shall be such as to permit complete joint penetration and complete fusion. Depends on plate thickness, welding procedure.

t = Thickness of vessel wall less corrosion allowance, in.

t_n = Nominal thickness of nozzle wall less corrosion allowance. in.

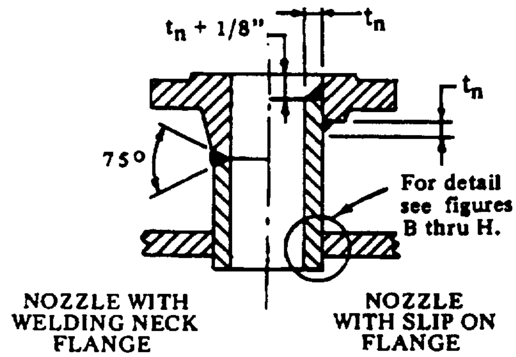
NOTES:

1. When complete joint penetration cannot be verified by visual inspection or other means permited by the Code, backing strips shall be used with full penetration weld deposited from only one side.
2. The purpose of weld b is to eliminate the irregularities of the groove weld at the root and secure full penetration. It is urually one pass only and may be omitted if not needed for the above purpose.
3. The weld sizes defined here are the minimum requirements. For calculation of strength of welds, see page 136.
4. Strength calculation of welds for pressure loading are not required for attachments shown in fig. B, C, E, F, G, and for openings:

   3 in. pipe size attached to vessel walls of 3/8 in. or less in thickness,

   2 in. pipe size attached to vessel walls over 3/8 in. thickness. (Code UG -36 (c) (3))

A



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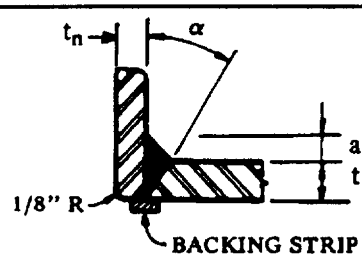
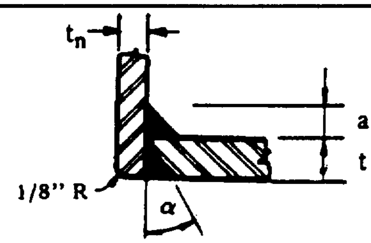
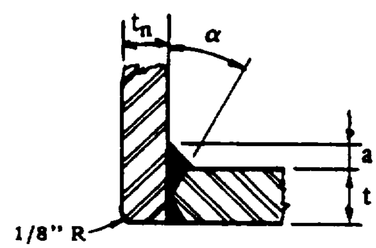


C



F



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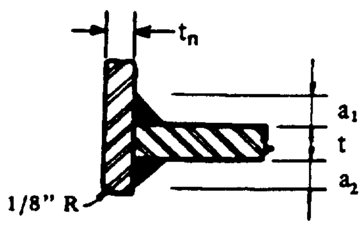
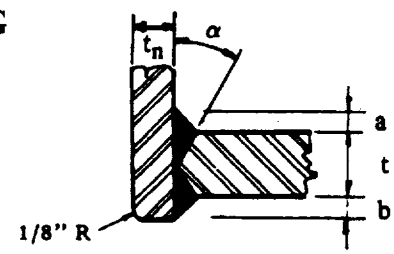
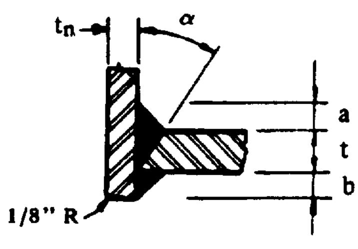


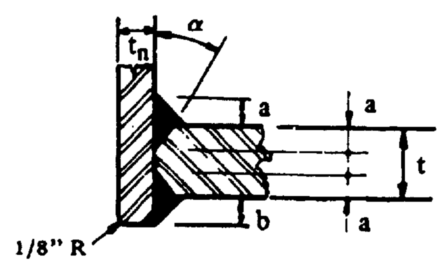
G



E



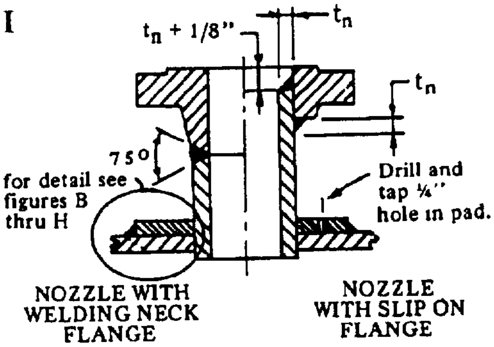
H



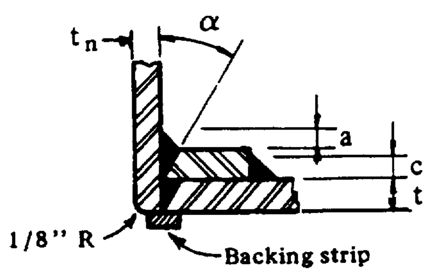
OPENINGS WITH REINFORCING PAD

Below the most commonly used types of welded attachments are shown. For other types see Code, Fig. UW-16.1.

I



J



NOTATION:

Minimum weld sizes, inches. Use the smallest values.

a = t_n or t_e or 0.375 in.

b = No minimum size requirement

c = $0.7t$, or $0.7t_e$, or 0.5 in.

d = $0.7t$, or $0.7t_n$, or $0.7t_e$ or 0.75 in.

e = t, or t_p or 1 in.

✓ = The angle of bevel shall be such as to permit complete joint penetration and complete fusion. Depends on plate thickness and welding techniques.

t = Thickness of vessel wall less corrosion allowance, in.

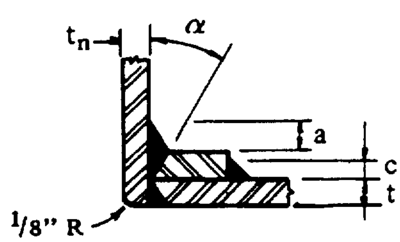
t_e = Thickness of reinforcing pad less corrosion allowance, in.

t_n = Nominal thickness of nozzle wall less corrosion allowance, in.

t_p = Thickness of pad type flange, in.

SEE NOTES ON FACING PAGE

K



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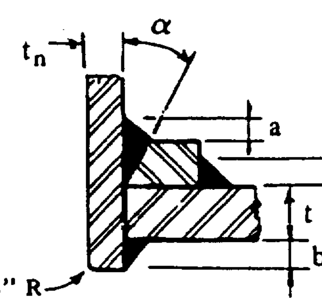
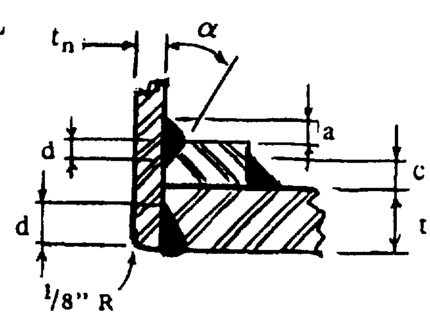
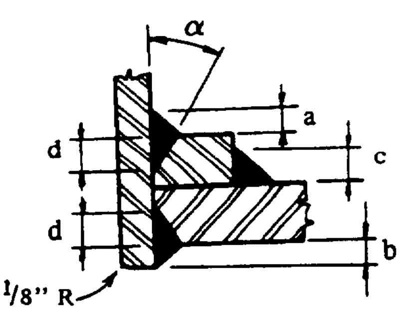


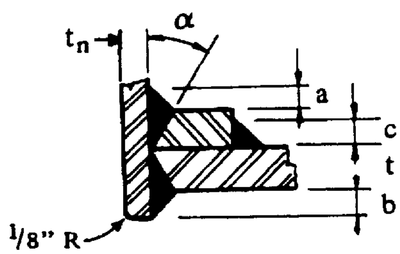
L



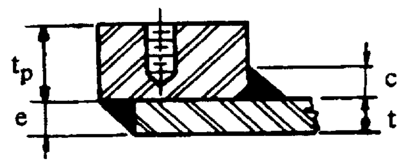
O



M



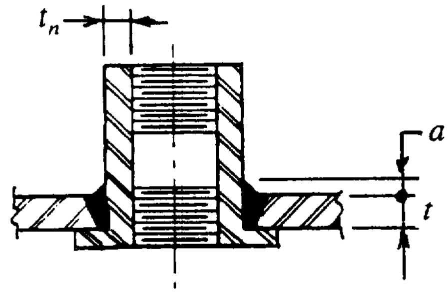
P



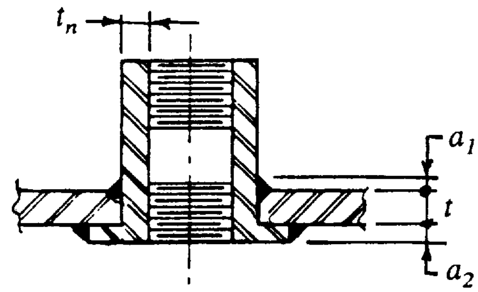
THREADED AND WELDED FITTINGS

THE FIGURES BELOW SHOW THE MOST COMMONLY USED TYPES OF WELDED CONNECTIONS. SEE CODE FIG. UW-16.1 FOR OTHER TYPES

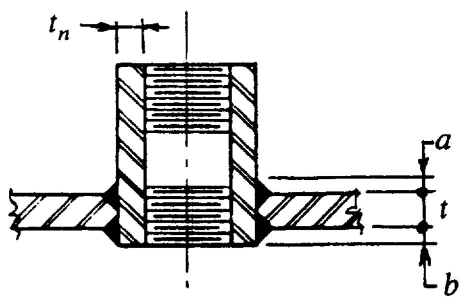
A



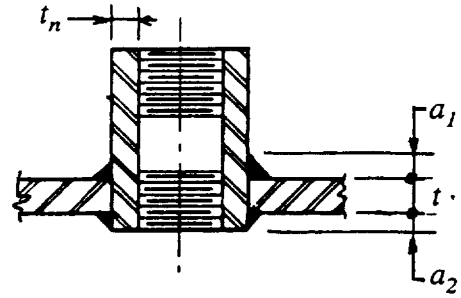
B



C



D



NOTATION

$a = t$, t_n or 0.375, whichever is the smallest, in.

$a_1 + a_2 =$ 1-1/4 times the smallest of t, t_n or 1 in.

a_1 or $a_2 =$ the smallest of t, t_n or 0.375 in.

$b =$ no minimum size requirement

$c =$ the smallest of t or 1/2 in.

$d =$ the thickness of Sch 160 pipe wall, in.

$e =$ the smallest of t or 3/4 in.

$t =$ thickness of vessel wall, less corrosion allowance, in.

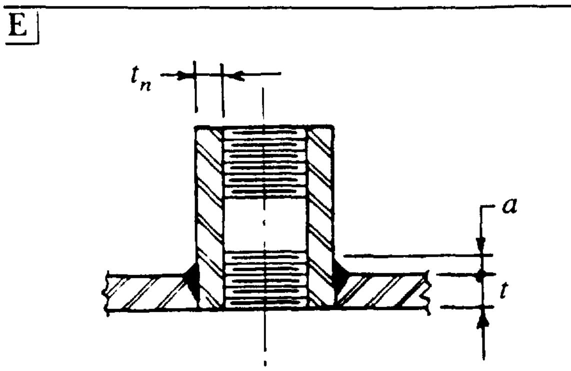
$t_n =$ nominal thickness of fitting wall less corrosion allowance, in.

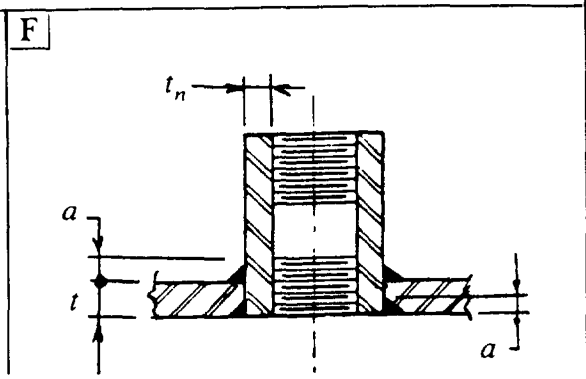
The weld sizes defined here are the minimum requirements.

SEE NOTES ON FACING PAGE

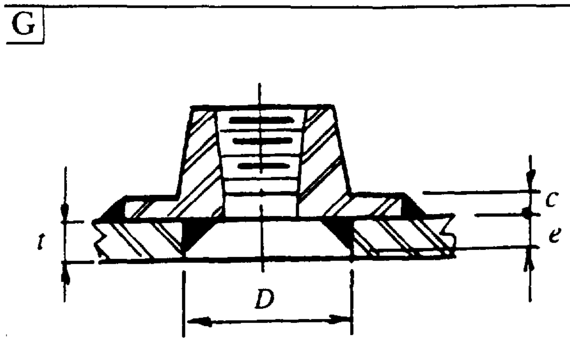
THREADED AND WELDED FITTINGS

THE FIGURES BELOW SHOW THE MOST COMMONLY USED TYPES OF WELDED CONNECTIONS. SEE CODE FIG. UW-16.1 FOR OTHER TYPES

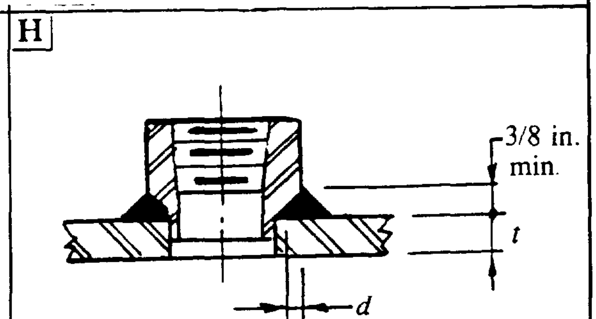




SEE NOTATION ON FACING PAGE:



D max = outside diameter of pipe + 3/4 in.



Max. pipe size: 3 in.

FITTINGS NOT EXCEEDING 3 IN. PIPE SIZE.

In some cases the welds are exempt from size requirements, or fittings and bolting pads may be attached to the vessels by fillet weld deposited from the outside only with certain limitations (Code UW-16 (f) (2) and (3)) such as:

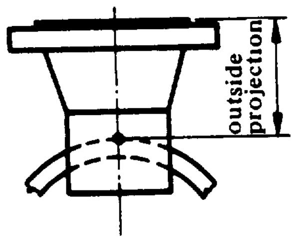
1. The maximum vessel thickness: 3/8 in.
2. The maximum size of the opening is limited to the outside diameter of the attached pipe plus ¾ in.
3. The weld throat shall be the greater of the minimum nozzle neck thickness required by the Code UG-45(a) or that necessary to satisfy the requirements of UW 18 for the applicable loadings of UG 22.
4. The welding may effect the threads of couplings. It is advisable to keep the threads above welding with a minimum ¼ in. or cut the threads after welding.
5. Strength calculation of attachments is not required for attachments shown in Figs. A, C and E, and for openings:

   3 in. pipe size fittings attached to vessel walls of 3/8 in. or less in thickness, 2 in. pipe size fittings attached to vessel walls over 3/8 in. in thickness. (Code UG-36(c)(3)).

SUGGESTED MINIMUM EXTENSION OF OPENINGS

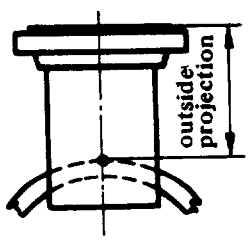
The tables give the approximate minimum outside projection of openings. When insulation or thick reinforcing pad are used it may be necessary to increase these dimensions.

OUTSIDE PROJECTION, INCHES USING WELDING NECK FLANGE



NOM. PIPE SIZE	PRESSURE RATING OF FLANGE LB					
	150	300	600	900	1500	2500
2	6	6	6	8	8	8
3	6	6	8	8	8	10
4	6	8	8	8	8	12
6	8	8	8	10	10	14
8	8	8	10	10	12	16
10	8	8	10	12	14	20
12	8	8	10	12	16	22
14	8	10	10	14	16	
16	8	10	10	14	16	
18	10	10	12	14	18	
20	10	10	12	14	18	
24	10	10	12	14	20	

OUTSIDE PROJECTION, INCHES USING SLIP ON FLANGE



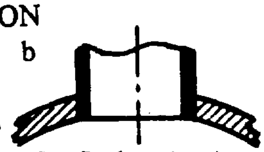
NOM. PIPE SIZE	PRESSURE RATING OF FLANGE LB					
	150	300	600	900	1500	2500
2	6	6	6	8	8	8
3	6	6	8	8	8	10
4	6	8	8	8	10	10
6	8	8	8	10	12	12
8	8	8	10	10	12	12
10	8	8	10	12	12	14
12	8	10	10	12	12	16
14	10	10	10	12		
16	10	10	12	12		
18	10	10	12	12		
20	10	10	12	12		
24	10	12	12	12		

INSIDE EXTENSION

a

Flush
Pipe cut to the curvature of vessel

b

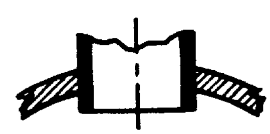


Set flush not cut to the curvature

c

Minimum extension for welding

d



Extension for reinforcement or other purpose

REINFORCEMENT OF OPENINGS
DESIGN FOR INTERNAL PRESSURE

Single, welded openings not subject to rapid fluctuation in pressure do not require reinforcing if they are not larger than:

3 inch pipe size - in vessel wall 3/8 in. or less.

2 inch pipe size in vessel wall over 3/8 in. (Code UG-36 (c) (3).

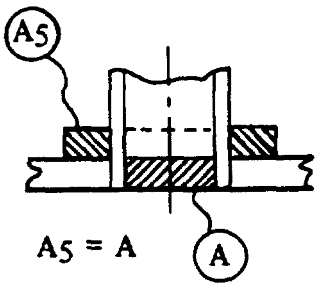


Fig. A

Larger vessel openings than the above shall be reinforced. The rules for reinforcement of openings are taken from the Code, UG-26 through UG-44, and are intended to apply primarily to openings not exceeding the following:

For vessels 60 in. in diameter and less: ½ the vessel diameter, but not to exceed 20 in.

For vessels over 60 in. in diameter: ⅓ the vessel diameter, but not to exceed 40 in. Larger opening should be given special attention as described in Code Appendix 1-7.

Here is given a brief outline of reinforcement design for better understanding of the procedure described in the following pages.

The basic requirement is that around the opening the vessel must be reinforced with an equal amount of metal which has been cut out for the opening. The reinforcement may be an integral part of the vessel and nozzle or may be an additional reinforcing pad. (Fig. A.)

This simple rule, however, needs further refinements as follows:

1. It is not necessary to replace the actually removed amount of metal, but only the amount which is required to resist the internal pressure. *(A)*. This required thickness of the vessel at the openings is usually less than at other points of the shell or head.
2. The plate actually used and nozzle neck usually are thicker than would be required according to calculation. The excess in the vessel wall (A_1) and nozzle wall (A_2) serve as reinforcements. Likewise the inside extension of the opening (A_3) and the area of the weld metal (A_4) can also be taken into consideration as reinforcement.
3. The reinforcement must be within a certain limit.
4. The area of reinforcement must be proportionally increased if its stress value is lower than that of the vessel wall.
5. The area required for reinforcement must be satisfied for all planes through the center of opening and normal to vessel surface.

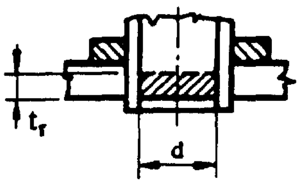
The required cross sectional area of the reinforcement shall then be:

The required area for the sell or head to resist the internal pressure, *(A)*. From this area subtracted the excess areas within the limit $(A_1 A_2 A_3 A_4)$. If the sum of the areas available for reinforcement $(A_1 + A_2 + A_3 + A_4)$ is equal or greater than the area to be replaced, *(A)*, the opening is adequately reinforced. Otherwise the difference must be supplied by reinforcing pad (A_5).

Some manufacturers follow a simple practice using reinforcing pads with a cross-sectional area which is equal to the metal area actually removed for the opening. This practice results in oversized reinforcement, but with the elimination of calculations they find it more economical.

REINFORCEMENT FOR OPENINGS
DESIGN FOR INTERNAL PRESSURE
(continued)

B



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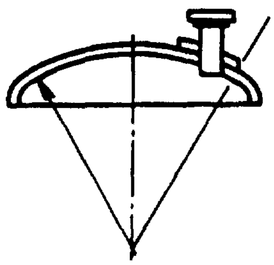
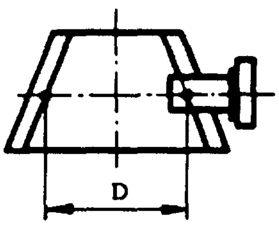
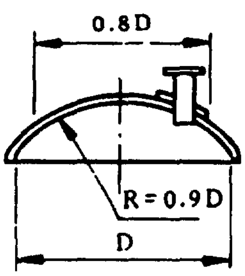


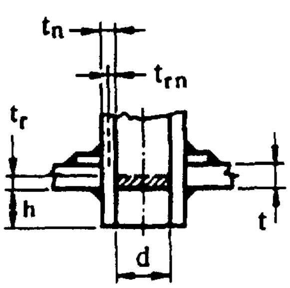
D



E



F



1. AREA OF REINFORCEMENT

For vessels under internal pressure the total cross-sectional area required for reinforcement of openings shall not be less than:

$$A = d \times t_r, \text{ where}$$

d = the inside diameter of opening in its corroded condition, inches.

t_r = the required thickness of shell or head computed by the applicable formulas using $E = 1.0$ when the opening is in solid plate or in a category B joint. When opening passes through any other welded joint, E = the efficiency of that joint. When the opening is in a vessel which is radiographically not examined, $E = 0.85$ for type No. 1 joint and $E = 0.80$ for type No. 2 joint.

When the opening and its reinforcement are entirely within the spherical portion of a flanged and dished head, t_r is the thickness required by the applicable formulas using $M = 1$.

When the opening is in a cone, t_r is the thickness required for a seamless cone of diameter, D measured where the nozzle axis intersects with the wall of the cone.

When the opening and its reinforcement are in a 2:1 ellipsoidal head and are located entirely within a circle the center of which coincides with the center of the head and the diameter of which is equal to 0.8 times the head diameter, t_r is the thickness required for seamless sphere of radius 0.9 times the diameter of the head.

If the stress value of the opening's material is less than that of the vessel material, the required area A shall be increased. (See next page for examples.)

2. AVAILABLE AREAS OF REINFORCEMENT

A_1= Area of excess thickness in the vessel wall $(t - t_r)\,d$ or $(t - t_r)\,(t_n + t)2$ use the larger value, square inches.

If the stress value of the opening's material is less than that of the vessel material, area A_1 shall be decreased. (See next page for examples.)

A_2= Area of excess thickness in the nozzle wall $(t_n - t_{rn})\,5t$ or $(t_n - t_{rn})\,5t_n$ use — the smaller value, square inches.

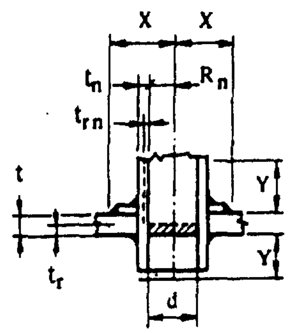
A_3= Area of inside extension of nozzle square inches $(t_n - c)2h$.

A_4= Area of welds, square inches.

If the sum of A, A_2 A_3 and A_4 *is* less than the area for reinforcement required, A the difference must be supplied by reinforcing pad.

REINFORCEMENT FOR OPENINGS
DESIGN FOR INTERNAL PRESSURE
(continued)

G



NOTATION:

t = thickness of the vessel wall less corrosion allowance, inches.

t_r = see preceeding page

t_n= nominal thickness of nozzle wall irrespective of product form, less corrosion allowance, inches.

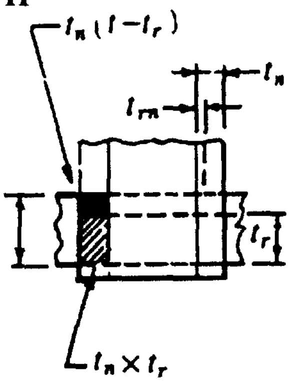
t_m= required thickness of seamless nozzle wall, inches.

h = distance nozzle projects beyond the inner surface of the vessel wall less corrosion allowance, inches.

c = corrosion allowance, inches.

d = see preceding page.

H



3. LIMITS OF REINFORCEMENT

The metal used as reinforcement must be located within the limits.

The limit measured parallel to the vessel wall $X = d$ or $R_n + t_n + t$, use larger value.

The limit measured parallel to the nozzle wall $Y = 2.5\,t$ or $2.5t_n$, use smaller value.

When additional reinforcing pad is used, the limit, Y to be measured from the outside surface of the reinforcing pad.

Rn= inside radius of nozzle in corroded condition, inches.

For other notations, see the preceding page.

4. STRENGTH OF REINFORCEMENT

If the strength of materials in A_1 A_2 A_3 A_4 and A_5 or the material of the reinforcing pad are lower than that of the vessel material, their area considered as reinforcement shall be proportionately decreased and the required area, A in inverse proportion increased. The strength of the deposited weld metal shall be considered as equivalent to the weaker material of the joint.

It is advisable to use for reinforcing pad material identical with the vessel material.

No credit shall be taken for additional strength of reinforcement having higher stress value than that of the vessel wall.

EXAMPLES:

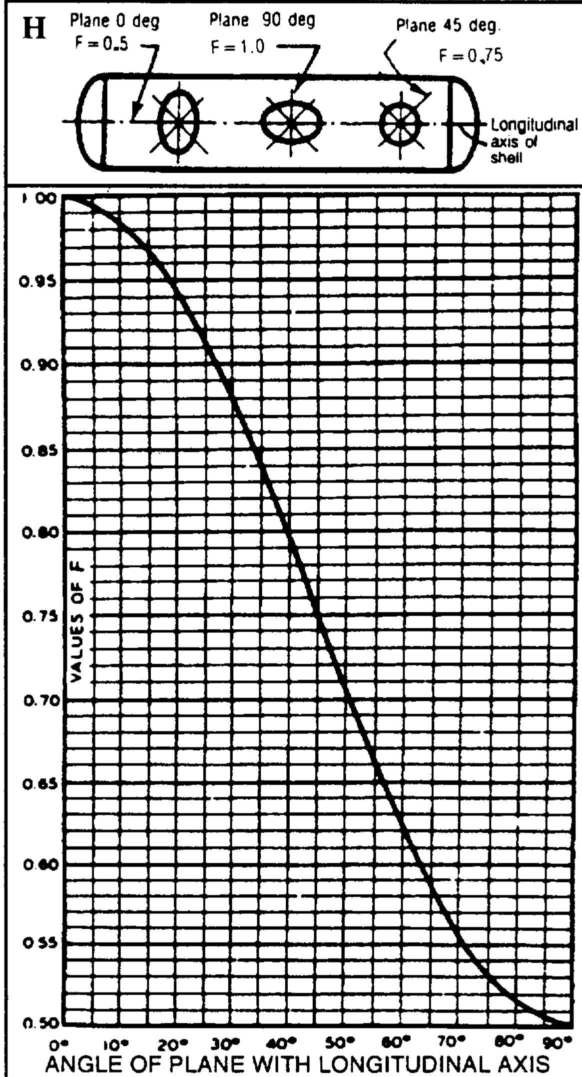
1. a. The stress value of nozzle material: 15,000 psi.
   The stress value of shell material: 17,500 psi.
   Ratio 15,000/17,5000 = 0.857
   To the required area, A shall be added:
   $$+\,2t_n \times t_r\,(1 - 0.857)$$
   b. From the area A_1 shall be subtracted:
   $$-\,2t_n \times (t - t_r)\,(1 - 0.857)$$

2. Using identical material for the vessel and reinforcing pad, the required area for reinforcement is 12 square inches.

   If the stress value of vessel material = 17,500 psi.,
   the stress value of the nozzle material = 15,000 psi.,
   ratio 17,500/15,000 = 1.167

   In this proportion shall be increased the area of reinforcing pad:
   $$12 \times 1.167 = 14.00 \text{ square inches.}$$

REINFORCEMENT FOR OPENINGS
DESIGN FOR INTERNAL PRESSURE
(continued)



5. REINFORCEMENT IN DIFFERENT PLANES FOR INTERNAL PRESSURE

The area requirement for reinforcement must be satisfied for all planes through the center of opening and normal to the vessel surface. When the long dimension of an elliptical or obround opening exceeds twice the short dimensions, the reinforcement across the short dimensions shall be increased as necessary to provide against excessive distortion due to twisting moment. Code UG-36 (a) (1).

Since the circumferential stress in cylindrical/conical/shells is two times greater than the longitudinal stress, at the opening the plane containing the axis of the shell is the plane of the greatest unit loading due to pressure. On the plane perpendicular to the vessel axis the unit loading is one half of this.

Chart shows the variation of the stresses on different planes. (Factor F)

The total cross-sectional area in any planes shall be: $A = d \times t_r \times F$

According to the Code, Factor F may be used for integrally reinforced openings in cylindrical shells and cones. (UG-26).

DESIGN FOR EXTERNAL PRESSURE.

The reinforcement required for openings in single-walled vessels subject to external pressure need be only 50 percent of that required for internal pressure where t_r is the wall thickness required by the rules for vessels under external pressure. Code UG-37 (d) (1).

REINFORCEMENT OF OPENINGS FOR EXTERNAL PRESSURE.

The cross-sectional area *(A)* of reinforcement required for openings in vessels subject to external pressure:

$$A = \frac{d \times t_r \times F}{2}$$

where

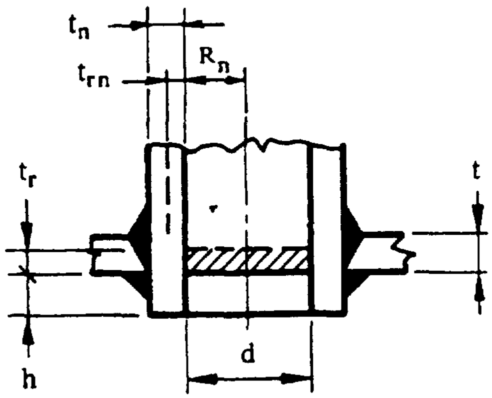
d = Diameter in the given plane of the opening in its corroded condition, inches.

t_r = The wall thickness required for external pressure, inches.

F = Factor for computation of the required reinforcement area on different planes (as the pressure-stress varies) when the opening is in cylindrical shell or cone and integrally reinforced. For all other configurations the value of F = 1.

REINFORCEMENT OF OPENINGS
EXAMPLES

EXAMPLE 1.



DESIGN DATA:
Inside diameter of shell: 48 in.
Design pressure: 250 psi at 200° F.
Shell Material: SA-285-C
$S = 13{,}800$ psi $\quad t = 0.265$ in.
The vessel is spot radiographed
No allowance for corrosion
Nozzle material: SA-53-B
$S = 15{,}000$ psi. $\quad t_n = 0.432$ in.
Nozzle nom. size: 6 in.
Extension of nozzle inside the vessel: 1.5 in.
$h = 2.5t_n = 2.5 \times 0.432 = 1.08$ in.
The nozzle does not pass through seams.
Fillet weld size: 0.375 in.

Wall thickness required:

for shell, $t = \dfrac{PR}{SE—0.6P} = \dfrac{250 \times 24}{13{,}800 \times 1.0—0.6 \times} = 0.440$ in.

for nozzle, $t_m = \dfrac{PR_n}{SE—0.6P} = \dfrac{250 \times 2.88}{15{,}000 \times 1.0—0.6 \times 250} = 0.048$ in.

AREA OF REINFORCEMENT REQUIRED

$A_l = dt_r = 5.761 \times 0.440 =$ 2.535 sq. in.

AREA OF REINFORCEMENT AVAILABLE

$A_l =$ (Excess in shell.) Larger of following:
$(t—t_r)d = (0.625—0.440) \times 5.761$ or 1.066 sq. in.
$(t\text{-}t_r)\ (t_n + t)\ 2 = (0.625\text{-}0.440) \times (0.432 + 0.625) \times 2 =$ 0.391 sq. in.

$A_2 =$ (Excess in nozzle neck.) Smaller of following:
$(t_n—t_m)\ 5t = (0.432—0.048) \times 5 \times 0.625 = 1.200$ sq. in.
$(t_n—t_m)\ 5t_n = (0.432—0.048) \times 5 \times 0.432 =$ 0.829 sq. in.
(No credit for additional strength of nozzle material having higher stress value than that of the vessel wall.)

$A_3 =$ (Inside projection.) $t_n \times 2h = 0.432 \times 2 \times 1.08 =$ 0.933 sq. in.

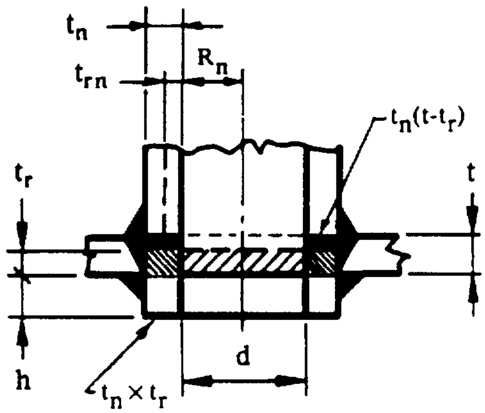
$A_4 =$ (Area of fillet weld) 0.375^2 0.140 sq. in.

$A_5 =$ (Area of fillet weld inside) 0.375^2 0.140 sq. in.

TOTAL AREA AVAILABLE 3.108 sq. in.
Since this area is greater than the area required for reinforcement, additional reinforcement is not needed.

REINFORCEMENT OF OPENINGS
EXAMPLES

EXAMPLE 2.



DESIGN DATA:
Inside radius of shell: $R = 24$ in.
Design pressure: $P = 300$ psi at 200^0 F.
Shell material: $t = 0.500$ in. SA-516-70 plate, $S = 17{,}500$ psi
The vessel is spot examined
There is no allowance for corrosion
Nozzle nominal size: 6 in.
Nozzle material: SA-53 B
$S = 15{,}000$ psi. $t_n = 0.432$ in.
Extension of nozzle inside the vessel: 1.5 in.
Fillet weld size inside: 0.500 in.;
Fillet weld size outside: 0.625 in.
Ratio of stress values: 15,000/17,500 = 0.857

Wall thickness required:

$$\text{Shell, } t_r = \frac{PR}{SE - 0.6P} = \frac{300 \text{ x } 24}{17{,}500 \text{ x } 1\text{-}0.6 \text{ x } 300} = 0.416 \text{ in.}$$

$$\text{Nozzle, } t_{rn} = \frac{PR_n}{SE - 0.6P} = \frac{300 \text{ x } 2.88}{15{,}000 \text{ x } 1.0 - 0.6 \text{ x } 300} = 0.058 \text{ in.}$$

Since the strength of the nozzle material is lower than that of the vessel material, the required area for reinforcement shall be proportionally increased and the areas available for reinforcement proportionally reduced.

AREA OF REINFORCEMENT REQUIRED

$A = dt_r = 5.761 \times 0.416 =$	2.397 sq. in.
Area increased: $+ 2t_n \times t_r$ (1-15,000/17,500) =	
$2 \times 0.432 \times 0.416$ (1-0.857) = 0.051 sq. in.	2.448 sq. in.

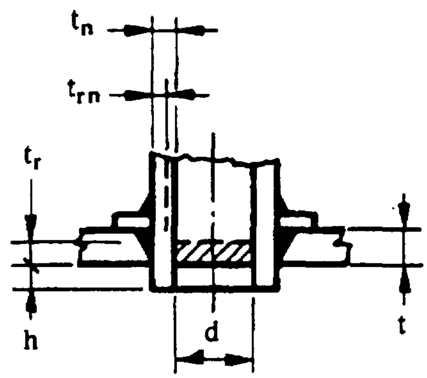
AREA OF REINFORCEMNT AVAILABLE

A_1 = (Excess in shell.) Larger of the following:	
$(t - t_r)d = (0.500 - 0.416) \times 5.761 = 0.484$ sq. in. or	
$(t-t_r)\ (t_n + t)\ 2 = (0.500-0.416) \times (0.432 + 0.500) \times 2 = 0.156$ sq. in.	
Area reduced: $- 2 \times t_n (t-t_r)$ (1-0.857) =	
$- 2 \times 0.432 \times (0.500-0.416)$ (1-0.857) = -0.010 sq. in.	0.474 sq. in.
A_2 =(Excess in nozzle neck.) Smaller of following:	
$(t_n - t_{rn})5t = (0.432-0.058)5 \times 0.500 = 0.935$	
$(t_n - t_{rn})5t_n = (0.432-0.058)\ 5 \times 0.432 = 0.808$	
Area reduced: $0.857 \times 0.808 = 0.692$ sq. in.	
Since the strength of the nozzle is lower than that of the shell, a decreased area shall be taken into consideration.	
15,000/17,500 = 0.857, 0.857×0.808 =	0.692 sq. in.
A_3 = (Inside projection.) $t_n \times 2h = 0.432 \times 2 \times 1.08 = 0.933$	
Area decreased 0.933×0.857 =	0.800 sq. in.
A_4 =(Area of fillet weld) $2 \times 0.5 \times .625^2 \times 0.857$ =	0.334 sq. in.
A_5 =(Area of fillet weld inside) $2 \times 0.5 \times .500^2 \times 0.857$ =	0.214 sq. in.
TOTAL AREA AVAILABLE	2.514 sq. in.

Additional reinforcement not required.

REINFORCEMENT OF OPENINGS
EXAMPLES

EXAMPLE 3.



DESIGN DATA:
Inside diameter of shell: 48 in.
Design pressure: 300 psi at 200° F.
Shell material: 0.500 in. SA-516-60 plate,
The vessel fully radiographed, $E = 1$
There is no allowance for corrosion
Nozzle nominal size: 8 in.
Nozzle material: SA-53 B, o.500 in. wall
Extension of nozzle inside the vessel: 0.5 in.
The nozzle does not pass through the main seams.
Size of fillet welds 0.375 in. (Reinforcement pad to nozzle neck.)

Wall thickness required:

$$\text{Shell } t_r = \frac{PR}{SE-0.6P} = \frac{300 \times 24}{15{,}000 \times 1\text{-}0.6 \times 300} = 0.486 \text{ in.}$$

$$\text{Nozzle, } t_{rn} = \frac{PR_n}{SE-0.6P} = \frac{300 \times 3.8125}{15{,}000 \times 1.0-0.6 \times 300} = 0.077 \text{ in.}$$

AREA OF REINFORCEMENT REQUIRED

$A = d \times t_r = 7.625 \times 0.486 =$ 3.706 sq. in.

AREA OF REINFORCEMNT AVAILABLE

A_1 = (Excess in shell.) Larger of the following:

$(t - t_r)d = (0.500 - 0.486)\ 7.625 =$ 0.106 sq. in.

or $(t - t_r)(t_n + t)\ 2 = (0.500\text{–}0.486)\ (0.500 + 0.500)\ 2 = 0.028$ sq. in.

A_2 =(Excess in nozzle neck.) Smaller of following:

$(t_n - t_{rn})5t = (0.500\text{-}0.077)5 \times 0.5 = 1.058$ or

$(t_n - t_{rn})5t_n = (0.500\text{-}0.077)5 \times 0.5 = 1.058$ 1.058 sq. in.

A_3 = (Inside projection.) $t_n \times 2h = 0.500 \times 2 \times 0.5 =$ 0.500 sq. in.

A_4 =(Area of fillet weld) 0.375^2 0.141 sq. in.

(The area of pad to shell weld disregarded)

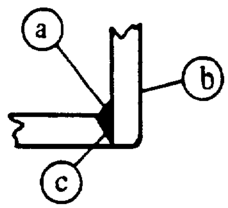
TOTAL AREA AVAILABLE 1.805 sq. in.

This area is less than the required area, therefore the difference shall be provided by reinforcing element. It may be heavier nozzle neck, larger extension of the nozzle inside of the vessel or reinforcing pad. Using reinforcing pad, the required area of pad: 3.706−1.805 = 1.901 sq. in. Using 0.375 in. SA-516-60 plate for reinforcing pad the width of the pad 1.901/0.375 = 5.069 in.

The outside diameter of reinforcing pad: Outside diameter of pipe: 8.625
width of reinforcing pad: 5.069
13.694 in.

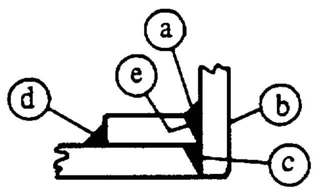
STRENGTH OF ATTACHMENTS JOINING OPENINGS TO VESSEL

A



Possible paths of failure
1. Through (a) and (b)
2. Through (a) and (c)

B



Possible paths of failure
1. Through (b) and (d)
2. Through (a) (c) and (e)
3. Through (c) and (d)

At the attachments, joining openings to the vessel, failure may occur through the welds or nozzle neck in the combinations shown in figures A and B.

The strength of the welds and the nozzle neck in those combinations shall be at least equal to the smaller of:

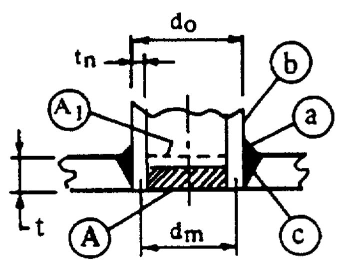
1. The strength in tension of the cross-sectional area of the element of reinforcement being considered, or
2. The strength in tension of area A $(A = d \times t_r)$ less the strength in tension of the excess in the vessel wall (A_1).

The allowable stress value of the welds is the stress value of the weaker material connected by the welds multiplied by the following factors:

Groove-weld tension	0.74
Groove-weld shear	0.60
Fillet-weld shear	0.49

The allowable stress value of nozzle neck in shear is 0.70 times the allowable stress value of nozzle material.

The strength of the joints shall be considered for its entire length on each side of the plane of reinforcement area.



EXAMPLE 3

$A =$ 2.397 sq. in. $A_1 = 0.484$ sq. in.
$d_o =$ 6.625 in., outside diameter of nozzle
$d_m =$ 6.193 in., mean diameter of nozzle
$S =$ 17,500 psi allowable stress value of vessel material
$S_n =$ 15,000 psi allowable stress value of nozzle material
$t_n =$ 0.432 in. wall thickness of nozzle.
$t =$ 0.500 in. wall thickness of vessel
0.375 in. fillet weld leg.

Check the strength of attachment of nozzle load to be carried by welds.
Load to be carried by welds $(A - A_1)S = 2.397 - 0.484 \times 17{,}500 = 33{,}478$ lb.

STRESS VALUE OF WELDS:

Fillet-weld shear	0.49 × 17500 = 8575 psi.
Groove-weld tension	0.74 × 17500 = 12950 psi.
Stress value of nozzle wall shear	0.70 × 15000 = 10500 psi.

STRENGTH OF WELDS AND NOZZLE NECK:

a. Fillet-weld shear $\frac{\pi d_o}{2} \times$ weld leg $\times 8575 = 10.4065 \times 0.375 \times 8575$ = 33463 lb.

b. Nozzle-wall shear $\frac{\pi d_m}{2} \times t_n \times 10500 = 9.72 \times 0.432 \times 10500$ = 44090 lb.

c. Groove-weld tension $\frac{\pi d_o}{2} \times$ weld leg $\times 12950 - 10.4065 \times 0.500 \times 12950$ = 67382 lb.

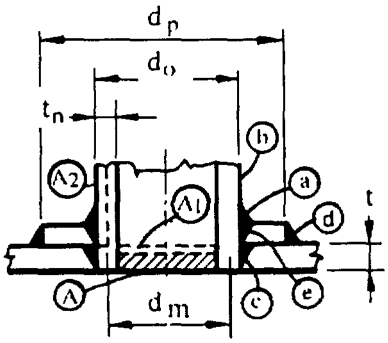
POSSIBLE PATH OF FAILURES:

1. Through a. and b. 33463 + 44090 = 77553 lb.
2. Through a. and c. 33463 + 67382 = 100845 lb.

Both paths are stronger than the required strength 33478 lb.

STRENGTH OF ATTACHMENTS JOINING OPENINGS TO VESSEL

EXAMPLE 4



DESIGN DATA

A = 3.172 sq. in., A_1= 0.641 sq. in., A_2= 0.907 sq. in.
d_p = 12.845 in. outside diameter of reinforcing pad.
d_o = 8.625 in. outside diameter of nozzle.
d_m= 8.125 in. mean diameter of nozzle.
S = 17,500 psi allowable stress value of vessel material
S_n = 15,000 psi allowable stress value of nozzle material
t = 0.500 in. thickness of vessel wall.
t_n = 0.500 in. thickness of nozzle wall.
0.375 in. leg of fillet - weld a
0.250 in. leg of fillet - weld d
t_e = 0.250 in. thickness of reinforcing pad.

Check the strength of attachment of nozzle.

LOAD TO BE CARRIED BY WELDS:
$(A—A_1)S$ = (3.172—0.641) 17,500 = 44,293 lb.

LOAD TO BE CARRIED BY WELDS a, c, e:
$(A_2 + 2\, t_n\, t)S$ = (0.907 + 2 × 0.500 × 0.500) 15,000 = 21,105 lb.

STRESS VALUE OF WELDS:

Fillet - weld shear	0.49 × 17,500 =	8,575 psi
Groove - weld tension	0.74 × 17,500 =	12,950 psi

STRESS VALUE OF NOZZLE WALL SHEAR:
0.70 × 15,000 = 10,500 psi

STRENGTH OF WELDS AND NOZZLE NECK:

a. Fillet weld shear $\frac{\pi d_o}{2}$ × weld leg × 8,575 = 13.55 × 0.375 × 8,575 = 43,572 lb.
b. Nozzle wall shear $\frac{\pi d_m}{2}$ × t_n × 10,500 = 12.76 × 0.500 × 10,500 = 66,990 lb.
c. Groove weld tension $\frac{\pi d_o}{2}$ × weld leg ×12,950 = 13.55 × 0.500 × 12,950 = 87,736 lb.
d. Filet weld shear $\frac{\pi d_p}{2}$ × weld leg × 8,575 = 20.18 × 0.25 × 8,575 = 43,260 lb.
e. Groove weld tension $\frac{\pi d_o}{2}$× weld leg × 12,950—13.55 × 0.25 × 12,950 = 43,868 lb.

POSSIBLE PATH OF FAILURE:

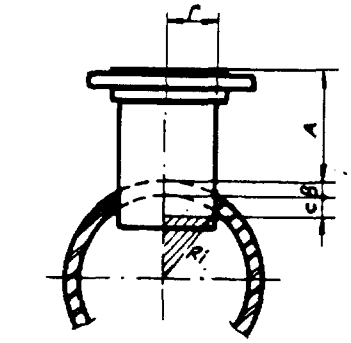
1. Through b and d	66,990 + 43,260	= 110,250 lb.
2. Through c and d	87,736 + 43,260	= 130,996 lb.
3. Through a, c and e	43, 572 + 87, 736 + 43,868	= 175,176 lb.

Paths 1. and 2. are stronger than the total strength of 44,293 lb.

Path 3. is stronger than the strength of 21,105 lb.

The outer fillet weld d strength 43,260 lb. is greater than the reinforcing pad strength of $(d_p—d_o)\, t_e$ × 17,500 = 1.055 × 17,500 = 18,463 lb.

LENGTH OF COUPLINGS AND PIPE FOR OPENINGS



NOZZLE IN SPHERE OR CYLINDER

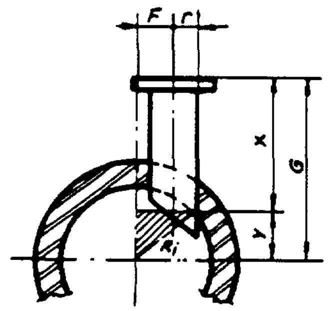
$C = R_i - \sqrt{R_i^2 - r^2}$

EXAMPLE:

Given: $R_i = 15$ in., $r = 8$ in.

Find: $C = 15 - \sqrt{15^2 - 8^2}$

$= 15 - \sqrt{225 - 4} = 15 - 12.6886 = 2.3114$ in.



NOZZLE IN SPHERE OR CYLINDER

$X = G - Y \qquad Y = \sqrt{R_i^2 - (F + r)^2}$

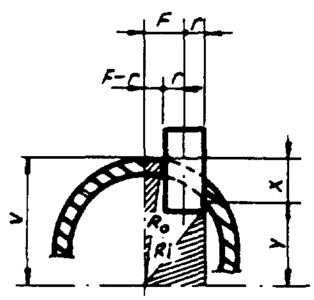
EXAMPLE:

Given: $R_i = 15$ in., $G = 24$ in., $F = 6$ in.
$r = 4.3125$ in.

Find: X

$Y = \sqrt{15^2 - (6+4.3125)^2} = \sqrt{225 - 106} = \sqrt{119}$

$Y = 10.9 \qquad X = 24 - 10.9 = 13.1$ in.



COUPLING IN SPHERE OR CYLINDER

$X = V - Y \qquad V = \sqrt{R_o^2 - (F - r)^2} \qquad Y = \sqrt{R_i^2 - (F + r)^2}$

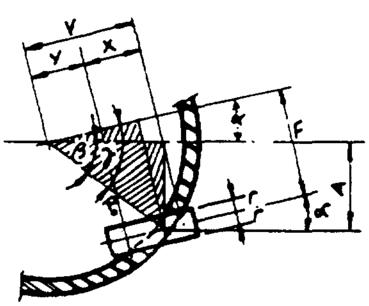
EXAMPLE:

Given: $R_i = 15$ in., $R_o = 16$ in., $F = 6$ in., $r = 1.25$ in.

$V = \sqrt{16^2 - (6 - 1.25)^2} = \sqrt{256 - 22.56} = 15.30$ in.

$Y = \sqrt{15^2 - (6 + 1.25)^2} = \sqrt{225 - 52.56} = 13.12$ in.

$X = 15.30 - 13.12 = 2.18$ in.



COUPLING IN SPHERE OR CYLINDER

$X = V - Y, \quad \sin\beta = A/R_o, \quad \gamma = \alpha + \beta$

$F = \sin\gamma \times R_o$

EXAMPLE:

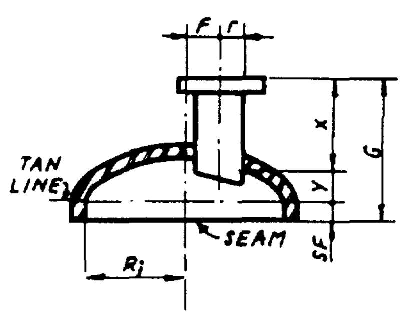
Given: $R_o = 12$ in., $\alpha = 15^\circ$, $A = 6$ in.

Find: F

$\sin\beta = 6/12 = 0.500 = 30^\circ \quad \gamma = 30^\circ + 15^\circ = 45^\circ$

$F = \sin 45^\circ \times 6 = 0.7071 \times 6 = 4.243$ in.

When F is known, Find X as in Example C above.



NOZZLE IN 2:1 ELLIPSOIDAL HEAD

$X = G - Y - SF \qquad Y = \dfrac{\sqrt{R_i^2 - (F + r)^2}}{2}$

EXAMPLE:

Given: $R_i = 24$ in., $F = 12$ in., $r = 8$ in., $SF = 2$ in.
$G = 20$ in.

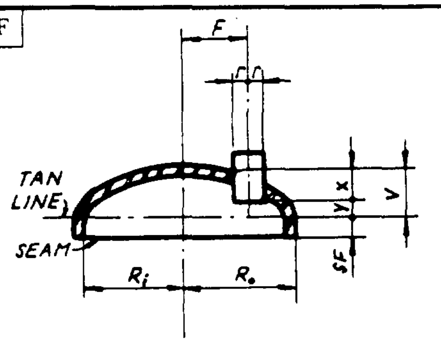
Find: X

$Y = \dfrac{\sqrt{24^2 - (12+8)^2}}{2} = \dfrac{\sqrt{576 - 400}}{2} = 6.3$ in.

$X = 20 - 6.63 - 2 = 11.37$ in.

LENGTH OF COUPLING AND PIPE FOR OPENINGS

F



COUPLING IN 2:1 ELLIPSOIDAL HEAD

$X = V - Y$, $V = \dfrac{\sqrt{R_o^2 - (F - r)^2}}{2}$, $Y = \dfrac{\sqrt{R_i^2 - (F + r)^2}}{2}$

EXAMPLE

Given: $R_i = 29$ in., $R_o = 30$ in., $F = 18$ in., $r = 1$ in.

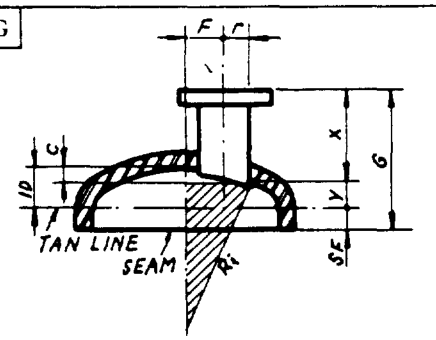
Find: X

$V = \dfrac{\sqrt{30^2 - (18 - 1)^2}}{2} = \dfrac{\sqrt{900 - 289}}{2} = 12.36$ in.

$Y = \dfrac{\sqrt{29^2 - (18 + 1)^2}}{2} = \dfrac{\sqrt{841 - 361}}{2} = 10.95$ in.

$X = 12.36 - 10.95 = 1.41$ in.

G



NOZZLE IN FLANGED & DISHED HEAD

$X = G - Y - SF$, $Y = ID - C$, $C = R_i - \sqrt{R_i^2 - (F + r)^2}$

EXAMPLE

Given: Inside depth of dish, ID = 8 in.

$R_i = 48$ in., $R_o = 49$ in., $F = 24$ in., $r = 2$ in., $G = 18$ in.,

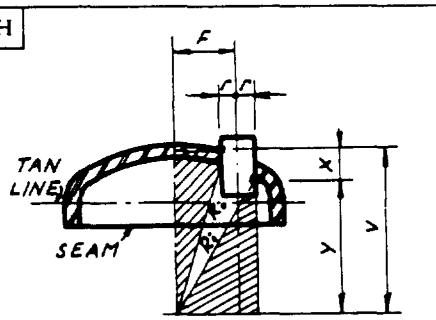
$SF = 2$ in.

Find: X

$C = 48 - \sqrt{48^2 - (24 + 2)^2} = 7.70$ in.

$X = 18 - 7.70 - 2 = 8.30$ in.

H



COUPLING IN FLANGED & DISHED HEAD

$X = V - Y$, $V = \sqrt{R_o^2 - (F - r)^2}$, $Y = \sqrt{R_i^2 - (F + r)^2}$

EXAMPLE

Given: $R_i = 24$ in., $R_o = 25$ in., $F = 8$ in., $r = 1$ in.

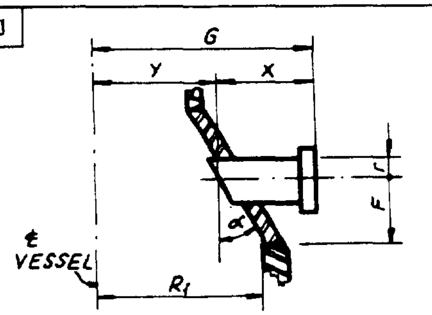
Find: X

$V = \sqrt{25^2 - (8 - 1)^2} = \sqrt{625 - 49} = 24$ in.

$Y = \sqrt{24^2 - (8 + 1)^2} = \sqrt{576 - 81} = 22.25$ in.

$X = 24 - 22.25 = 1.75$ in.

J



NOZZLE IN CONE

When α is less than 45°

$X = G - Y$, $Y = R_i - [\tan\alpha \times (F + r)]$

EXAMPLE

Given: $R_i = 24$ in., $G = 30$ in., $F = 12$ in., $r = 2$ in.,

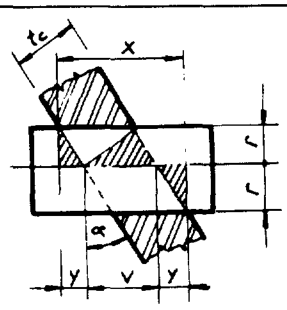
$\alpha = 30°$

Find: X

$Y = 24 - [\tan 30° (12 + 2)] = 24 - 8.08 = 15.92$ in.

$X = 30 - 15.92 = 14.08$ in.

K



COUPLING IN CONE

$X = V + 2Y$, $V = \dfrac{t_c}{\cos\alpha}$, $Y = \tan\alpha \times r$

EXAMPLE

Given: $t_c = 2$ in., $r = 1$ in., $\alpha = 30°$

Find: X

$V = \dfrac{2}{0.866} = 2.31$ $Y = 0.5774 \times 1 = 0.5774$

$X = 2.31 + 2 \times 0.5774 = 3.46$ in.

NOZZLE NECK THICKNESS

THE REQUIRED THICKNESS FOR NOZZLE NECKS IN VESSELS UNDER INTERNAL PRESSURE (Code UG-45)

1. The thickness computed for the applicable loadings in UG-22 plus corrosion allowance, but for other than access and inspection openings, not less than the smaller of the following:
2. The thickness required for the vessel for internal pressure (assuming joint efficiency, E = 1.0), but in no case less than the minimum for shells and heads specified in UG-16 (b);
3. The minimum thickness of standard wall pipe plus corrosion allowance.

THE REQUIRED THICKNESS FOR ACCESS AND INSPECTION OPENINGS (manways, handholes) IN VESSELS UNDER INTERNAL OR EXTERNAL PRESSURE.

1. The thickness computed for the applicable load plus corrosion allowance (there is no other requirement).

For selection of required pipe under internal pressure, see table "Maximum Allowable Internal Working Pressure for Pipes" on the following pages.

EXAMPLES for using the table:

1. Opening Diam: 18"
   Design Pressure: 800 psig.
   Corrosion Allowance: 0.125"
   The Required Pipe for Manway: Sch. 60, 0.750" Wall
   The Required Pipe for Nozzle: Sch. 60, 0.750" Wall

2. Opening Diam: 18"
   Design Pressure: 150 psig.
   Corrosion Allowance: 0.125"
   The Vessel Wall Thickness: 0.3125"
   The Required Pipe for Manway: Sch. 10, 0.250" Wall
   The Required Pipe for Nozzle: Std. Wt. 0.375" Wall

3. Opening Diam: 18"
   Design Pressure: 140 psig.
   Corrosion Allowance: 0.125"
   Vessel Wall Thickness: 0.750"
   The Required Pipe for Manway: Sch. 10, 0.250" Wall
   The Required Pipe for Nozzle:
   Std. Wt. 0.328" + 0.125" Corr. Allow. = 0.453, Min. Wall = Sch. 40 Pipe

THE REQUIRED NOZZLE NECK THICKNESS FOR VESSELS UNDER EXTERNAL PRESSURE (Code UG-45)

1. The thickness for the applicable load plus corrosion allowance, but not less than the smaller of the following:
2. The thickness of head or shell required for internal pressure using the external design pressure as an equivalent internal pressure, but in no case less than the minimum thickness specified for material in UG-16(b) (1/16 in. for shells and heads, 3/32 in. in compressed air, steam and water service, ¼ in. for unfired steam boilers), plus corrosion allowance;
3. The minimum thickness of standard wall pipe plus corrosion allowance.

EXAMPLE 1.

External design pressure: $P = 35$ psi.
Material SA 516-60; $S = 15{,}000$
Outside diameter of cylindrical shell: $D_0 = 96$ in.
Shell thickness: $t = 1$ in.
The required tickness for 14 O.D., 12 in. long nozzle neck:

1. To withstand 25 psi external pressure approximately 0.05 in. wall required, but the thickness shall not be less than the smaller of;
2. The thickness required for the shell under 35 psi internal pressure (as equivalent external pressure)

$$t = \frac{PR}{SE - 0.6P} = \frac{35 \times 47}{15{,}000 - 21} = 0.110 \text{ in.}$$

3. The minimum thickness of standard wall pipe: 0.328 in. (0.375 in. nom.) The smaller of 2. and 3. 0.110 in. for wall thickness of nozzle neck is satisfactory.

EXAMPLE 2.

External design pressure: $P = 15$ psi.
Material SA 516-60; $S = 15{,}000$
Outside diameter of cylindrical shell, $D_o = 36$ in.
Shell thickness: $t = 0.3125$ in.
The required thickness for a 14 in. D.O., 12 in. long nozzle neck:

1. To withstand 15 psi external pressure approximately 0.02 in. wall required, but the thickness shall not be less than the smaller of the following:
2. The thickness required for the shell under 15 psi. internal pressure

$$t = \frac{PR}{SE - 0.6\,P} = \frac{15 \times 17.6875}{15{,}000 - 9} = 0.018 \text{ in.}$$

3. The minimum thickness of standard wall pipe: 0.328 in. (0.375 in. nom.) The smaller of 2. and 3. is 0.018 in., but the thickness of the nozzle neck shall in no case be less than 0.0625 in. UG-45 (a) (2).

MAXIMUM ALLOWABLE INTERNAL WORKING PRESSURE FOR PIPES

The Calculations Based on the Formula:

$$P = \frac{2SEt}{D + 1.2t}$$, where

P = The max. allowable working pressure, psig.
S = 15,000 psig. the stress value of the most commonly used materials for pipe (A53B, A106B) at temperature - 20 to 650°F. For higher temperature see notes at the end of the tables.
E = 1.0 joint efficiency of seamless pipe
D = Inside diameter of pipe, in.
t = Minimum pipe wall thickness, in. (.875 times the nominal thickness).

The figures underlined are the maximum allowable pressure in corroded condition for the pipe of which wall thickness is minimum the standard wall plus corrosion allowance.

NOM. PIPE SIZE	DESIG-NATION	PIPE WALL THICKNESS		CORROSION ALLOWANCE IN.				
				O	1/16	1/8	3/16	1/4
		NOM.	MIN.	Max. Allow. Pressure psig.				
1/2	STD.	0.109	0.095	3730	1198			
	X-STG.	0.147	0.129	5252	2534	143		
	SCH. 160	0.187	0.164	6941	4013	1447		
	XX-STG.	0.294	0.257	12153	8526	5392	2658	252
3/4	STD.	0.113	0.099	3059	1072			
	X-STG.	0.154	0.135	4299	2192	288		
	SCH. 160	0.218	0.191	6386	4069	1985	100	
	XX-STG.	0.308	0.270	9712	7041	4657	2515	580
1	STD.	0.133	0.116	2847	1261			
	X-STG.	0.179	0.154	3959	2287	744		
	SCH. 160	0.250	0.219	5764	3946	2274	732	
	XX-STG.	0.358	0.313	8820	7423	4842	3099	1494
1-1/4	STD.	0.140	0.123	2362	1126			
	X-STG.	0.191	0.167	3282	1988	774		
	SCH. 160	0.250	0.219	4424	3059	1779	578	
	XX-STG.	0.382	0.334	7194	5645	4200	2848	1582
1-1/2	STD.	0.145	0.127	2118	1046	31		
	X-STG.	0.200	0.175	2982	1864	806		
	SCH. 160	0.281	0.246	4333	3139	2013	947	
	XX-STG.	0.400	0.350	6481	5164	3924	2754	1648
2	STD.	0.154	0.135	1786	938	126		
	X-STG.	0.218	0.191	2578	1696	852	44	
	SCH. 160	0.343	0.300	4215	3260	2348	1477	642
	XX-STG.	0.436	0.382	5537	4522	3553	2629	1744

MAXIMUM ALLOWABLE WORKING PRESSURE (cont)

NOM. PIPE SIZE	DESIG-NATION	PIPE WALL THICKNESS		CORROSION ALLOWANCE IN.				
				O	1/16	1/8	3/16	1/4
		NOM.	MIN.	Max. Allow. Pressure Psig.				
2½	STD.	0.203	0.178	1954	1245	561		
	X-STG.	0.276	0.242	2707	1971	1261	577	
	SCH-160	0.375	0.328	3766	2991	2245	1525	831
	XX-STG.	0.552	0.483	5822	4969	4148	3359	2599
3	STD.	0.216	0.189	1693	1116	556	12	
	X-STG.	0.300	0.263	2398	1801	1221	658	111
	SCH. 160	0.438	0.383	3597	2964	2350	1754	1175
	XX-STG.	0.600	0.525	5113	4432	3773	3134	2515
3½	STD.	0.226	0.198	1546	1044	555	78	
	X-STG.	0.318	0.278	2207	1689	1183	691	211
	XX-STG.	0.636	0.557	4701	4115	3546	2992	1937
4	STD.	0.237	0.208	1439	995	561	137	
	X-STG.	0.337	0.295	2075	1616	1168	730	280
	SCH. 120	0.438	0.383	2739	2265	1802	1350	908
	SCH. 160	0.531	0.465	3379	2890	2412	1946	1490
	XX-STG.	0.674	0.590	4394	3880	3379	2890	2412
5	STD.	0.258	0.226	1259	902	552	208	
	X-STG.	0.375	0.328	1856	1488	1127	773	425
	SCH. 120	0.500	0.438	2520	2140	1767	1401	1042
	SCH. 160	0.625	0.547	3201	2808	2422	2044	1673
	XX-STG.	0.750	0.656	3906	3499	3100	2709	2325
6	STD.	0.280	0.245	1143	845	551	262	
	X-STG.	0.432	0.378	1793	1485	1181	882	588
	SCH. 120	0.562	0.492	2368	2051	1738	1431	1128
	SCH. 160	0.718	0.628	3077	2748	2425	2106	1793
	XX-STG.	0.864	0.756	3767	3427	3093	2764	2440
8	SCH. 20	0.250	0.219	777	552	329	113	
	SCH. 30	0.277	0.242	861	634	411	190	
	STD.	0.322	0.282	1007	779	554	331	111
	SCH. 60	0.406	0.355	1276	1045	817	591	368
	X-STG.	0.500	0.438	1587	1353	1121	892	665
	SCH. 100	0.593	0.519	1896	1658	1422	1189	959
	SCH. 120	0.718	0.628	2319	2075	1835	1597	1362

MAXIMUM ALLOWABLE WORKING PRESSURE (cont)								
NOM. PIPE SIZE	DESIG-NATION	PIPE WALL THICKNESS		CORROSION ALLOWANCE IN.				
				0	1/16	1/8	3/16	1/4
		NOM.	MIN.	Max. Allow. Pressure Psig.				
8	SCH. 140	0.812	0.711	2647	2400	2155	1913	1675
	SCH. 160	0.906	0.793	2977	2725	2476	2231	1988
	XX-STG.	0.875	0.766	2868	2617	2370	2126	1885
10	SCH. 20	0.250	0.219	621	441	264	90	
	SCH. 30	0 307	0.269	766	585	406	228	50
	STD.	0.365	0.319	911	729	549	370	193
	X-STG.	0.500	0.438	1263	1078	894	712	532
	SCH. 80	0.593	0.519	1506	1318	1132	948	766
	SCH. 100	0.718	0.628	1838	1647	1458	1270	1085
	SCH. 120	0.843	0.738	2179	1984	1792	1601	1413
	SCH. 140	1.000	0.875	2611	2413	2216	1986	1829
	SCH. 160	1.125	0.984	2963	2760	2560	2362	2166
12	SCH. 20	0.250	0.219	522	371	222	76	
	SCH. 30	0.330	0.289	692	540	389	240	91
	STD.	0.375	0.328	787	635	483	333	184
	SCH. 40	0.406	0.355	854	701	549	398	248
	X-STG.	0.500	0.438	1059	904	751	598	486
	SCH. 60	0.562	0.492	1194	1038	883	730	578
	SCH. 80	0.687	0.601	1469	1311	1154	998	844
	SCH. 100	0.843	0.738	1820	1659	1500	1341	1184
	SCH. 120	1.000	0.875	2178	2014	1851	1690	1530
	SCH. 140	1.125	0.984	2467	2301	2136	1972	1810
	SCH. 160	1.312	1.148	2910	2740	2572	2404	2239
14	SCH. 10	0.250	0.219	475	338	202	69	
	SCH. 20	0.312	0.273	594	456	319	184	49
	STD.	0.375	0.328	716	577	440	303	167
	SCH. 40	0.438	0.383	839	699	561	423	287
	X-STG.	0.500	0.438	962	822	682	544	407
	SCH. 60	0.593	0.519	1146	1004	863	724	585
	SCH. 80	0.750	0.656	1460	1316	1173	1031	890
	SCH. 100	0.937	0.820	1843	1696	1550	1406	1262
	SCH. 120	1.093	0.956	2166	2017	1869	1722	1576
	SCH. 140	1.250	1.094	2500	2348	2198	2048	1900

MAXIMUM ALLOWABLE WORKING PRESSURE (cont.)

NOM. PIPE SIZE	DESIG-NATION	PIPE WALL THICKNESS NOM.	PIPE WALL THICKNESS MIN.	CORROSION ALLOWANCE IN. 0	1/16	1/8	3/16	1/4
				Max. Allow Pressure Psig.				
14	SCH. 160	1.406	1.230	2834	2680	2527	2375	2224
16	SCH. 10	0.250	0.219	415	295	166	57	
	SCH. 20	0.312	0.273	518	398	279	161	43
	SCH. 30. STD.	0.375	0.328	625	504	384	265	146
	SCH. 40X-STG.	0.500	0.438	839	717	596	475	355
	SCH. 60	0.656	0.574	1108	984	861	738	617
	SCH. 80	0.843	0.738	1436	1310	1185	1061	937
	SCH. 100	1.031	0.902	1771	1643	1515	1389	1263
	SCH. 120	1.218	1.066	2111	1980	1851	1722	1595
	SCH. 140	1.438	1.258	2517	2384	2251	2120	1990
	SCH. 160	1.593	1.394	2809	2674	2540	2407	2275
18	SCH. 10	0.250	0.219	368	262	157	54	
	SCH. 20	0.312	0.273	460	354	248	143	38
	STD.	0.375	0.328	554	447	341	235	130
	SCH. 30	0.438	0.383	649	541	434	328	222
	X-STG.	0.500	0.438	744	636	529	422	315
	SCH. 40	0.562	0.492	838	729	621	514	407
	SCH. 60	0.750	0.656	1129	1015	906	797	689
	SCH. 80	0.937	0.820	1418	1306	1195	1084	974
	SCH. 100	1.156	1.012	1766	1652	1539	1426	1314
	SCH. 120	1.375	1.203	2118	2002	1887	1772	1658
	SCH. 140	1.562	1.367	2425	2308	2190	2074	1958
	SCH. 160	1.781	1.558	2789	2669	2550	2432	2314
20	SCH. 10	0.250	0.219	331	231	141	48	
	SCH. 20 STD.	0.375	0.328	498	402	306	211	117
	SCH. 30 X-STG.	0.500	0.438	668	571	475	379	284
	SCH. 40	0.593	0.519	795	697	600	503	407
	SCH. 60	0.812	0.711	1097	998	900	802	704
	SCH. 80	1.031	0.902	1403	1303	1202	1103	1004
	SCH. 100	1.281	1.121	1760	1657	1555	1454	1353
	SCH. 120	1.500	1.313	2078	1974	1870	1767	1665
	SCH. 140	1.750	1.531	2446	2340	2234	2129	2025
	SCH. 160	1.968	1.722	2774	2666	2558	2452	2346

MAXIMUM ALLOWABLE WORKING PRESSURE (cont.)

NOM. PIPE SIZE	DESIG-NATION	PIPE WALL THICKNESS		CORROSION ALLOWANCE IN.				
				0	1/16	1/8	3/16	1/4
		NOM.	MIN.	Max. Allow. Pressure Psig.				
22		0.250	0.219	301	214	128	44	
		0.312	0.273	376	289	202	116	31
		0.375	0.328	452	365	278	192	106
		0.437	0.382	528	440	353	267	136
		0.500	0.438	606	519	431	344	258
		0.562	0.492	681	594	507	419	332
		0.625	0.547	761	672	584	496	409
		0.688	0.602	839	750	661	573	486
		0.750	0.656	916	827	738	649	561
24	SCH. 10	0.250	0.219	275	196	117	40	
	SCH. 20 STD.	0.375	0.328	414	334	255	176	97
	X-STG.	0.500	0.438	555	475	395	315	236
	SCH. 30	0.562	0.492	625	544	464	384	304
	SCH. 40	0.687	0.601	766	685	604	524	443
	SCH. 60	0.968	0.847	1089	1006	924	842	761
	SCH. 80	1.218	1.066	1381	1297	1214	1131	1048
	SCH. 100	1.531	1.340	1753	1667	1582	1498	1413
	SCH. 120	1.812	1.586	2093	2006	1919	1833	1747
	SCH. 140	2.062	1.804	2399	2311	2223	2135	2048
	SCH. 160	2.343	2.050	2750	2660	2571	2482	2393
26		0.250	0.219	254	181	108	37	
		0.312	0.273	317	244	171	98	26
		0.375	0.328	382	308	235	162	90
		0.437	0.382	446	372	298	225	152
		0.500	0.438	512	438	364	291	218
		0.562	0.492	576	502	428	354	281
		0.625	0.547	641	567	493	419	345
		0.688	0.602	707	633	558	484	410
		0.750	0.656	772	697	622	548	474
30		0.312	0.273	275	211	148	85	23
		0.375	0.328	330	267	204	141	78
		0.500	0.438	443	379	315	252	188

NOTE: IF THE STRESS VALUE OF PIPE LESS THAN 15,000 PSIG. DUE TO HIGHER TEMPERATURE, MULTIPLY THE MAX. ALLOWABLE PRESSURE GIVEN IN THE TABLES BY THE FACTORS IN THIS TABLE:

		TEMPERATURE NOT EXCEEDING DEGREE OF							
		650	700	750	800	850	900	950	1000
A 53 B	stress values psig	15000	14350	12950	10800	8650	6500	–	–
A 106 B		15000	14350	12950	10800	8650	6500	4500	2500
FACTOR		1.000	0.9566	0.8633	0.7200	0.5766	0.4333	0.3000	0.1666

Example:

The Maximum Allowance Pressure for 6" x Stg. Pipe With a Corrosion Allowance of 1/8" From Table = 1181 psi. - at Temperature 800^{o}F

The Max. Allow. Press. 1181 x 0.72 = 850 psig.

Example to find max. allow. pressure for any stress values:

The Max. Allow. Press. 1181 Psig. From Tables

The Stress Value 13000 psi.

For This Pipe The Max. Allow. Pressure $\frac{13000}{15000}$ x 1181 = 1023 psi.

NOZZLE NECK THICKNESS EXAMPLES			#1	#2	#3
			THICKNESS, in.		
CORROSION			0	0	0.0625
1	Required for Loadings (UG-22)		0.250*	0.018	0.3125
2	Vessel Wall	J.E. 0.85	0.250	0.250	0.3125
		J.E. 1.00	0.213	0.213	0.2660
3	6 in. Std. Pipe	NOM.	0.280	0.280	0.280
		MIN.	0.245	0.245	0.245
4	Minimum for Shells & Heads UG-16 (b)		0.0625	0.0625	0.0625
	In Compressed Air, Steam & Water Service UG-16 (b)		0.0938	0.0938*	0.0938
	For Unfired Steam Boilers UG-16 (b)		0.2500	0.2500	0.2500
*The minimum required thickness for nozzle neck					0.0625 CA 0.3125*

REQUIRED WALL THICKNESS FOR PIPES UNDER INTERNAL PRESSURE

The required wall thickness for pipes, tabulated on the following pages, has been computed with the following formula:

$$t=\frac{PR}{SE-0.6P}$$, where

t = the required minimum wall thickness of pipe, in.
P = internal pressure, psig.
S = 15,000 psig. the stress value of the most commonly used materials for pipe. A 53 B and A 106 B @ temperature –20 to 650°F.
E = Joint efficiency of seamless pipe
R = inside radius of the pipe, in.

For the inside diameter of the pipe round figures are shown. With interpolation the required thickness can be determined with satisfactory accuracy.

The thicknesses given in the tables do not include allowance for corrosion.

For the determination of the required pipe wall thickness in piping systems the various piping codes shall be applied.

Selecting pipe, the 12.5% tolerance in wall thickness shall be taken into consideration. The minimum thickness of the pipe wall equals the nominal thickness times .875.

REQUIRED PIPE WALL THICKNESS FOR INTERNAL PRESSURE

I.S. DIAM.	PRESSURE PSIG.									
	50	100	150	200	250	300	350	400	450	500
1	0.002	0.003	0.005	0.007	0.008	0.010	0.012	0.014	0.015	0.017
2	0.003	0.007	0.010	0.013	0.017	0.020	0.024	0.027	0.031	0.034
3	0.005	0.010	0.015	0.020	0.025	0.030	0.035	0.041	0.046	0.051
4	0.007	0.013	0.020	0.027	0.034	0.040	0.048	0.054	0.061	0.068
5	0.008	0.017	0.025	0.034	0.042	0.051	0.059	0.068	0.076	0.085
6	0.010	0.020	0.030	0.040	0.051	0.061	0.071	0.081	0.092	0.102
7	0.012	0.023	0.035	0.047	0.059	0.071	0.083	0.095	0.107	0.119
8	0.013	0.027	0.040	0.054	0.067	0.081	0.095	0.108	0.122	0.136
9	0.015	0.030	0.045	0.060	0.076	0.091	0.106	0.122	0.137	0.153
10	0.017	0.033	0.050	0.067	0.084	0.101	0.118	0.136	0.153	0.170
11	0.018	0.037	0.055	0.074	0.093	0.111	0.130	0.149	0.168	0.187
12	0.020	0.040	0.060	0.081	0.101	0.121	0.142	0.163	0.183	0.204
13	0.022	0.044	0.065	0.087	0.109	0.132	0.154	0.176	0.198	0.221
14	0.023	0.047	0.070	0.094	0.118	0.142	0.166	0.190	0.214	0.238
15	0.025	0.050	0.075	0.101	0.126	0.152	0.177	0.203	0.229	0.255
16	0.027	0.054	0.080	0.108	0.135	0.162	0.189	0.217	0.244	0.272
17	0.028	0.057	0.086	0.114	0.143	0.172	0.201	0.230	0.260	0.289
18	0.030	0.060	0.091	0.121	0.152	0.182	0.213	0.244	0.275	0.306
19	0.032	0.064	0.096	0.128	0.160	0.192	0.225	0.257	0.290	0.323
20	0.033	0.067	0.101	0.134	0.168	0.202	0.237	0.271	0.305	0.340
21	0.035	0.070	0.107	0.141	0.177	0.213	0.248	0.285	0.321	0.357
22	0.037	0.074	0.111	0.148	0.185	0.223	0.260	0.298	0.336	0.374
23	0.038	0.077	0.116	0.155	0.194	0.233	0.272	0.312	0.351	0.391
24	0.040	0.080	0.121	0.161	0.202	0.243	0.284	0.325	0.367	0.408
25	0.042	0.084	0.126	0.168	0.210	0.253	0.296	0.339	0.382	0.425
26	0.044	0.087	0.131	0.175	0.219	0.263	0.308	0.352	0.397	0.442
27	0.045	0.090	0.136	0.181	0.227	0.273	0.319	0.366	0.412	0.459
28	0.047	0.094	0.141	0.188	0.236	0.283	0.331	0.379	0.428	0.476
29	0.048	0.097	0.146	0.195	0.244	0.294	0.343	0.393	0.443	0.493
30	0.050	0.100	0.151	0.202	0.253	0.304	0.355	0.407	0.458	0.510

REQUIRED PIPE WALL THICKNESS
FOR INTERNAL PRESSURE (cont)

I.S. DIAM.	PRESSURE PSIG.									
	550	600	650	700	750	800	850	900	950	1000
1	0.019	0.020	0.022	0.024	0.026	0.028	0.029	0.031	0.033	0.035
2	0.037	0.041	0.044	0.048	0.052	0.055	0.059	0.062	0.066	0.069
3	0.056	0.062	0.067	0.072	0.077	0.083	0.088	0.093	0.099	0.104
4	0.075	0.082	0.089	0.096	0.103	0.110	0.117	0.124	0.132	0.139
5	0.094	0.102	0.111	0.120	0.129	0.138	0.147	0.156	0.165	0.174
6	0.112	0.123	0.133	0.144	0.155	0.165	0.176	0.187	0.198	0.208
7	0.131	0.143	0.156	0.168	0.180	0.193	0.205	0.218	0.230	0.243
8	0.150	0.164	0.178	0.192	0.206	0.220	0.235	0.249	0.263	0.278
9	0.169	0.184	0.200	0.216	0.232	0.248	0.264	0.280	0.296	0.312
10	0.187	0.205	0.222	0.240	0.258	0.275	0.293	0.311	0.329	0.347
11	0.206	0.225	0.245	0.264	0.284	0.303	0.323	0.342	0.362	0.382
12	0.225	0.246	0.267	0.268	0.309	0.331	0.352	0.373	0.393	0.417
13	0.244	0.266	0.289	0.312	0.335	0.358	0.381	0.405	0.428	0.451
14	0.262	0.287	0.311	0.336	0.361	0.386	0.411	0.436	0.461	0.486
15	0.281	0.307	0.334	0.360	0.387	0.413	0.440	0.467	0.494	0.521
16	0.300	0.328	0.356	0.384	0.412	0.441	0.469	0.498	0.527	0.556
17	0.319	0.348	0.378	0.408	0.438	0.468	0.499	0.529	0.560	0.590
18	0.337	0.369	0.400	0.432	0.464	0.496	0.528	0.560	0.593	0.625
19	0.356	0.389	0.423	0.456	0.490	0.523	0.557	0.591	0.625	0.660
20	0.375	0.410	0.445	0.480	0.515	0.551	0.587	0.622	0.658	0.694
21	0.394	0.430	0.467	0.504	0.541	0.579	0.616	0.654	0.692	0.729
22	0.412	0.451	0.489	0.528	0.567	0.606	0.645	0.685	0.724	0.764
23	0.431	0.471	0.512	0.552	0.593	0.634	0.675	0.716	0.757	0.799
24	0.450	0.492	0.534	0.576	0.619	0.661	0.704	0.747	0.790	0.833
25	0.469	0.512	0.556	0.600	0.645	0.689	0.733	0.778	0.823	0.868
26	0.487	0.533	0.578	0.624	0.670	0.716	0.763	0.809	0.856	0.903
27	0.506	0.553	0.601	0.648	0.696	0.744	0.792	0.840	0.889	0.937
28	0.525	0.574	0.623	0.672	0.722	0.771	0.821	0.871	0.922	0.972
29	0.544	0.594	0.645	0.696	0.747	0.779	0.851	0.902	0.955	1.007
30	0.562	0.615	0.667	0.720	0.773	0.826	0.880	0.934	0.988	1.042

REQUIRED PIPE WALL THICKNESS FOR INTERNAL PRESSURE (cont.)

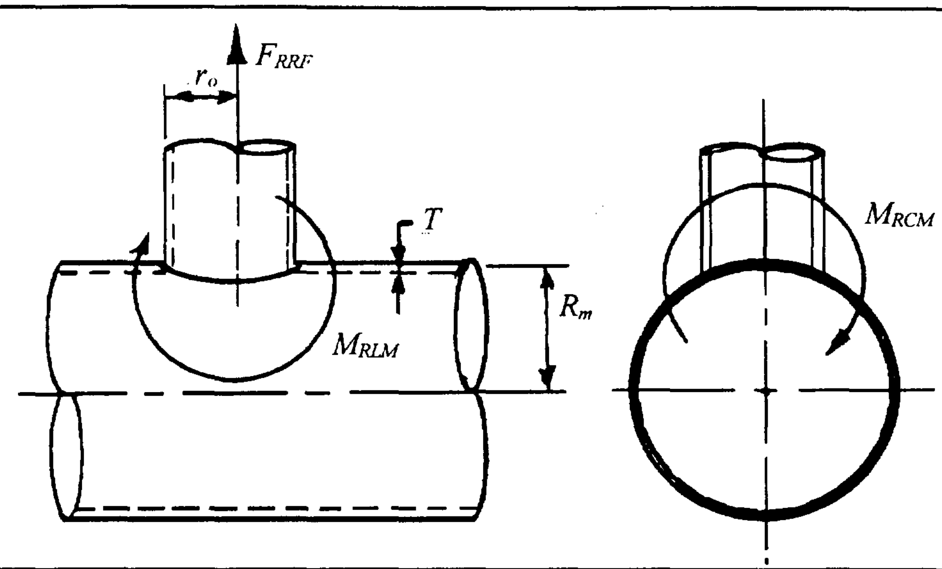
I.S. DIAM.	PRESSURE PSIG.									
	1100	1200	1300	1400	1500	1600	1700	1800	1900	2000
1	0.038	0.042	0.046	0.049	0.053	0.057	0.061	0.065	0.069	0.072
2	0.077	0.084	0.091	0.099	0.106	0.114	0.122	0.129	0.137	0.145
3	0.115	0.126	0.137	0.148	0.160	0.171	0.182	0.194	0.206	0.217
4	0.153	0.168	0.183	0.198	0.213	0.228	0.243	0.259	0.274	0.290
5	0.192	0.210	0.229	0.247	0.266	0.285	0.304	0.323	0.343	0.362
6	0.230	0.252	0.274	0.297	0.319	0.342	0.365	0.388	0.411	0.435
7	0.268	0.294	0.320	0.346	0.372	0.399	0.426	0.453	0.480	0.507
8	0.307	0.336	0.366	0.395	0.426	0.456	0.486	0.517	0.548	0.580
9	0.345	0.378	0.411	0.445	0.479	0.513	0.547	0.582	0.617	0.652
10	0.384	0.420	0.457	0.494	0.532	0.570	0.608	0.647	0.685	0.725
11	0.422	0.462	0.503	0.544	0.585	0.627	0.669	0.711	0.784	0.797
12	0.460	0.504	0.549	0.593	0.638	0.684	0.730	0.776	0.823	0.870
13	0.499	0.546	0.594	0.643	0.691	0.741	0.790	0.841	0.891	0.942
14	0.537	0.588	0.640	0.692	0.745	0.798	0.851	0.905	0.960	1.014
15	0.575	0.630	0.686	0.742	0.798	0.855	0.912	0.970	1.028	1.087
16	0.614	0.672	0.732	0.791	0.851	0.912	0.973	1.034	1.097	1.159
17	0.652	0.714	0.777	0.840	0.904	0.969	1.034	1.099	1.165	1.232
18	0.690	0.756	0.823	0.890	0.958	1.026	1.094	1.164	1.234	1.305
19	0.729	0.798	0.868	0.939	1.011	1.083	1.155	1.228	1.302	1.377
20	0.768	0.840	0.914	0.989	1.064	1.140	1.216	1.293	1.371	1.449
21	0.805	0.882	0.960	1.038	1.117	1.197	1.277	1.358	1.439	1.522
22	0.844	0.924	1.006	1.088	1.170	1.254	1.338	1.422	1.508	1.594
23	0.882	0.966	1.051	1.137	1.223	1.311	1.398	1.487	1.576	1.667
24	0.920	1.008	1.097	1.186	1.277	1.368	1.459	1.552	1.645	1.739
25	0.959	1.050	1.143	1.236	1.330	1.425	1.520	1.616	1.714	1.812
26	0.997	1.092	1.188	1.286	1.383	1.481	1.581	1.681	1.782	1.884
27	1.036	1.134	1.234	1.334	1.436	1.538	1.642	1.746	1.851	1.957
28	1.074	1.176	1.280	1.384	1.498	1.595	1.702	1.810	1.919	2.029
29	1.112	1.218	1.326	1.434	1.543	1.652	1.763	1.875	1.988	2.101
30	1.151	1.260	1.371	1.483	1.596	1.709	1.824	1.940	2.056	2.174

REQUIRED PIPE WALL THICKNESS FOR INTERNAL PRESSURE (cont.)

I.S. DIAM.	PRESSURE PSIG.									
	2100	2200	2300	2400	2500	2600	2700	2800	2900	3000
1	0.076	0.080	0.084	0.088	0.093	0.097	0.101	0.105	0.109	0.114
2	0.153	0.161	0.169	0.177	0.185	0.193	0.202	0.210	0.219	0.227
3	0.229	0.241	0.253	0.265	0.278	0.290	0.303	0.315	0.328	0.341
4	0.306	0.322	0.338	0.354	0.370	0.387	0.404	0.420	0.437	0.455
5	0.382	0.402	0.422	0.442	0.463	0.484	0.504	0.526	0.547	0.568
6	0.459	0.482	0.507	0.531	0.556	0.580	0.605	0.631	0.656	0.682
7	0.535	0.563	0.591	0.619	0.648	0.677	0.706	0.736	0.765	0.795
8	0.611	0.643	0.675	0.708	0.741	0.774	0.807	0.841	0.875	0.909
9	0.688	0.724	0.760	0.796	0.833	0.871	0.908	0.946	0.984	1.023
10	0.764	0.804	0.844	0.885	0.926	0.967	1.009	1.051	1.093	1.136
11	0.841	0.884	0.929	0.973	1.019	1.064	1.110	1.156	1.203	1.250
12	0.917	0.965	1.013	1.062	1.111	1.161	1.211	1.261	1.312	1.364
13	0.993	1.045	1.098	1.150	1.204	1.257	1.312	1.366	1.422	1.477
14	1.070	1.126	1.182	1.239	1.296	1.354	1.413	1.471	1.531	1.591
15	1.146	1.206	1.267	1.327	1.389	1.451	1.513	1.577	1.640	1.705
16	1.223	1.287	1.351	1.416	1.481	1.548	1.614	1.682	1.750	1.818
17	1.299	1.367	1.435	1.504	1.574	1.644	1.715	1.787	1.859	1.932
18	1.376	1.447	1.520	1.593	1.667	1.741	1.816	1.892	1.968	2.045
19	1.452	1.528	1.604	1.681	1.759	1.838	1.917	1.997	2.078	2.159
20	1.528	1.608	1.689	1.770	1.852	1.935	2.018	2.102	2.187	2.273
21	1.605	1.689	1.773	1.858	1.944	2.031	2.119	2.207	2.296	2.386
22	1.681	1.769	1.858	1.947	2.037	2.128	2.220	2.312	2.406	2.500
23	1.758	1.849	1.942	2.036	2.130	2.225	2.321	2.417	2.515	2.614
24	1.834	1.930	2.026	2.124	2.222	2.321	2.422	2.523	2.624	2.727
25	1.910	2.010	2.111	2.212	2.315	2.418	2.522	2.628	2.734	2.841
26	1.987	2.090	2.195	2.301	2.407	2.515	2.623	2.733	2.843	2.955
27	2.063	2.171	2.280	2.389	2.450	2.612	2.724	2.838	2.952	3.068
28	2.140	2.251	2.364	2.478	2.593	2.708	2.825	2.943	3.062	3.182
29	2.216	2.332	2.449	2.566	2.685	2.805	2.926	3.048	3.171	3.295
30	2.293	2.412	2.533	2.655	2.778	2.902	3.027	3.153	3.281	3.409

NOZZLE EXTERNAL FORCES AND MOMENTS IN CYLINDRICAL VESSELS

Piping by the adjoining nozzles exert local stress in the vessel. The method, below, to determine the nozzle loads is based in part on the Bulletin 107 of Welding Research Council and represents a simplification of it. The vessels are not intended to serve as anchor points for the piping. To avoid excessive loading in the vessel, the piping shall be adequately supported.



External Forces & Moments

To calculate the maximum force and moment, first evaluate β and γ. Then determine α, Σ, *and* Δ from Figures 1, 2 and 3, for the specified β and γ, substitute into the equations below, and calculate F_{RRF}, M_{RCM} and M_{RLM}.

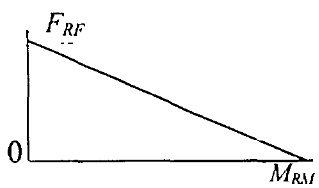
$$\beta = .875\left(\frac{r_o}{R_m}\right) \qquad \gamma = \frac{R_m}{T}$$

Determine α, Σ and Δ from Figures 1, 2 and 3.
Calculate Pressure Stress (σ).

$$\sigma = \left(\frac{2P}{T}\right)\left(R_m - \frac{T}{2}\right)$$

If σ is greater than S_a, then use S_a as the stress due to design pressure.

$$F_{RRF} = \frac{R_m^2}{\sigma}(S_\gamma - \sigma) \qquad M_{RCM} = \frac{R_m^2\, r_o\, S_\gamma}{\Sigma} \qquad M_{RLM} = \frac{R_m^2\, r_o}{\Delta}(S_\gamma - \sigma)$$



Plot the value of F_{RRF} as F_{RF} and the smaller of M_{RCM} and M_{RLM} as M_{RM}. The allowable nozzle loads are bounded by the area of F_{RF}, 0, M_{RM}.

EXAMPLE: Determine Resultant Force and Moment

R_m = 37.5	T = .75"	S_γ = 31,500 psi @ 460°
r_o = 15"	P = 150 psi	S_a = 17,500 psi

$$\beta = .875\left(\frac{r_o}{R_m}\right) = .875\left(\frac{15}{37.5}\right) = .35 \qquad \gamma = \left(\frac{R_m}{T}\right) = \frac{37.5}{.75} = 50$$

From Figure 1, α = 440 From Figure 2, Σ = 1,070 From Figure 3, Δ = 340

NOZZLE EXTERNAL FORCES AND MOMENTS IN CYLINDRICAL VESSELS *(continued)*

Calculate Pressure Stress

$$\sigma = \frac{2P}{T}\left(R_m - \frac{T}{2}\right) = \frac{2(150)}{.75}\left(37.5 - \frac{.75}{2}\right) = 14{,}850 \text{ psi} < S_a = 17{,}500 \text{ psi}$$

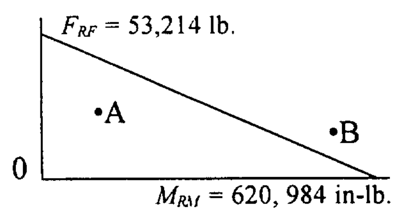
Use $\sigma = 14{,}850$ in the equations for calculating F_{RRF} and M_{RLM}

Calculate Allowable Forces and Moments

$$F_{RRF} = \frac{R_m^2}{\alpha}(S_Y - \sigma) = \frac{(37.5)^2}{440}(31{,}500—14{,}850) = 53{,}214 \text{ lb.}$$

$$M_{RCM} = \frac{R_m^2\, r_o\, S_Y}{\Sigma} = \frac{37.5^2\ (15)\ (31{,}500)}{1{,}070} = 620{,}984 \text{ in-lb.}$$

$$M_{RLM} = \frac{R_m^2\, r_o}{\Delta}(S_Y — \sigma) = \frac{(37.5)^2\,(15)}{340} = (31{,}500—14{,}850—1{,}032{,}973 \text{ in-lb.}$$



Plot for the value of F_{RRF} as F_{RF} and the smaller of M_{RCM} and M_{RLM} as M_{RM}. The allowable nozzle loads are bounded by the area of F_{RF}, *O*, M_{RM}.

Therefore, a nozzle reaction of $F = 20{,}000$ lbs. and $M = 100{,}000$ in. lbs. would be allowable (point *A*) but a nozzle reaction of $F = 5{,}000$ lbs. and $M = 620{,}000$* in. lbs. would not be allowable (point *B*).

*Note: Use absolute values in the graph.

NOTATION:

- P = Design Pressure, pounds per sq. in.
- r_0 = Nozzle Outside Radius, inches
- R_m = Mean Radius of Shell, inches
- T = Shell Thickness, inches
- S_y = Yield Strength of Material at Design Temperature, pounds per square inch
- σ = Stress Due to Design Pressure, pounds per square inch
- S_a = Stress Value of Shell Material, pounds per square inch.
- β = Dimensionless Numbers
- γ = Dimensionless Numbers
- α = Dimensionless Numbers
- Σ = Dimensionless Numbers
- Δ = Dimensionless Numbers
- F_{RRF} = Maximum Resultant Radial Force, pounds*
- M_{RCM} = Maximum Resultant Circumferential Momentm , inch-pounds*
- M_{RLM} = Maximum Resultant Longitudinal Moment, inch-pounds*
- F_{RF} = Maximum Resultant Force, pounds*
- F_{RM} = Maximum Resultant Moment, inch-pounds*

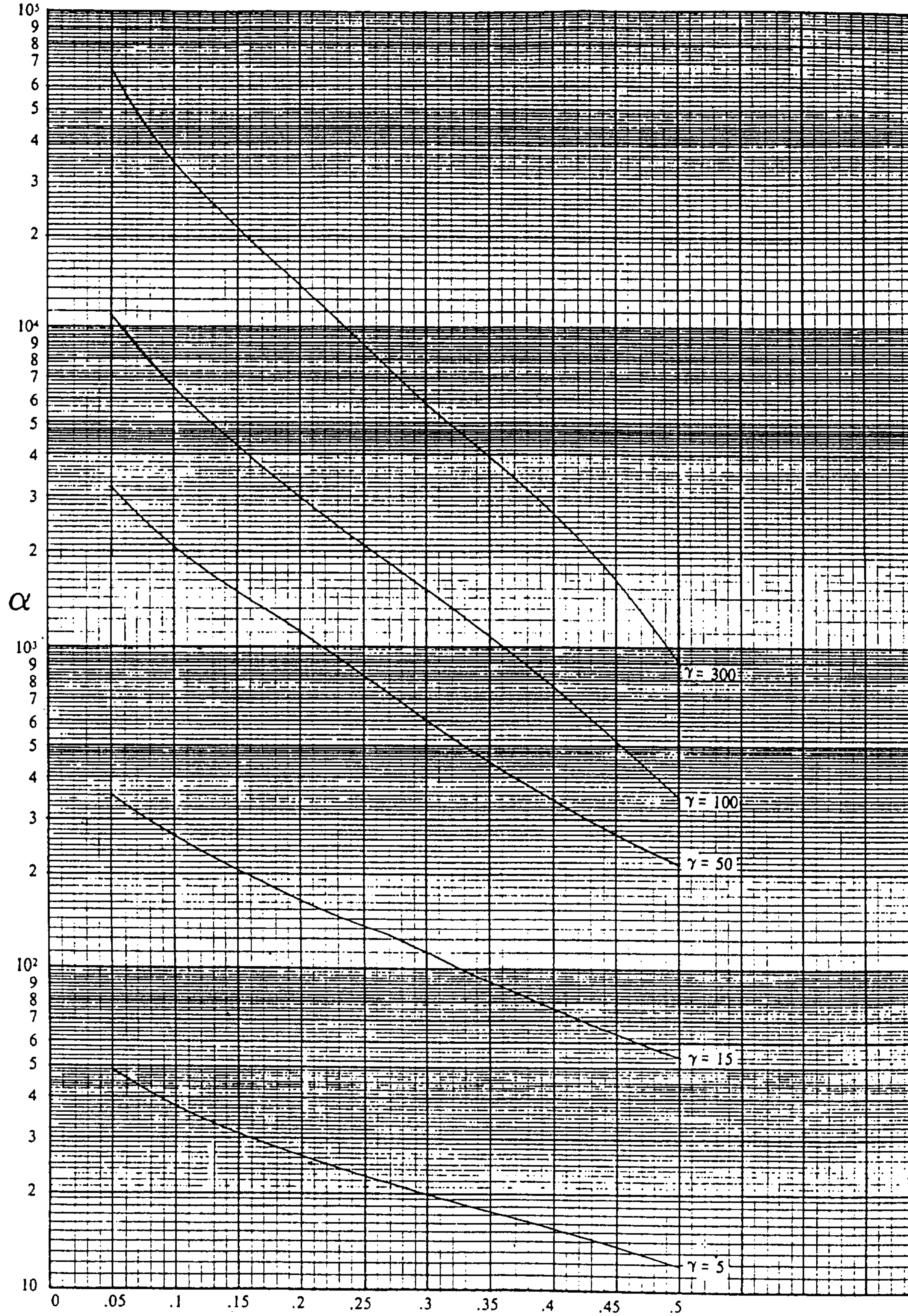
*Use absolute values.

REFERENCES:

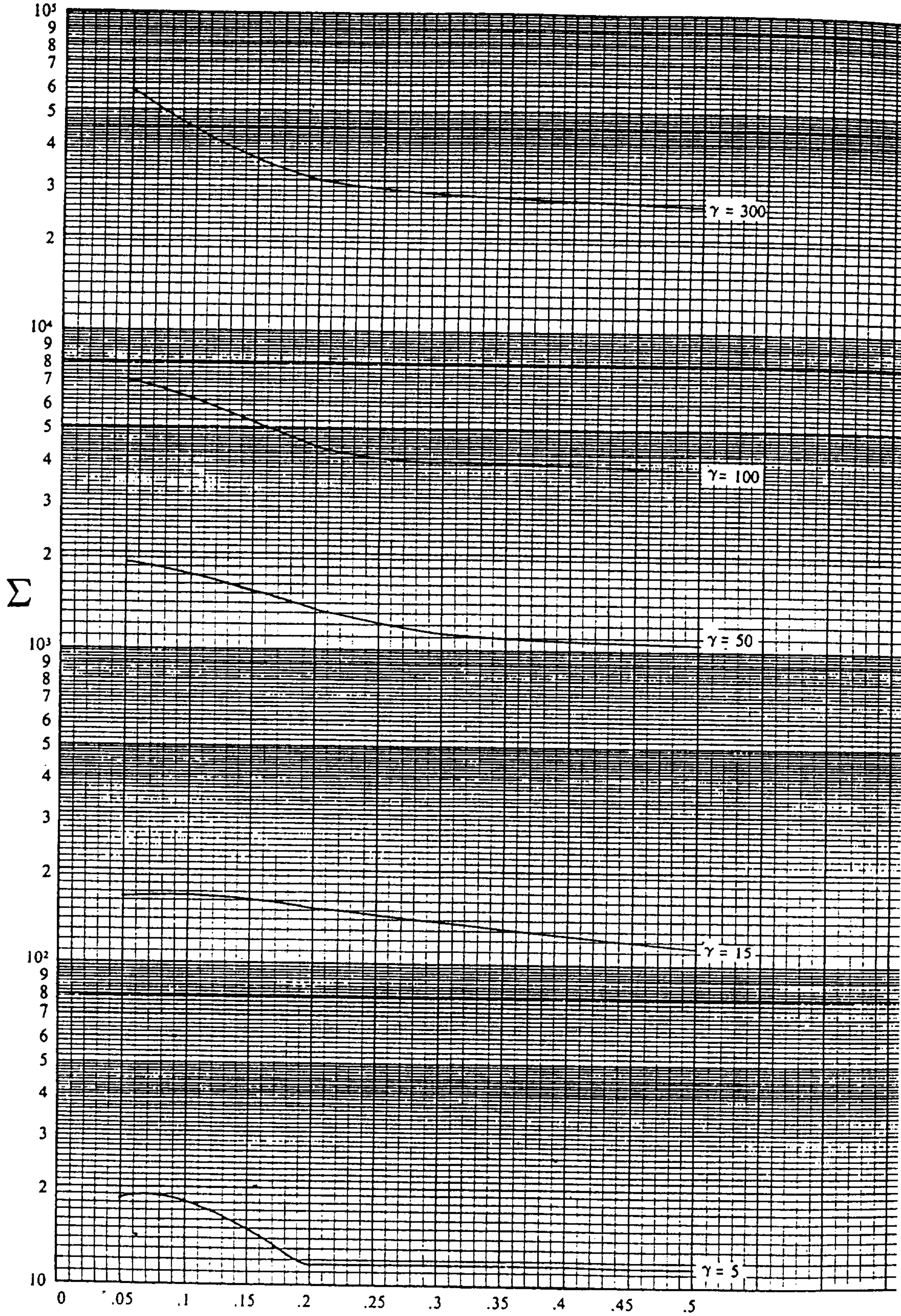
Local Stresses in Spherical and Cylindrical Shells due to External Loadings, K. R. Wichman, A. G. Hopper and J. L. Mershon — Welding Research Council. Bulletin 107/August 1965 — Revised Printing — December 1968.

Standards for Closed Feedwater Heaters, Heat Exchange Institute, Inc., 1969.

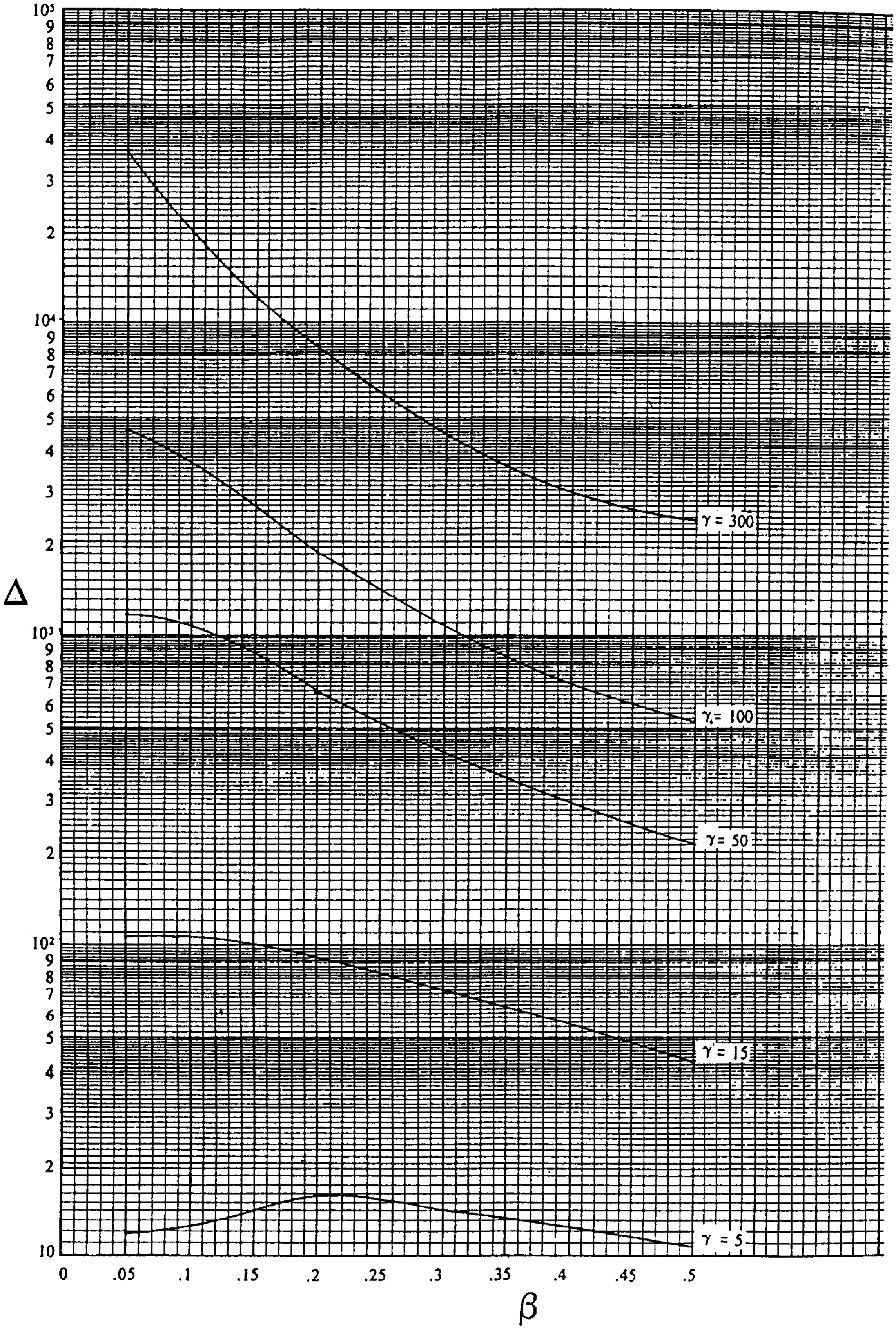
NOZZLE LOADS
Fig. 1



NOZZLE LOADS
Fig 2



NOZZLE LOADS
Fig. 3



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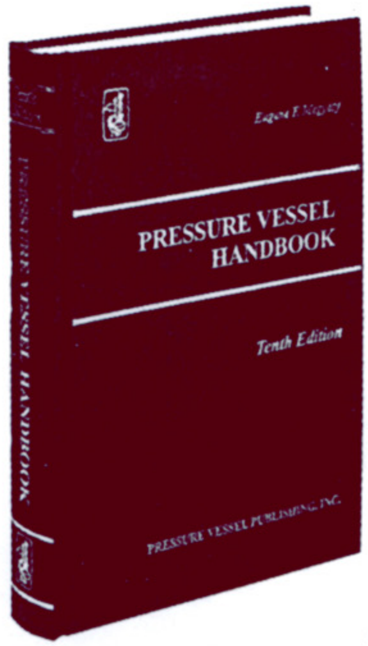

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REINFORCEMENT AT THE JUNTION OF CONE TO CYLINDER UNDER INTERNAL PRESSURE

At the junction of cone or conical section to cylinder (Fig. C and D) due to bending and shear, discontinuity stresses are induced which are with reinforcement to be compensated.

DESIGN PROCEDURE (The half apex angle $\alpha \leq 30$ deg.)

1. Determine $P/S_s E_1$ and read the value of Δ from tables A and B.
2. Determine factor y, For reinforcing ring on shell, $y = S_s E_s$
   For reinforcing ring on cone, $y / S_c E_c$

TABLE A - VALUES OF Δ FOR JUNCTIONS AT THE LARGE END									
$P/S_s E_1$	0.001	0.002	0.003	0.004	0.005	0.006	0.007	0.008	0.009*
Δ, deg.	11	15	18	21	23	25	27	28.5	30
TABLE B - VALUES OF Δ FOR JUNCTIONS AT THE LARGE END									
$P/S_s E_1$		0.002	0.005	0.010	0.020	0.040	0.080	0.100	0.125*
Δ, deg.		4	6	9	12.5	17.5	24	27	30

* $\Delta = 30$ deg. for greater value of $P/S_s E_1$

When the value of Δ is less than α, reinforcement shall be provided.

3. Determine factor $k = y / S_r E_r$ (Use minimum 1.0 for k in formula).
4. Design size and location of reinforcing ring (see next page).

NOTATION

E = with subscripts s, c or r modulus of elasticity of shell, cone or reinforcing ring material respectively, psi.
See charts beginning on page 43 for modulus of elasticity.

E = with subscripts 1or 2 efficiency of welded joints in shell or cone respectively.
For compression E=1.0 for butt welds.

f_1 = axial load at large end due to wind, dead load, etc. excluding pressure, lb/in.

f_2 = axial load at small end due to wind, dead load, etc. excluding pressure, lb/in.

P = Design pressure, psi

Q_l = algebraic sum of $PR_L/2$ and f_1 lb/in.

Q_s = algebraic sum of $PR_s/2$ and f_2 lb/in.

R_L = inside radius of large cylinder at large end of cone, in.

R_s = inside radius of small cylinder at small end of cone, in.

S = with subscripts s, c or r allowable stress of shell, cone or reinforcing material, psi.

t = minimum required thickness of cylinder at the junction, in.

t_s = actual thickness of cylinder at the junction, in.

t_r = minimum required thickness of cone at the junction, in.

t_c = actual thickness of cone at the junction, in.

α = half apex angle of cone or conical section, deg.

Δ = angle from table A or B, deg.

y = factor: $S_s E_s$ or $S_c E_c$

REINFORCEMENT AT THE JUNCTION OF CONE TO CYLINDER

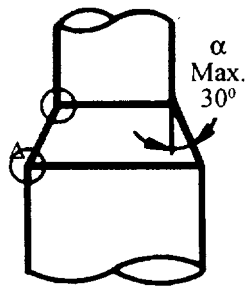


FIG. C

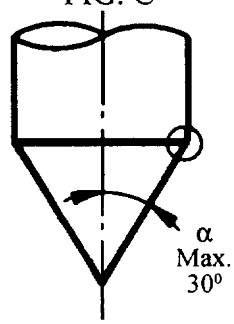


FIG. D

FORMULAS

JUNCTION AT THE LARGE END

Required area of reinforcement, A sq. in. when tension governs (see notes)

$$A_{rL} = \frac{kQ_L R_L}{S_s E_l}\left(1 - \frac{\Delta}{\alpha}\right)\tan\alpha$$

Area of excess metal for reinforcement, sq. in.

$$A_{eL} = (t_s - t)\sqrt{R_L t_s} + (t_c - t_r)\sqrt{R_L t_c / \cos\alpha}$$

The distance from the junction within which the additional reinforcement shall be situated, in.

$$\sqrt{R_L t_s}$$

The distance from the junction within which the centroid of the reinforcement shall be situated, in.

$$0.25 \times \sqrt{R_L t_s}$$

JUNCTION AT THE SMALL END

Required area of reinforcement A sq. in. when tension governs (see notes)

$$A_{rs} = \frac{kQ_s R_s}{S_s E_l}\left(1 \frac{\Delta}{\alpha}\right)\tan\alpha$$

Area of excess metal available for reinforcement A_e, sq. in.

$$A_{es} = (t_s / t)\cos(\alpha - \Delta)(t_s - t)\sqrt{R_s t_s} + (t_c / t_r) \times \cos(\alpha - \Delta)(t_c - t_r)\sqrt{R_s t_c / \cos\alpha}$$

The distance from the junction within which the centroid of the reinforcement shall be situated, in.

$$\sqrt{R_s t_s}$$

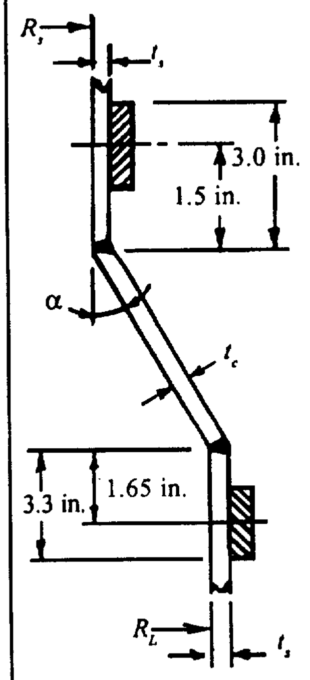
The distance from the junction within which the centroid of the reinforcement shall be situated, in.

$$0.25 \times \sqrt{R_s t_s}$$

NOTES: When at the junction compressive loads f_l or f_2 exceed the tensional loads determined by $PR_l/2$ or $PR_s/2$ respectively, the design shall be in accordance with U2 (g): ("as safe as those provided by the rules of the Code, Section VIII, Division 1.")

When the reducers made out of two or more conical sections of different apex angles without knuckle, and when the half apex angle, α is greater than 30 deg., the design may be based on special analysis. (Code 1-5 (f) & (g).

REINFORCEMENT AT THE JUNCTION OF CONE TO CYLINDER EXAMPLE



DESIGN DATA:

α	= 30 deg. half apex angle of cone.
$E_sE_cE_r$	= 30 x 10^6, modulus of elasticity, psi.
E_1E_2	= 1.0, joint efficiency in shell and cone
E_3	= 0.55, joint efficiency in reinforcing ring
f_1	= 800 lb/in, axial load at large end
f_2	= 952 lb/in, axial load at small end
P	= 50 psi., internal design pressure
R_L	= 100 in., inside radius of large cylinder
R_s	= 84 in., inside radius of small cylinder
S_s	= 13,800 psi., allowable stress of shell material
S_c	= 13,800 psi., allowable stress of cone material
S_r	= 14,500 psi., allowable stress of ring material
t	= 0.429 in., required min. thickness for large cylinder
t	= 0.360 in., required min. thickness for small cylinder
t_c	= 0.500 in. actual thickness of cone.
t_s	= 0.4375 in., actual thickness of large cylinder
t_s	= 0.375 in., actual thickness of small cylinder
t_{rs}	= 0.41 in., required thickness of cone at small cylinder
t_{rL}	= 0.49 in., required thickness of cone at large cylinder

Using the same material for shell and cone.

1. $P/S_sE_1 = \dfrac{50}{13{,}800 \times 1} = 0.0036$ from table A $\quad \Delta = 19.8$
   Since Δ is less than α, reinforcements is required.

2. Using reinforcement ring on the shell
   $y = S_sE_s = 13{,}800 \times 30 \times 10^6$

3. Factor $k = y/S_rE_r = 13{,}800 \times 30 \times 10^6 / 14{,}500 \times 30 \times 10^6 = 0.95$
   Use $k = 1$

4. $Q_L = PR_L/2\, f_1$, lb/in. $= \dfrac{50 \times 100}{2} + 800 = 3{,}300$ lb/in.

5. The required cross-sectional area of compression ring:

   $$A_{rL} = \frac{kQ_LR_L}{S_sE_1}\left(1 - \frac{\Delta}{\alpha}\right)\tan a = \frac{1 \times 3{,}300 \times 100}{13{,}800 \times 1}\left(1 - \frac{19.8}{30}\right)\tan 30^0 = 4.69 \text{ sq in.}$$

   The area of excess in shell available for reinforcement:

   $$A_{eL} = (t_s - t)\sqrt{R_Lt_s} + (t_c - t_r)\sqrt{R_Lt_c}/\cos\alpha$$
   $$= (0.4375 - 0.429) \times \sqrt{100 \times 0.4375} + (0.5 - 0.49) \times \sqrt{100 \times 0.5}/\cos 30^0$$
   $$= 0.132 \text{ sq. in.}$$

   $A_{rL} - A_{eL} = 4.69 - 0.132 = 4.55$ sq. in. the required cross sectional area of compression ring

   Using 1 in. thick bar, the width of ring: 4.55/1 = 4.55 in.

   Location of compression ring:
   Maximum distance from the junction = $\sqrt{R_Lt_s} = \sqrt{100 \times 0.4375} = 6.60$ in.

   Maximum distance of centroid from the junction = $0.25\sqrt{R_Lt_s} =$
   $0.25\sqrt{100 \times 0.4375} = 1.65$ in.

REINFORCEMENT
AT THE JUNCTION OF CONE TO CYLINDER
EXAMPLE *(continued)*

JUNCTION AT SMALL CYLINDER

1. $P/S_s\,E_1 = 0.0036$; from table B $\Delta = 5^0$
   Since Δ is less than α, reinforcement is required.
2. Factor $\gamma = S_s\,E_s = 13{,}800 \times 30 \times 10^6$
3. Factor $k = 1$
4. $Q_s = PR_s/2 + f_2$ lb./in $= \frac{50 \times 84}{2} + 952 = 3{,}052$ lb./in.
5. The required cross-sectional area of compression ring:
   $A_{rs} = \frac{kQ_sR_s}{S_sE_1}\left(1 - \frac{\Delta}{\alpha}\right)\tan\alpha = \frac{1 \times 3{,}052 \times 84}{13{,}800 \times 1}\left(1 - \frac{5}{30}\right)\tan 30^0 = 8.94$ sq. in.

   The area of excess in shell available for reinforcement:

   $A_{es} = (t_s/t)\cos(\alpha - \Delta)(t_s - t)\sqrt{R_st_s} + (t_c/t_r)$

   $\times \cos(\alpha - \Delta)(t_c - t_r)\sqrt{R_st_c/\cos\alpha}$

   $(0.395/0.36) \times \cos(30\text{-}5) \times (0.375 - 0.36) \times \sqrt{84 \times .0375}$

   $+ (0.5/0.41)\cos(30\text{-}5) \times (0.5\text{-}0.41) \times \sqrt{84 \times 0.5/\cos 30^0} = 0.77$ sq. in.

$A_{rs} - A_{es} = 8.94\text{-}0.77 = 8.17$ sq. in., the required cross sectional area of compression ring.

Using 1½ thick bar, the required width of the bar: 8.17/1.5 = 5.45 in.

Location of the compression ring:

Maximum distance from the junction: $\sqrt{R_st_s} = \sqrt{84 \times 0.375} = 5.6$ in.

Maximum distance of centroid from the junction:
$0.25\ \sqrt{R_st_s} = \sqrt{84 \times 0.4375} = 1.5$ in.

Insulation ring may be utilized as compression ring provided it is continuous and the ends of it are joined together.

Since ~~the~~ moment of intertia of the ring is not factor, the use of flat bar rolled easy-way is more economical than the use of structural shapes.

To eliminate the necessity of additional reinforcement by using thicker plate for the cylinders at the junction in some cases may be more advantageous than the application of compression rings.

REINFORCEMENT AT THE JUNCTION OF CONE TO CYLINDER UNDER EXTERNAL PRESSURE

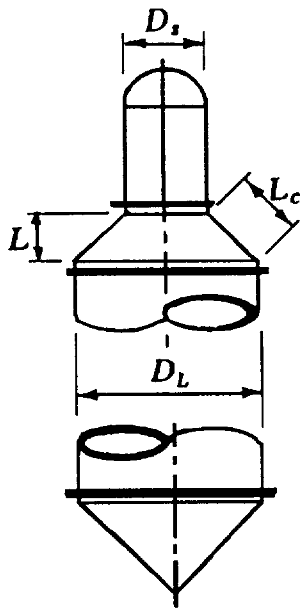


FIG. F

Reinforcement shall be provided at the junction of cone to cylinder, or at the junction of the large end of conical section to cylinder when cone, or conical section doesn't have knuckles and the value of Δ, obtained from table E, is less than α.

TABLE E - VALUES OF Δ

P/SE	0	0.002	0.005	0.010	0.02	0.04	0.08	0.10
Δ, deg.	0	5	7	10	15	21	29	33
P/SE	0.125	0.15	0.20	0.25	0.30	0.35		
Δ, deg.	37	40	47	52	57	60		

α= 60 deg. for greater values of P/SE
Note: Interpolation may be made for intermediate values.

The required moment of inertia and cross-sectional area of reinforcing (stiffening) ring — when the half apex angle α is equal to or less than 60 degrees — shall be determined by the following formulas and procedure.

1. Determine *P/SE*, and read the value of Δ from table E.
2. Determine the equivalent area of cylinder, cone and stiffening ring, A_{TL}, sq. in. (See page 46 for construction of stiffening ring)

$$A_{TL} = \frac{L_L t_s}{2} + \frac{L_c t_c}{2} + A_s \qquad \text{Calculate factor } B \quad B = \frac{3}{4}\left(\frac{F_L D_L}{A_{TL}}\right)$$

where

$$F_L = PM + f_l \tan\alpha \qquad M = \frac{-RL\tan\alpha}{2} + \frac{L_L}{2} + \frac{R_L^2 - R_s^2}{3R_L\tan\alpha}$$

3. From the applicable chart (pages 43 thru 47) read the value of *A* entering at the value of *B*, moving to the left to the material/temperature line and from the intersecting point moving vertically to the bottom of the chart.

   For values of *B* falling below the left end of the material/temperature line for the design temperature, the value of $A = 2B/E$.

   If the value of *B* is falling above the material/temperature line for the design temperature: the cone or cylinder configuration shall be changed, and/or the stiffening ring relocated, the axial compression stress reduced.

4. Compute the value of the required moment of inertia

   For the stiffening ring only: $I_s = \dfrac{AD_L^2 A_{TL}}{14.0}$ For the ring-shell-cone section: $I'_s = \dfrac{AD_L^2 A_{TL}}{10.9}$

5. Select the type of stiffening ring and determine the available moment of inertia (see page 87) of the ring only *I*, or the shell-cone or the ring-shell-cone section *I'*.

REINFORCEMENT AT THE JUNCTION OF CONE TO CYLINDER
(continued)

If I or I' is less than I_s or I'_s respectively, select stiffening ring with larger moment of inertia.

6. Determine the required cross-sectional area of reinforcement, A_{rL}, sq. in. (when compression governs):

$$A_{rL} = \frac{kQ_L R_L \tan\alpha}{SE}\left[1 - \tfrac{1}{4}\left(\frac{PR_L - Q_L}{Q_L}\right)\frac{\Delta}{\alpha}\right]$$

NOTE: When at the junction the compressive loads determined by $PR_L/2$ or $PR_s/2$ are exceeded by f_1 or f_2 tensional loads respectively, the design shall be in accordance with U-2 (g) ("as safe as those provided by the Code Section VIII, Division 1.")

Area of excess metal available for reinforcement: A_{eL} sq. in.:

$$A_{eL} = 0.55\sqrt{D_L t_s}\,(t_s + t_c/\cos\alpha)$$

The distance from the junction within which the additional reinforcement shall be situated, in.

$$\sqrt{R_L t_s}$$

The distance from the junction within which the centroid of the reinforcement shall be situated, in.

$$0.25\sqrt{R_L t_s}$$

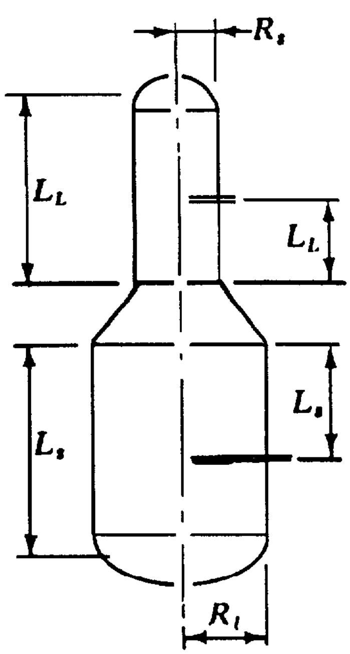


FIG. G

Reinforcing shall be provided at the junction of small end of conical section without flare to cylinder.

The required moment of inertia and cross-sectional area of reinforcing (stiffening) ring shall be determined by the following formulas and procedure.

1. Determine the equivalent area of cylinder, cone and stiffening ring, A_{TS} sq. in.

$$A_{TS} = \frac{L_s t_s}{2} + \frac{L_c t_c}{2} + A_s$$

2. Calculate factor B

$$B = \frac{3}{4}\left(\frac{F_s D_s}{A_{TS}}\right)$$

where

$$F_s = PN + f_2 \tan\alpha$$

$$N = \frac{R_s \tan\alpha}{2} + \frac{L_s}{2} + \frac{R_L^2 - R_s^2}{6R_s \tan\alpha}$$

REINFORCEMENT
AT THE JUNCTION OF CONE TO CYLINDER
(continued)

3. From the applicable chart (pages 43 thru 47) read the value of A entering at the value of B, moving to the left to the material/temperature line and from the intersecting point moving vertically to the bottom of the chart.

   For values of B falling below the left end of the material/temperature line for the design temperature, the value of $A = 2B/E$.

   If the value of B is falling above the material/temperature line for the design temperature: the cone or cylinder configuration shall be changed, and/or the stiffening ring relocated, the axial compression stress reduced.

4. Compute the value of the required moment of inertia:

   For the ring-shell-cone section:
   $$I'_s = \frac{AD_s^2 A_{TS}}{10.9}$$
   For the stiffening ring only:
   $$I_s = \frac{AD_s^2 A_{TS}}{14.0}$$

5. Select the type of stiffening ring and determine the available moment of inertia (see page 89) of the ring only, I and of the ring-shell-cone section, I'. If I or I' is less than I_s or I'_s respectively, select stiffening ring with larger moment of inertia.

6. Determine the required cross-sectional area of reinforcement. A_{rs}, sq. in:
   $$A_{rs} = \frac{kQ_sR_s \tan\alpha}{SE}$$
   Area of excess metal available for reinforcement, A_e, sq. in.
   $$A_{es} = 0.55\sqrt{D_st_s}\ [(t_s-t) + (t_c-t_r)/\cos\alpha]$$
   The distance from the junction within which the additional reinforcement shall be situated, in.
   $$\sqrt{R_st_s}$$
   The distance from the junction within which the centroid of the reinforcement shall be situated, in.
   $$0.25\sqrt{R_st_s}$$

NOTE: When the reducers made out of two or more conical sections of different apex angles without knuckle, and when the half apex angle is greater than 60 degrees, the design may be based on special analysis. (Code 1-8 (d) and (e).)

NOTATION

A_e = area of excess metal available for reinforcement, sq. in.

A_{rL} = required area of reinforcement when Q_L is in compression, sq. in.

A_{rs} = required area of reinforcement when Q_L is in compression, sq. in.

A_s = cross-sectional area of the stiffening ring, sq. in.

A_T = equivalent area of cylinder, cone and stiffening ring, sq. in.

B = factor

D_L = outside diameter of cone or large end of conical section, in.

REINFORCEMENT AT THE JUNCTION OF CONE TO CYLINDER
(continued)

D_o = outside diameter of cylindrical shell, in.

D_s = outside diameter at small end of conical section, in.

E = lowest efficiency of the longitudinal joint in the shell, head or cone; E = 1 for butt welds in compression.

E = with subscripts *c, r or* s modulus of elasticity of cone, reinforcement or shell material respectively, psi.

k = S_sE_s/S_RE_R but not less than 1.0.

f_1 = axial load at large end due to wind etc., lb./in. The value of f_1 shall be taken as positive in all calculations.

f_2 = axial load at small end due to wind, etc. lb./in. The value of f_2 shall be taken as positive in all calculations.

I = available moment of inertia of the stiffening ring, in^4

I' = available moment of inertia of combined ring-shell cross-section, in^4. The width of the shell which is taken as contributing to the moment of inertia of the combined section:

$$1.10\sqrt{D_o t}$$

I_s = required moment of inertia of the stiffening ring, in^4.

I_s' = required moment of inertia of the combined ring-shell-cone cross-section, in^4.

L = axial length of cone, in.

L_c = length of cone along surface of cone, or distance between stiffening rings of cone, in.

L_L = design length of a vessel section, in. *for stiffened vessel section:* the distance between the cone-to-large shell junction and an adjacent stiffening ring on the large shell.

for unstiffened vessel section: the distance between the cone-to-large-shell junction and one-third the depth of head on the other end of the large shell.

L_s = design length of a vessel section, in. *for stiffened vessel section:* distance between the cone-to-small-shell junction and an adjacent stiffening ring on the small shell.

for unstiffened vessel section: distance between the cone-to-small-shell junction and one third the depth of head on the other end of the small shell.

P = external design pressure, psi.

Q_L = $\dfrac{PR_L}{2}+f_1 \quad Q_s=\dfrac{PR_s}{2}+f_2$ axial compressive force due to pressure and axial load.

R_L = outside radius of large cylinder, in.

R_s = outside radius of small cylinder, in.

S = allowable working stress, psi. of cone material.

S_R = allowable stress of reinforcing material, psi.

S_s = allowable stress of shell material, psi.

t = minimum required thickness of cylinder without allowance for corosion, in.

t_c = actual thickness of cone without corrosion allowance, in.

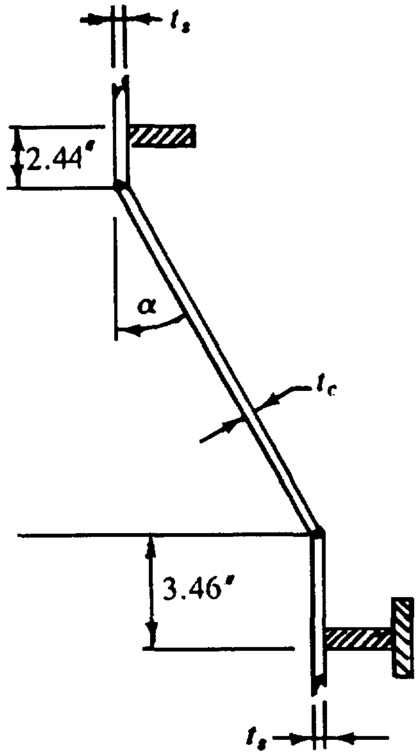
t_r = minimum required thickness of cone without corrosion allowance, in.

t_s = actual thickness of shell without allowance for corrosion., in.

α = half apex angle, deg.

Δ = value to indicate need for reinforcement, from table E, deg.

REINFORCEMENT AT THE JUNCTION OF CONE TO CYLINDER EXAMPLE



Design temperature = 650° F

DESIGN DATA

D_L = 96 in., outside diameter of large cylinder

D_s = 48 in., outside diameter of small cylinder

E = 0.7, efficiency of longitudal welded joints of shell and cone.

E_s, E_c, E_r = 30×10^6, modulus of elasticity of shell, cone and ring material, psi.

f_1 = 100 lb./in., axial load due to wind

f_2 = 30 lb./in., axial load due to wind.

L_L = 120 in., design length of large vessel section.

L_s = 244 in., design length of small vessel section.

L_c = 48 in.

P = 15 psi, external design pressure

R_L = 48.00 in. outside radius of large cylinder

R_s = 24.00 in. outside radius of small cylinder

S_s = 13,800 psi. maximum allowable working stress of shell and cone material.

S_R = 12,700 psi. maximum allowable working stress of reinforcement material.

t = 0.25 in. minimum required thicknes of large cylinder.

t = 0.1875 in. minimum required thickness of small cylinder.

t_c = 0.25 in. actual thickness of cone.

t_r = 0.25 in. minimum required thickness of cone.

t_s = 0.25 in. actual thickness of cylinder.

JUNCTION AT THE LARGE END

1. P/SE = 15/13,800 = 0.0016; from table E Δ = 4 since Δ is less than α, reinforcement is required.
2. Assuming A_s= 0, $A_{TL} = L_L t_s/2 + L_c t_c/2 + A_s$ =

$$= 120 \times 0.125 + 48 \times 0.125 + 0 = 21 \text{ in}^2.$$

$$M = -\frac{R_L \tan\alpha}{2} + \frac{L_L}{2} + \frac{R_L^2 - R_s^2}{3R_L \tan\alpha} = -\frac{48 \times 0.5774}{2} + \frac{120}{2} + \frac{48^2 - 24^2}{3 \times 48 \times 0.5774} = 66.9$$

$$F_L = PM + f_1 \tan\alpha = 15 \times 66.9 + 100 \times 0.5774 = 1061$$

REINFORCEMENT AT THE JUNCTION OF CONE TO CYLINDER EXAMPLE *(continued)*

$$B = \frac{3}{4}\left(\frac{F_L D_L}{A_{TL}}\right) = 0.75 \text{ x } 1061 \text{ x } 96/21 = 3636$$

3. $A = 0.0003$ from chart page 43
4. Required moment of inertia of the combined ring-shell-cone cross section:

$$I'_s = \frac{AD_L A_{TL}}{10.9} = \frac{0.00035 \text{ x } 96^2 \text{ x } 21}{10.9} = 5.32 \text{ in.}^4$$

5. Using two 2½ x ½ flat bars as shown, and the effective width of the shell:

$1.10 \text{ x } \sqrt{D_L t} = 1.1 \sqrt{96 \text{ x } .025} = 5.389$ in.,

The available moment of inertia: 5.365 in. (see page 96)

It is larger than the required moment of inertia. The stiffening is satisfactory.

6. The required cross-sectional area of reinforcing:

$$k = \frac{S_s E_s}{S_R E_R} = \frac{13{,}800 \text{ x } 30 \text{ x } 10^6}{12{,}700 \text{ x } 30 \text{ x } 10^6} = 1.09$$

$$Q_L = \frac{PR_L}{2} + f_l = \frac{15 \text{ x } 48}{2} + 100 = 460$$

$$A_{rL} = \frac{kQ_L R_L \tan\alpha}{S_s E}\left[1 - \tfrac{1}{4}\left(\frac{PR_L - Q_L}{Q_L}\right)\frac{\Delta}{\alpha}\right]$$

$$= \frac{1.09 \text{ x } 460 \text{ x } 48 \text{ x } 0.5774}{13{,}800 \text{ x } 0.7}\left[1 - 0.25\left(\frac{15 \text{ x } 48 - 460}{460}\right)\frac{4}{30}\right] = 1.412 \text{ in.}^2$$

The cross-sectional area of the stiffening ring is 2.5 in^2. It is larger than the area required.

The reinforcing shall be situated within a distance from the junction:

$\sqrt{R_L t_s} = \sqrt{48 \text{ x } 0.25} = 3.46$ in.

The centroid of the ring shall be within a distance from the junction:

$0.25\sqrt{R_L t_s} = 0.25\sqrt{48 \text{ x } 0.25} = 0.86$ in.

JUNCTION AT THE SMALL END

1. The conical section having no flare, reinforcement shall be provided.
2. Asuming $A_s = 0$, $A_{TS} = L_s t_s/2 + L_c t_c/2 + A_s$

$A_{rs} = L_s t/2 + L_c t_c/2 + A_s = 244 \text{ x } 0.25/2 + 48 \text{ x } 0.25/2 + 0 = 36.5$ in.

$$N = \frac{R_s \tan\alpha}{2} + \frac{L_s}{2} + \frac{R_L^2 - R_S^2}{6R_S \tan\alpha} = \frac{24 \text{ x } 0.5774}{2} + \frac{244}{2} + \frac{48^2 - 24^2}{6 \text{ x } 24 \text{ x } .5774} = 149.7 \text{ in.}$$

REINFORCEMENT
AT THE JUNCTION OF CONE TO CYLINDER
EXAMPLE *(continued)*

$F_s = PN + f_2 \tan \alpha \quad = 15 \times 149.7 + 30 \times 0.5774 = 2263$

$$B = \frac{3}{4}\ \frac{F_S D_S}{A_{TS}} = 3/4\left(\frac{2263 \times 48}{36.5}\right) = 2232$$

3. Since value of B falls below the left end of material/temperature line:
   $A = 2\ B/E = 2 \times 2232 / 30 \times 10^6 = 0.00014$

4. Required moment of inertia of the combined ring-shell-cone cross section:
   $$I'_s = \frac{AD_s^2 A_{TS}}{10.9} = \frac{0.00014 \times 48^2 \times 36.5}{10.9} = 1.08 \text{ in.}^4$$

5. Using 2½ x ½ flat bar, and the effective shell width:

   $1.1\ \sqrt{48 \times 0.25} = 3.81$ in.

   The available moment of inertia 1.67 in.^{4} (see page 96)

   It is larger than the required moment of inertia; the stiffening is satisfactory.

6. The required area of reinforcing:

   $$k = 1.09 \qquad Q_s = \frac{PR_s}{2} + f_2 = \frac{15 \times 24}{2} + 30 = 210 \text{ lb./in.}$$

   $$A_{rs} = \frac{kQ_sR_s \tan \alpha}{S_sE} = \frac{1.09 \times 210 \times 24 \times 0.5774}{13{,}800 \times 0.7} = 0.328 \text{ in.}^2$$

   Area of excess metal available for reinforcement:

   $$A_e = \sqrt{\frac{R_s t_c}{\cos \alpha}}\ (t_c - t_r) + \sqrt{R_s t_s}\ (t_s - t)$$

   $$= \sqrt{\frac{24 \times 0.25}{0.866}}\ (0.25 - 0.25) + \sqrt{24 \times 0.25}\ (0.25 - 0.1875) = 0.153 \text{ in.}^2$$

   $A_{rs} - A_e = 0.328 - 0.153 = 0.175$ in.^{2}

   The area of ring used for stiffening 1.25 in.^{2}. It is larger than the required area for reinforcement.

   The reinforcing shall be situated within a distance from the junction:

   $\sqrt{R_s t_s} = \sqrt{24 \times 0.25} = 2.44$ in.

   and the centroid of the ring shall be within a distance from the junction:

   $0.25\ \sqrt{R_s t_s} = 0.25\ \sqrt{24 \times 0.25} = 0.61$ in.

WELDING
OF PRESSURE VESSELS

There are several methods to make welded joints. In a particular case the choice of a type from the numerous alternatives depend on:

1. The circumstances of welding
2. The requirements of the Code
3. The aspect of economy

1. THE CIRCUMSTANCES OF WELDING.

In many cases the accessibility of the joint determines the type of welding. In a small diameter vessel (under 18 - 24 inches) from the inside, no manual welding can be applied. Using backing strip it must remain in place. In larger diameter vessels if a manway is not used, the last (closing) joint can be welded from outside only. The type of welding may be determined also by the equipment of the manufacturer.

2. CODE REQUIREMENTS.

Regarding the type of joint the Code establishes requirements based on service, material and location of the welding. The welding processes that may be used in the construction of vessels are also restricted by the Code as described in paragraph UW-27.

The Code-regulations are tabulated on the following pages under the titles:

a. **Types of Welded Joints**
(Joints permitted by the Code, their efficiency and limitations of their applications.) Table UW-12

b. **Design of Welded Joints**
(Types of Joints to be used for vessels in various services and under certain design conditions.) UW-2, UW-3

c. **Examination of Welded Joints**
The efficiency of joints depends only on the type of joint and on the degree of examination and does not depend on the degree of examination of any other joint. (Except as required by UW-11(a)(5)
This rule of the 1989 edition of the Code eliminates the concept of collective qualification of butt joints, the requirement of stress reduction.

3. THE ECONOMY OF WELDING.

If the two preceding factors allow free choice, then the aspect of economy must be the deciding factor.

Some considerations concerning the economy of weldings:

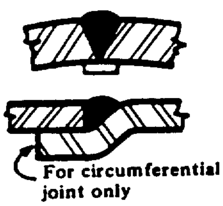
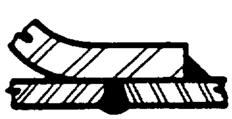
V-edge preparation, which can be made by torch cutting, is always more economical than the use of J or U preparation.

Double V preparation requires only half the deposited weld metal required for single V preparation.

Increasing the size of a fillet weld, its strength increases in direct proportion, while the deposited weld metal increases with the square of its size.

Lower quality welding makes necessary the use of thicker plate for the vessel. Whether using stronger welding and thinner plate or the opposite is more economical, depends on the size of vessel, welding equipment, etc. This must be decided in each particular case.

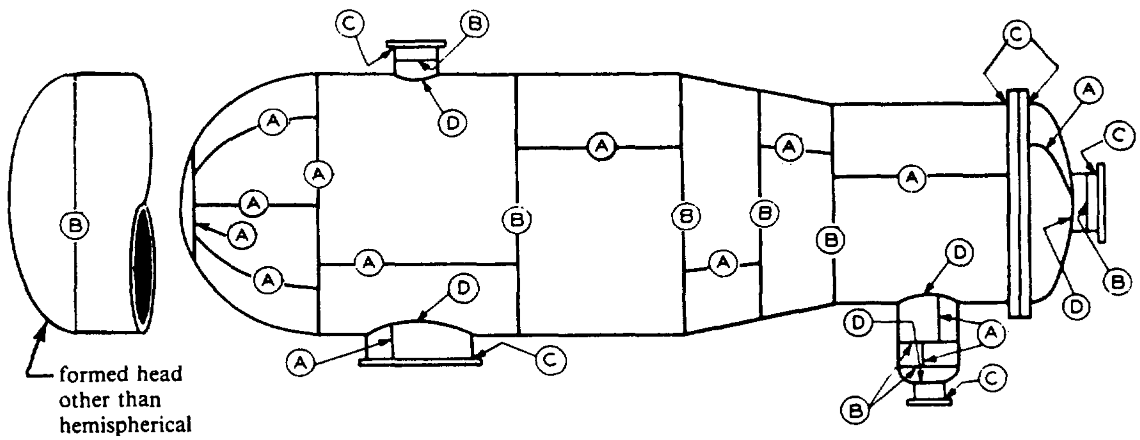
TYPES OF WELDED JOINTS

TYPES CODE UW-12		JOINT EFFICIENCY, E When the Joint:		
		a. Fully Radio-graphed	b. Spot Examined	c. Not Examined
1 	Butt joints as attained by double-welding or by other means which will obtain the same quality of deposited weld metal on the inside and outside weld surface. Backing strip if used shall be removed after completion of weld.	1.00	0.85	0.70
2 	Single-welded butt joint with backing strip which remains in place after welding	0.90	0.80	0.65
3 	Single-welded butt joint without use of backing strip	–	–	0.60
4 	Double-full fillet lap joint	–	–	0.55
5 	Single-full fillet lap joint with plug welds	–	–	0.50
6 	Single full fillet lap joint without plug welds	–	–	0.45

TYPES OF WELDED JOINTS

LIMITATIONS IN APPLYING VARIOUS WELD TYPES	NOTES
FOR TYPE 1: NONE Joint Category: A,B,C,D FOR TYPE 2: NONE Joint Category: A,B,C,D Except butt weld with one plate off-set — for circumferential joints only. FOR TYPE 3: Joint Category: A,B,C Circumferential joints only, not over 5/8 in. thick and not over 24 in. outside diameter. FOR TYPE 4: (a) Longitudinal joints not over 3/8 in. thick Joint Category: A (b) Circumferential joints not over 5/8 in. thick. Joint Category: B,C FOR TYPE 5 (a) Circumferential joints for attachment of heads not over 24 in. outside diameter to shells not over 1/2 in. thick. Joints attaching hemispherical heads to shells are excluded. Joint Category: B (b) Circumferential joints for the attachment to shells of jackets not over 5/8 in. in nominal thickness where the distance from the center of the plug weld to the edge of the plate is not less than 1-1/2 times the diameter of the hole for the plug. Joint Category:C FOR TYPE 6 (a) For the attachment of heads convex to pressure to shells not over 5/8 in. required thickness, only with use of fillet weld on inside of shell; Joint Category: A,B (b) For attachment of heads having pressure on either side, to shells not over 24 in. inside diameter and not over 1/4 required thickness with fillet weld on outside of head flange only. Joint Category: A,B	1. In this table are shown the types of welded joints which are permitted by the Code in arc and gas welding processes. 2. The shape of the edges to be joined by butt-weld shall be such as to permit complete fusion and penetration. 3. Butt joints shall be free from undercuts, overlaps and abrupt ridges and valleys. To assure that the weld-grooves are completely filled, weld metal may be built up as reinforcement. The thickness of the reinforcement shall not exceed the following thicknesses. Plate thickness in. — Maximum reinf. in. up to ½ incl. — 3/32 over ½ to 1 incl. — 1/8 over 1 — 3/16 4. Before welding the second side of a double welded butt joint, the impurities of the first side welding shall be removed by chipping, grinding or melting out to secure sound metal for complete penetration and fusion. For submerged arc welding, chipping out a groove in the crater is recommended. 5. The maximum allowable joint efficiencies given in this table are to be used in formulas, when the joints made by arc or gas welding processes. 6. Joint efficiency, E = 1 for butt joints in compression.

DESIGN OF WELDED JOINTS



WELDED JOINT LOCATIONS

To the joints under certain condition special requirements apply, which are the same for joints designated by identical letters.

These special requirements, which are based on service, material, thickness and other design conditions, are tabulated below.

DESIGN CONDITION	JOINT TYPE AND CATEGORY	RADIOGRAPHIC EXAMINATION	JOINT EFFICIENCY	POST WELD HEAT TREATMENT
1. The design is based on joint efficiency 1.0 or 0.9 (See design conditions listed below when full radiography is mandatory.) UW-11 UW-12(d)	All category A and D butt welds in vessel sections and heads	Full	Type (1) 1.0 Type (2) 0.9	Per Code UCS-56
	All category B or C butt welds (but not including those in nozzles or communicating chambers) which intersects the category A welds in vessel sections or heads or connect seamless vessel sections or heads	Spot		
		None	0.85 0.80	
	Category A and B butt welds in vessel sections and heads shall be of Type (1) or Type (2)	Joints B and C butt welds in nozzles and communicating chambers that neither exceed 10 in. nom pipe size nor 1 1/8 in wall thickness do not require any radiographic examination except as required for ferritic steel with tensile properties enhanced by heat treatment UHT-57		
2. Full radiographic examination is not mandatory UW-11(b)	Type (1) or Type (2) butt welded joints	Spot	Type (1) 0.85 Type (2) 0.80	Per Code UCS-56

DESIGN OF WELDED JOINTS (CONT.)

<table>
<tr><th>DESIGN CONDITION</th><th>JOINT TYPE AND CATEGORY</th><th>RADIOGRAPHIC EXAMINATION</th><th>JOINT EFFICIENCY</th><th>POST WELD HEAT TREATMENT</th></tr>
<tr><td>3. Full radiographic examination is not mandatory. The vessel is designed for external pressure only UW-11(c)</td><td>Any Type of welded joints</td><td>None</td><td>Type (1) 0.70
Type (2) 0.65
Type (3) 0.60
Type (4) 0.55
Type (5) 0.50
Type (6) 0.45</td><td>Per Code UCS-56</td></tr>
<tr><td rowspan="3">4. Vessels containing lethal substances UW-2(a)
Joints B and C butt welds in nozzles and communicating chambers that neither exceed 10 in. nom pipe size nor 1 1/8 in wall thickness do not require any radiographic examination except as required for ferritic steel with tensile properties enhanced by heat treatment UHT-57</td><td>Joints A shall be Type No. (1) UW-2(a) (1) (a)</td><td>Full</td><td>1.0</td><td rowspan="3">Vessels fabricated of carbon or low alloy steel shall be post weld heat treated UW-2(a)</td></tr>
<tr><td>Joints B and C shall be Type No. (1) or Type No. (2) UW-2(a) (1) (b)</td><td></td><td>**1.0 Type (1)**
0.9 Type (2)</td></tr>
<tr><td>Joints D shall be full penetration welds extending through the entire thickness of the vessel or nozzle wall UW-2(a) (1) (d).
Joints of category C for the fabricated lap joint stub ends UW-2(a)(1)(c)</td><td>All butt welded joints in shell and heads shall be fully radiographed except exchanger tubes and exchangers UW-2(a) (2) and (3) and per UW-11(a) (4)</td><td></td></tr>
<tr><td>5. Vessels operated below −20°F or impact test is required for the material or weld metal UW-2(b)</td><td>Joints A shall be Type No (1) (except for austenific chromium nickel stainless steel).
Joints B shall be type No. (1) or No. (2) UW-2(b) (1) and (2)
Joints C full penetration welds extending through the entire section of the joint
Joints D full penetration welds extending through the entire section at the joint UW-2(b) (2) and (3)</td><td>Full
Spot
No</td><td>Type (1) Type (2)
1.0 0.90
0.85 0.80
0.70 0.65</td><td>Per Code UCS-56</td></tr>
<tr><td>6. Unfired steam boilers with design pressure exceeding 50 psi
See note above in this column at design condition 4:</td><td>Joints A shall be type No. (1)
Joints B shall be type No. (1) or No. (2) UW-2(c)</td><td>All butt welded joints in shell and heads shall be fully radiographed except under the provisions of UW-11(a) (4) UW-2(c)</td><td>1.0
1.0 Type (1)
0.9 Type (2)</td><td>Vessels fabricated of carbon or low alloy steel shall be post weld heat treated UW-2(c)</td></tr>
</table>

DESIGN OF WELDED JOINTS (CONT.)

DESIGN CONDITION	JOINT TYPE AND CATEGORY	RADIOGRAPHIC EXAMINATION	JOINT EFFICIENCY	POST WELD HEAT TREATMENT
7. Pressure vessels subject to direct firing	Joints A shall be type No. (1) Joints B shall be type No. (1) or No. (2) when the thickness exceeds 5/8 in. No welded joints of type (3) are permitted for either A or B joints in any thickness UW-2(d)	Full Spot No	Type (1) Type (2) 1.0 0.90 0.85 0.80 0.70 0.65	When the thickness at welded joints of carbon steels (P-No. 1) exceeds 5/8 in. and all thicknesses for low alloy steels (other than P-No. 1) post weld heat treatment is mandatory
8. Electroslag welding	All but welds UW-11(a) (6)	Full	1.0 Type (1) 0.9 Type (2)	Per Code UCS-56
9. Final closure of vessels	Any welds UW-11(a) (7)	Full Ultrasonic examination when the construction does not permit radiographs	1.0 Type (1) 0.9 Type (2)	Per Code UCS-56
10. Seamless vessel sections or heads UW-11(a) (5) (b) UW-12(d)	Joints connecting vessel sections and heads	Spot	1.0*	Per Code UCS-56
		None or when A or B welds are type 3, 4, 5, 6	0.85*	
11. Joints completed by pressure UW-12(f)	Any Welds		Not greater than .80	

EFFICIENCY (E) TO BE USED IN CALCULATIONS OF SEAMLESS HEAD THICKNESS ASME Code UW-12(d)

TYPE OF HEAD	TYPE OF JOINT	DEGREE OF EXAMINATION OF HEAD TO SHELL JOINT		
		FULL	SPOT	NO
Hemi spherical	N°1	1.00	0.85	0.70
	N°2	0.90	0.80	0.65
Others	ANY	1.00		0.85

*For calculation involving circumferential stress or for thickness of seamless head

EXAMINATION OF WELDED JOINTS

RADIOGRAPHIC EXAMINATION

Full radiography is mandatory of joints: (Code UW-11)

1. All butt welds in shells, heads, nozzles, communicating chambers of *unfired steam boilers* having design pressures exceeding 50 psi and vessels containing *lethal substances.*
2. All butt welds in vessels in which the least nominal thickness at the welded joint exceeds:
   1 1/4 in. of carbon steel and 1 1/2 in. of SA-240 stainless steel.
   Exemption: Categories B and C butt welds in nozzles and communicating chambers that neither exceed 10 in pipe size nor 1 1/8 in. wall thickness do not require radiographic examination in any of the above cases.
3. All category A and D butt welds in vessel sections and heads where the design of the joint or part is based on joint efficiency: 1.0, or 0.9. (see preceding pages: Design of Welding Joints).
4. All butt welds joined by electroslag welding and all electrogas welding with any single pass greater than 1 1/2 in.

Spot radiography, as a minimum, is mandatory of

1. Category B or C welds which intersect the Category A butt welds in vessel sections (including nozzles and communicating chambers above 10 in. pipe size and 1 in. wall thickness) or connect seamless vessel sections or heads when the design of Category A and D butt welds in vessel sections and heads based on a joint efficiency of 1.0 or 0.9.
2. Spot radiography is optional of butt welded joints (Type 1 or 2) which are not required to be fully radiographed. If spot radiography specified for the entire vessel, radiographic examination is not required of Category B and C butt welds in nozzles and communicating chambers.

No Radiography. No radiographic examination of welded joints is required when the vessel or vessel part is designed for external pressure only, or when the design of joints based on no radiographic examination.

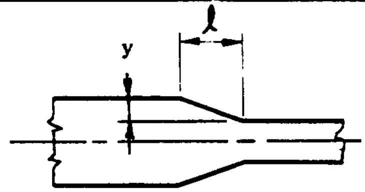
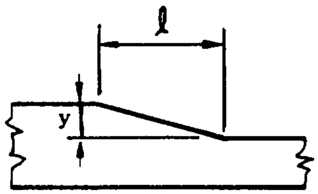
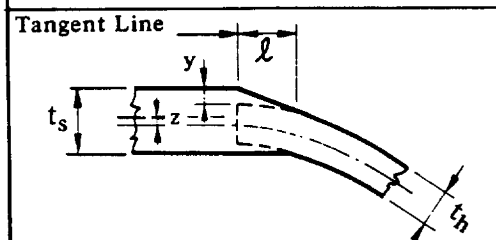
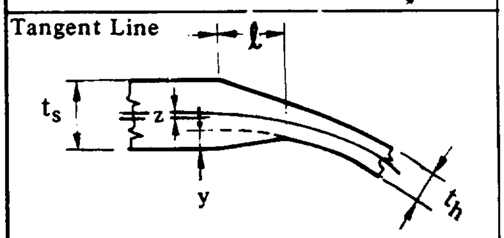
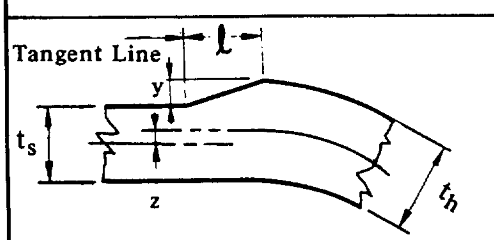
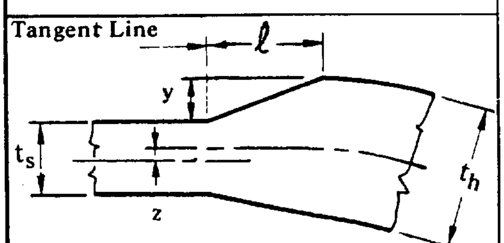
ULTRASONIC EXAMINATION

1. In ferritic materials electroslag welds and electrogas welds with any single pass greater than 1 1/2 in. shall be ultrasonically examined throughout their entire length.
2. In addition to the requirements of radiographic examination, all welds made by the electron beam process or by the inertia and continuous drive friction welding process shall be ultrasonically examined for their entire length.
3. Ultrasonic examination may be substituted for radiography for the final closure seam if the construction of the vessel does not permit interpretable radiograph.

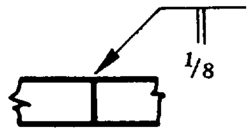
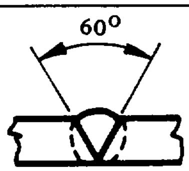
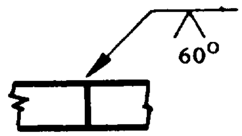
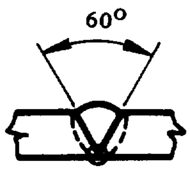
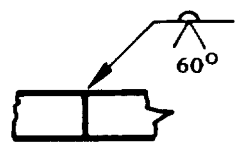
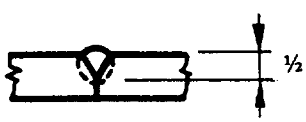
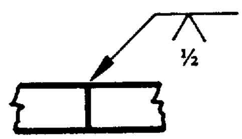
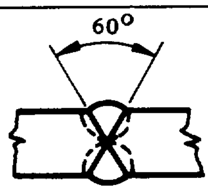
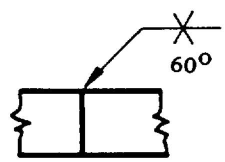
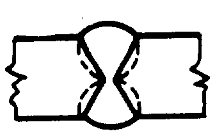
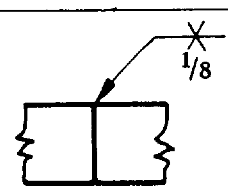
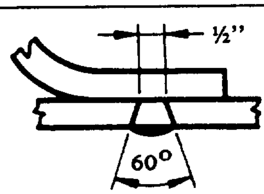
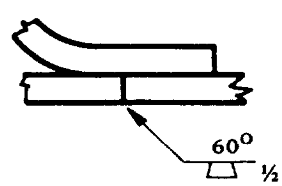
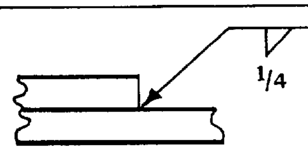
BUTT WELDED JOINTS OF PLATES OF UNEQUAL THICKNESSES

JOINING PLATES OF UNEQUAL THICKNESSES WITH BUTT WELD, THE THICKER PLATE SHALL BE TAPERED IF THE DIFFERENCE IN THICKNESS IS MORE THAN 1/8 IN. OR ONE-FOURTH OF THE THINNER PLATE. CODE UW-9(c), UW-13.

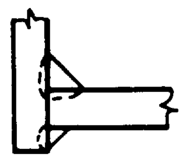
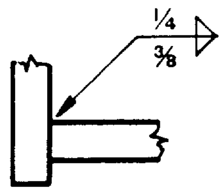
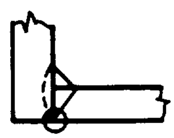
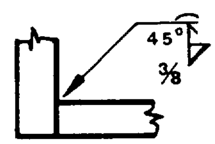
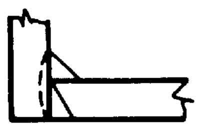
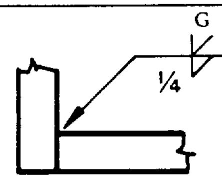
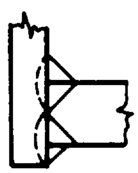
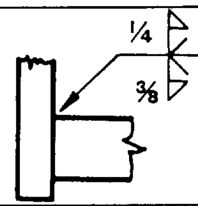
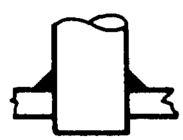
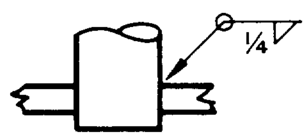
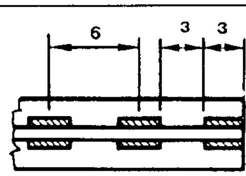
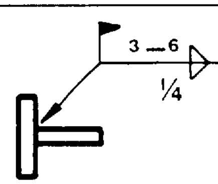
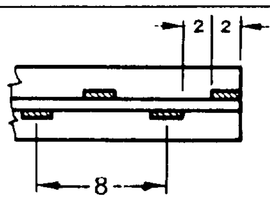
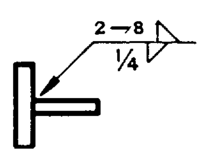
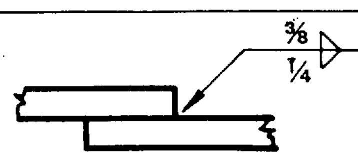
THE LENGTH OF THE TAPERED TRANSITION SHALL BE MINIMUM 3 TIMES THE OFFSET BETWEEN THE ADJACENT SURFACES. THE WELD MAY BE PARTLY OR ENTIRELY IN THE TAPERED SECTION OR ADJACENT TO IT.

	$\ell \geqq 3y$
	$\ell \geqq 3y$ Taper either inside or outside of vessel
	HEADS TO SHELLS ATTACHMENT $\ell \geqq 3y \quad Z \gtreqless 1/2(t_s - t_h)$ The shell plate centerline may be on either side of the head plate centerline.
	HEADS TO SHELLS ATTACHMENT $\ell \geqq 3y \quad Z \gtreqless 1/2\,(t_h - t_s)$ When t_h exceeds t_s, the minimum length of straight flange is $3t_h$, but need not exceed 1-1/2 in. except when necessary to provide required length of taper. When t_h is equal to or less than $1.25t_s$, the length of straight flange shall be sufficient for any required taper. The shell plate centerline may be on either side of the head plate centerline.

APPLICATION OF WELDING SYMBOLS

WELD	SYMBOL	MEANING OF SYMBOL
		SYMBOL INDICATES SQUARE GROOVE WELD ON ARROW SIDE. ROOT GAP 1/8 IN.
		SYMBOL INDICATES V-GROOVE WELD WITH AN ANGLE OF 60 DEGREES ON ARROW SIDE
		SYMBOL INDICATES V-GROOVE WELD WITH AN ANGLE OF 60 DEGREES ON ARROW SIDE AND BEAD-TYPE BACK WELD ON THE OTHER SIDE
		SYMBOL INDICATES 1/2 IN. V-GROOVE WELD
		SYMBOL INDICATES V-GROOVE WELD ON ARROW SIDE AND ON OTHER SIDE WITH AN ANGLE OF 60 DEGREES
		SYMBOL INDICATES V-GROOVE WELD ON ARROW SIDE AND ON OTHER SIDE WITH A ROOT OPENING OF 1/8 IN.
		SYMBOL INDICATES PLUG WELD OF 1/2 IN. DIAMETER AND WITH AN ANGLE OF 60 DEGREES
		SYMBOL INDICATES 1/4 IN. FILLET WELD

APPLICATION OF WELDING SYMBOLS

WELD	SYMBOL	MEANING OF SYMBOL
		SYMBOL INDICATES 3/8 IN. FILLET WELD ON ARROW SIDE AND 1/4 IN. FILLET WELD ON THE OTHER SIDE
		SYMBOL INDICATES BEVEL GROOVE WITH AN ANGLE OF 45 DEGREES, 3/8 FILLET WELD ON ARROW SIDE AND BEAD TYPE BACK WELD ON OTHER SIDE
		SYMBOL INDICATES 1/4 IN. FILLET WELD ON ARROW SIDE AND BEVEL GROOVE WELD ON OTHER SIDE GRIND FLUSH ON OTHER SIDE
		SYMBOL INDICATES BEVEL GROOVE WELD AND 3/8 FILLET WELD ON ARROW SIDE, BEVEL GROOVE AND 1/4 FILLET WELD ON OTHER SIDE
		SYMBOL INDICATES WELD ALL AROUND 1/4 IN. FILLET WELD
		SYMBOL INDICATES 1/4 IN. INTERMITTENT FILLET WELDS EACH 3 IN. LONG AND SPACED ON 6 IN. CENTERS. FIELD WELDED
		SYMBOL INDICATES 1/4 IN. INTERMITTENT FILLET WELD. EACH 2 IN. LONG AND SPACED ON 8 IN. CENTERS. THE WELDS ARE STAGGERED.
		SYMBOL INDICATES 1/4 IN. FILLET WELD ON ARROW SIDE AND 3/8 FILLET WELD ON OTHER SIDE

CODE RULES RELATED TO VARIOUS SERVICES

Service	Brief extracts of Code requirements	Code paragraph
Air	All pressure vessels for use with compressed air, except as permitted otherwise in this paragraph shall be provided with suitable inspection opening. Vessels with a required minimum thickness of less than ¼ inch that are to be used in compressed air service shall be provided with corrosion allowance not less than 1/6 of the calculated plate thickness. Min. thickness 3/32 in.	UG - 46 (a) UCS - 25 UG 16-(b) (6)
Flammable and or noxious gases and liquids	Expanded connections shall not be used.	UG - 43 (g)
Lethal substances	Butt welded joints in vessels to contain lethal substances shall be fully radiographed. When fabricated of carbon or low alloy steel shall be post weld heat treated. The joints of various categories shall conform to paragraph UW - 2. Steel plates conforming to specifications SA-36, SA-283 shall not be used.	UW - 2 (a) UW - 2 (a) UCS - 6 (b) (1)
Steam	Vessels with a required minimum thickness of less than ¼ inch that are to be used in steam service shall be provided with corrosion allowance of not less than 1/6 of the calculated plate thickness. Min. thickness 3/32 in. shells & heads	UCS - 25 UG-16 (b) (6)
Unfired steam boilers (1)	With design pressures exceeding 50 psi., the joints of various categories shall conform to paragraph UW-2. Steel plates conforming to specifications SA-36, and SA-283 shall not be used. Min. thickness 1/4 in. shells & heads	UCS - 6 (b) (2) UG-16 (b) (5)
Water (2)	Vessels with a required minimum thickness of less than ¼ inch that are to be used in water service shall be provided with a corrosion allowance of not less than 1/6 of the calculated plate thickness. Min. thickness 3/32 in. shells & heads	UCS - 25 UG-16 (b) (6)

NOTES:

1. Unfired steam boilers may also be constructed in accordance with the rules of Code Section I.
2. Vessels in water service excluded from the jurisdiction of the code are listed in U-1 (c) (6) and (7).

CODE RULES RELATED TO VARIOUS WALL THICKNESSES OF VESSEL

Wall Thick-ness, in.	1/16	3/32	3/16	1/4	5/16	3/8	7/16	1/2
Applicable Notes	2, 4, 15 5, 6, 8, 9, 11, 12, 14	2, 4, 15 5, 6, 8, 9, 11, 12, 14	2, 3, 4, 5, 6, 8, 9, 11 12, 14, 15	2, 4, 5, 6, 8, 9, 11, 12, 14	4, 6, 8, 9 11, 12, 14 15	4, 6, 8, 9 11, 12, 14 15	7, 8, 9, 11, 12, 14, 15	7, 8, 9, 11, 12, 14, 15
Wall thick-ness, in.	9/16	5/8	11/16	3/4	13/16	7/8	15/16	1
Applicable Notes	7, 10, 11, 12, 14, 15	7, 10, 11, 12, 14, 15	7, 10, 13, 16, 20	7, 10, 13, 16, 20	7, 10, 13, 16, 20	7, 10, 13, 16, 20	7, 10, 13, 16, 20	7, 10, 13, 16, 20
Wall Thick-ness, in.	1 1/16	1 1/8	1 3/16	1 1/4	1 5/16	1 3/8	1 7/16	1 1/2 & over
Applicable Notes	7, 13, 16, 17, 20	7, 13, 16, 17, 20	7, 13, 16, 17, 20	7, 13, 16, 17, 20, 19, 22	7, 13, 16, 17, 18, 21 19, 20, 22	7, 13, 16, 17, 18, 21 19, 20, 22	7, 13, 16, 17, 18, 21 19, 20, 22	7, 13, 16, 17, 18, 19, 20, 21

Notes
(Brief Extracts of Code Requirements)

1. The minimum thickness of plate for welded construction shall be not less than 1/16.	UG-16 (b)
The minimum thickness of shells and heads used in compressed air service, steam service and water service shall be 3/32 in.	UG-16 (b) (4)
2. Manufacturers' marking shall be other than deep die stamping.	UG-77 (b)
3. In compressed air, steam and water service corrosion allowance not less than 1/6 of the calculated plate thickness shall be provided.	UCS-25
4. Single, welded openings up to 3 in. pipe size do not require reinforcement.	UG-36 (c) (3)
5. The minimum thickness of shells and heads of unfired steam boilers shall not be less than ¼ in.	UG-16 (b) (5)
6. Double full fillet lap joint for longitudinal welded joints is acceptable.	Table UW-12
7. Single, welded openings up to 2 in. pipe size do not require reinforce-forcement.	UG-36 (c) (3)
8. Single full fillet lap joint with plug weld for attachment of heads not over 24 in. outside diameter to shells, acceptable.	Table UW-12
9. Maximum thickness of reinforcement for butt weld 3/32 in.	UW-35 (a)
10. Maximum thickness of reinforcement for butt weld 1/8 in.	UW-35 (a)
11. Single full fillet lap joint with plug welds for circumferential joint acceptable.	Table UW-12

CODE RULES RELATED TO VARIOUS WALL THICKNESSES OF VESSEL
(Continued)

Notes
(Brief Extracts of Code Requirements)

12. Single full fillet lap joints without plug welds acceptable for attachment of heads convex to pressure to shells.	Table UW-12
13. Welded joints of pressure vessels subject to direct firing in category B shall be type (1) or (2). Post weld heat treatment required.	UW-2 (d) (1) (2)
14. Single welded butt joint without use of backing strip acceptable for circumferential joints not over 24 in. outside diameter.	Table UW-12
15. Double full fillet lap joints for circumferential joint acceptable.	Table UW-12
16. Steel plates conforming to SA-36 and SA-283 shall not be used.	UCS-6 (b) (4)
17. The maximum thickness of reinforcement for butt weld 3/16 in.	UW-35 (a)
18. Butt welded joints in material classified P-1 shall be fully radiographed.	UCS-57
19. Post weld heat treatment of P-1 materials is mandatory for all welded connections and attachments.	Table UCS-56
20. Double welded butt joint or single welded butt joint with backing strip shall be used for circumferential or longitudinal joints.	Table UW-12
21. Full radiographic examination of butt welded joints of P-1 Grade 1, 2, 3 materials is mandatory.	UW-11 (a)(2)
22. Post weld heat treatment of P-1 materials is not mandatory provided that material is pre-heated.	Table UCS-56 Note (2)(a)(b)

See page 179 for low temperature operation.

NOTE:
Post weld heat treatment is neither required nor prohibited for joints between austenitic stainless steels of the P-No. 8 group. (Tabulated on page 185).

TANKS AND VESSELS CONTAINING FLAMMABLE AND COMBUSTIBLE LIQUIDS

Excerpt from the Department of Labor Occupational Safety and Health Standards (OSHA), Chapter XVII, Part 1910.106, (Federal Register, July 1, 1985)

CLASSIFICATION	REGULATION
ATMOSPHERIC TANKS Storage tank which has been designed to operate at pressures from atmospheric through 0.5 psig.	Atmospheric tanks shall be built in accordance with acceptable good standards of design. Atmospheric tanks may be built in accordance with: 1. Underwriters' Laboratories, Inc. Standards 2. American Petroleum Institute Standards No. 12A, No. 650, No. 12B, No. 12D, & No. 12F.
LOW PRESSURE TANKS Storage tank which has been designed to operate at pressures above 0.5 psig. but not more than 15 psig.	Low-Pressure tanks shall be built in accordance with acceptable standards of design. Low-Pressure tanks may be built in accordance with 1. American Petroleum Institute Standard No. 620. 2. ASME Code for Pressure Vessels, Section VIII. (These tanks are not within the jurisdiction of the ASME Code Section VIII (U-1d) but may be stamped with the Code U Symbol U-1g)
PRESSURE VESSEL Storage tank or vessel which has been designed to operate at pressures above 15 psig.	Pressure Vessels shall be built in accordance with the ASME Code for Pressure Vessels, Section VIII.

In addition to the regulations of the above mentioned standards and code, the occupational safety and health standards contain rules concerning tanks and vessels as follows:

1. Definition of combustible and flammable liquids
2. Material of storage tanks
3. Location of tanks
4. Venting for tanks
5. Emergency relief venting
6. Drainage
7. Installation of tanks

LOW TEMPERATURE OPERATION

If a minimum design metal temperature- and thickness-combination of carbon and low alloy steels is below the curves in FIG. UCS-66, impact testing is required.

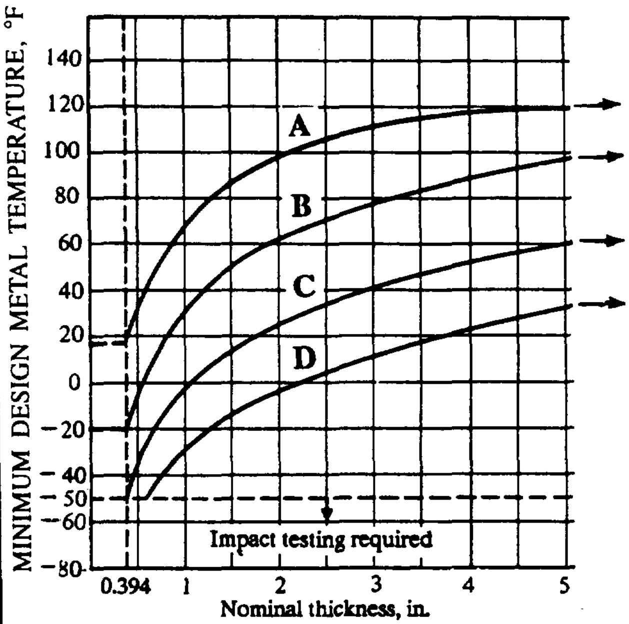


FIG. UCS-66 IMPACT TEST CURVES

NOTE. In the Handbook the most commoly used materials are listed. For others see ASME Code.

- Curve A: All carbon and alloy steels listed in the following pages and not shown below.
- Curve B: SA-515 Gr 55 & 60, SA - 285 Gr A & B, SA-516 Gr65 & 70 if not normalized.
- Curve C: SA-516 Gr 55 & 60 if not normalized
- Curve D: SA-516 all grades if normalized

If the thickness at any welded joint exceeds 4 in. and the minimum design metal temperature is colder than 120°F. impact tested material shall be used. UCS-66(b)

No impact test is required for material:
SA-193 GR B7 at temperature -40 F and warmer,
SA-307 Gr B at temperature -20 F and warmer.

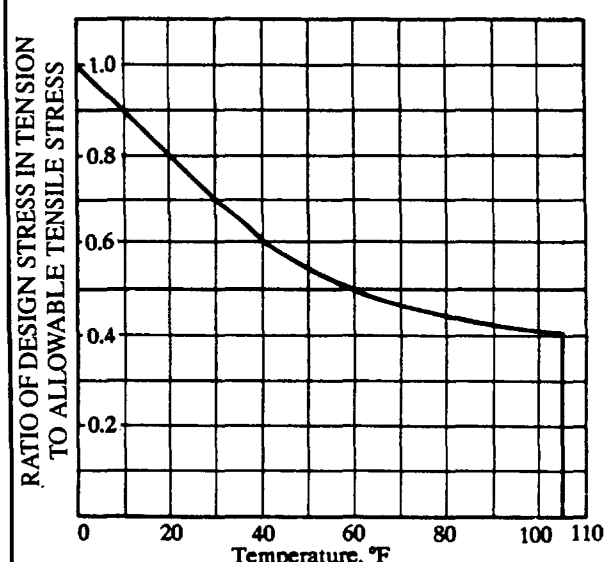


FIG. UCS-66.1 REDUCTION OF MINIMUM METAL TEMPERATURE

For stationary vessels, when the coincident ratio in Fig. UCS-66.1 is less than one, this Figure provides further basis to use material without impact testing. UG-66(b).

REDUCTION OF MINIMUM METAL TEMPERATURE

EXAMPLE:

FOR 1 1/2 thick, SA-515 Gr 60 plate the minimum design temperature is from FIG. UCS-66 50°F.

If the actual stress in tension from internal pressure and other loads is 12,000 psi., and the maximum allowable stress of the material is 15,000 psi., the ratio:

12,000/15,000 = 0.8

and from FIG. UCS-66.1 the reduction is 20°F. The minimum design temperature is: 50-20 = 30F.

(Applicable joint efficiencies shall be included in the calculation of stresses.)

Impact test is not mandatory for materials which satisfy all of the following:

1. **the thickness of material listed in curve A does not exceed 1/2 in.**
2. **the thickness of material listed in curves B, C, and D does not exceed 1 in.**
3. **the vessel is hydrostatically tested.**
4. **the design temperature is not lower than -20 F and not higher than 650 F.**
5. **thermal, mechanical shock loading or cyclical loading is not controlling design requirement.**

PROPERTIES OF MATERIALS

CARBON & LOW ALLOY STEEL *

Form	Nominal Composition	Specification Number	Specification Grade	APPLICATION
Plate	C	SA-283	C	Structural quality. For pressure vessel may be used with limitations see note :1
	C	SA-285	C	Boilers for stationary service and other pressure vessels
	C - Si	SA-515	55 *	Primarily for intermediate and high temperature service
	C - Si	SA-515	60 *	– " –
	C - Si	SA-515	65	– " –
	C - Si	SA-515	70	– " –
	C - Si	SA-516	55 *	For moderate and lower temperature service
	C - Si	SA-516	60 *	– " –
	C - Mn - Si	SA-516	65 *	– " –
	C - Mn - Si	SA-516	70 *	– " –
Flange and Fitting	C - Mn - Si	SA-105		For high temperature service
	C - Si	SA-181	I	For general service
	C - Mn C - Mn - Si	SA-350	LF1 LF2	For low temperature service
Pipe	C - Mn	SA-53	B	For general service
	C - Mn	SA-106	B	For high temperature service
Bolting	1Cr-1/5 Mo.	SA-193	B7 *	For high temperature service Bolt 2½ in. diam. or less
		SA-194	2H	For high temperature service nut
		SA-307	B *	Machine bolt for general use
				*For low temperature operation see page 185

* Data of the most frequently used materials from ASME Code Section II and VIII.

PROPERTIES OF MATERIAL (cont.)

Form	Specification Number	Specification Grade	P Number	Tensile Strength 1,000 psi.	Yield Point 1,000 psi.		See Notes
PLATE	SA-283	C	1	55.0	30.0		1
	SA-285	C	1	55.0	30.0		2,6
	SA-515	55	1	55.0	30.0		3
	SA-515	60	1	60.0	32.0		3
	SA-515	65	1	65.0	35.0		3
	SA-515	70	1	70.0	38.0		3
	SA-516	55	1	55.0	30.0		3,8
	SA-516	60	1	60.0	32.0		3,8
	SA-516	65	1	65.0	35.0		3,8
	SA-516	70	1	70.0	38.0		3,8
FLANGE AND FITTING	SA-105		1	70.0	36.0		2,3
	SA-181	I	1	60.0	30.0		2,3
	SA-350	LF1 LF2	1	60.0 70.0	30.0 36.0		–
Seamless PIPE	SA-53	B	1	60.0	35.0		2,3,4,7
	SA-106	B	1	60.0	35.0		3
BOLTING	SA-193	B7	–	125.0	105.0	DIAM > 2½ in and < 4 in	–
	SA-194	2H	–	55.0	–		–
	SA-307	B	–	55.0	–		5

PROPERTIES OF MATERIAL
(continued)

NOTES:

1. SA-36 and SA-283 ABCD plate may be used for pressure parts in pressure vessels provided all of the following requirements are met:

   (1) The vessels are not used to contain lethal substances, either liquid or gaseous;

   (2) Tmaterial is not used in the construction of unfired steam boilers (see Code U-1 (g) .;

   (3) With the exception of flanges, flat bolted covers, and stiffening rings on which strength welding is applies does not exceed 5/8 in.

2. For service temperatures above 850° F it is recommended that killed steels containing not less than 0.10% residual silicon be used. Killed steels which have been deoxidized with large amounts of aluminum and rimmed steels may have creep and stress-rupture properties in the temperature range above 850° F, which are somewhat less than those on which the values in the table are based.

3. Upon prolonged exposure to temperatures above 800° F, the carbide phase of carbon steel may be converted to graphite.

4. Only killed steel shall be used above 850° F.

5. Not permitted above 450° F, allowable stress value 7000 psi.

6. The material shall not be used in thicknesses above 2 in.

7. For welded pipe maximum allowable stress values are 15% less. No increase in these stress values shall be allowed for the performance of radiography.

8. The stress values to be used for temperatures below -20° F when steels are made to conform with supplement (5) SA-20 shall be those that are given in the column for -20 to 650° F.

MODULI OF ELASTICITY FOR FERROUS MATERIALS

Material	Million psi, for Temperature F. of										
	70	200	300	400	500	600	700	800	900	1000	1100
Carbon steels with C≤ 0.30%	29.5	28.8	28.3	27.7	27.3	26.7	25.5	24.2	22.4	20.4	18.0
Carbon steels with C> 0.30%	29.3	28.6	28.1	27.5	27.1	26.5	25.3	24.0	22.3	20.2	17.9
High alloy steels	28.3	27.6	27.0	26.5	25.8	25.3	24.8	24.1	23.5	22.8	22.1

The values in the External Pressure Charts are intended for external pressure calculations only.

PROPERTIES OF MATERIALS CARBON & LOW ALLOY STEEL
Maximum Allowable Stress Values in Tension 1000 psi. *

Specification		For Metal Temperature Not Exceeding Deg. F.										
Number	Grade	-20to 650	700	750	800	850	900	950	1050	1100	1150	1200
SA-283	C	13.8	-	-	-	-	-	-	-	-	-	-
SA-285	C	13.8	13.3	12.1	10.2	8.4	6.5	-	-	-	-	-
SA-515	55	13.8	13.3	12.1	10.2	8.4	6.5	4.5	2.5	-	-	-
SA-515	60	15.0	14.4	13.0	10.8	8.7	6.5	4.5	2.5	-	-	-
SA-515	65	16.3	15.5	13.9	11.4	9.0	6.5	4.5	2.5	-	-	-
SA-515	70	17.5	16.6	14.8	12.0	9.3	6.5	4.5	2.5	-	-	-
SA-516	55	13.8	13.3	12.1	10.2	8.4	6.5	4.5	2.5	-	-	-
SA-516	60	15.0	14.4	13.0	10.8	8.7	6.5	4.5	2.5	-	-	-
SA-516	65	16.3	15.5	13.9	11.4	9.0	6.5	4.5	2.5	-	-	-
SA-516	70	17.5	16.6	14.8	12.0	9.3	6.5	4.5	2.5	-	-	-
SA-105		17.5	16.6	14.8	12.0	9.3	6.5	4.5	2.5	-	-	-
SA-181	I	15.0	14.4	13.0	10.8	8.7	6.5	4.5	2.5	-	-	-
SA-350	LF1 LF2	15.0 17.5	14.4 16.6	13.0 14.8	10.8 12.0	7.8 7.8	5.0 5.0	3.0 3.0	1.5 1.5	-	-	-
SA-53	B	15.0	14.4	13.0	10.8	8.7	6.5	-	-	-	-	-
SA-106	B	15.0	14.4	13.0	10.8	8.7	6.5	4.5	2.5	-	-	-
SA-193	B7 ≤ 2½"	25.0	25.0	23.6	21.0	17.0	12.5	8.5	4.5	-	-	-
SA-194	2H	-	-	-	-	-	-	-	-	-	-	-
SA-307	B		-	-	-	-	-	-	-	-	-	-

See page 177 for low temperature operation.

* The Stress Values in this table may be interpolated to determine values for intermediate temperatures.

PROPERTIES OF MATERIALS
STAINLESS STEEL

P- No. 8 Group No. 1

NOMINAL COMPOSITION 18 Cr - 8 Ni

TABLE 1

Min. Yield, Ksi. 30.0
Min. Tensile ksi. 75.0

Product	Spec. No.	Grade	Notes
Plate	SA-240	304	2 3
Smls. Tb.	SA-213	TP304	2
Smls. Tb.	SA-213	TP304H	—
Smls. Pp.	SA-312	TP304	2
Smls. Pp.	SA-312	TP304H	—
Smls. Pp.	SA-376	TP304	2
Smls. Pp.	SA-376	TP304H	—
Cast. Pp.	SA-452	TP304H	—
Forg.	SA-182	F304	2
Forg.	SA-182	F304H	—
Bar	SA-479	304	2 3 5

TABLE 2

Yield 25.0
Tens 70.0

Product	Spec. No.	Grade	Notes
Plate	SA-240	304L	—
Smls. Tb.	SA-213	TP304L	—
Smls. Pp.	SA-312	TP304L	—
Bar	SA-479	304L	5

NOMINAL COMPOSITION 16 Cr - 12 Ni - 2 Mo.

TABLE 3

Min. Yield, ksi 30.0
Min. Tensile, ksi. 75.0

Product	Spec. No.	Grade	Notes
Plate	SA-240	316	2 3
Plate	SA-240	317	2 3
Smls. Tb.	SA-213	TP316	2
Smls. Tb.	SA-213	TP316H	—
Smls. Pp.	SA-312	TP316	2
Smls. Pp.	SA-312	TP316H	—
Smls. Pp.	SA-312	317	2
Smls. Pp.	SA-376	TP316	2
Smls. Pp.	SA-376	TP316H	—
Cast Pp.	SA-452	TP316H	—
Forg.	SA-182	F316	2
Forg.	SA-182	F316H	—
Bar	SA-479	316	2 3 5

TABLE 4

Yield 25.0
Tens 70.0

Product	Spec. No.	Grade	Notes
Plate	SA-240	316L	—
Smls. Tb.	SA-213	TP316L	—
Smls. Pp.	SA-312	TP316L	—
Bar	SA-479	316L	5

MAXIMUM ALLOWABLE STRESS VALUES, 1.000 psi.

MATERIALS IN TABLE	FOR METAL TEMPERATURES NOT EXCEEDING DEG. °F.												
	-20 - 100	200	300	400	500	600	650	700	750	800	850	900	NOTES
1	18.8 18.8	17.8 15.7	16.6 14.1	16.2 12.9	15.9 12.1	15.9 11.4	15.9 11.2	15.9 11.1	15.6 10.8	15.2 10.6	14.9 10.4	14.7 10.2	1
2	16.7 16.3	16.5 14.3	15.3 12.8	14.7 11.7	14.4 10.9	14.0 10.3	13.7 10.1	13.5 10.0	13.3 9.8	13.0 9.7			1
3	18.8 18.8	18.8 17.7	18.4 15.6	18.1 14.3	18.0 13.3	17.0 12.6	16.7 12.3	16.3 12.1	16.1 11.9	15.9 11.7	15.7 11.6	15.6 11.5	1
4	16.7 16.7	16.7 14.1	16.0 12.7	15.6 11.7	14.8 10.9	14.0 10.4	13.8 10.2	13.5 10.0	13.2 9.8	13.0 9.6	12.7 9.4		1

MATERIALS IN TABLE	FOR METAL TEMPERATURES NOT EXCEEDING DEG. °F.												
	950	1000	1050	1100	1150	1200	1250	1300	1350	1400	1450	1500	
1	14.4 10.0	14.1 9.8	12.4 9.5	9.8 8.9	7.7 7.7	6.1 6.1	4.7 4.7	3.7 3.7	2.9 2.9	2.3 2.3	1.8 1.8	1.4 1.4	1
3	15.4 11.4	15.3 11.3	14.5 11.2	12.4 11.0	9.8 9.8	7.4 7.4	5.5 5.5	4.1 4.1	3.1 3.1	2.3 2.3	1.7 1.7	1.3 1.3	1

NOTES:
1. These higher stress values exceed 2/3 but do not exceed 90% of the yield strength at temperature. Use of these stress values may result in dimensional changes due to permanent strain. These stress values are not recommended for flanges or gasketed joints or other applications where slight amounts of distortion can cause leakage or malfunction.
2. At temperatures above 1000°F, these stress values apply only when the carbon is 0.04% or higher.
3. For temperatures above 1000°F, these stress values may be used only if the material is heat treated by heating it to a minimum temperature of 1900°F and quenching in water or rapidly cooling by other means.
4. Specified min. tensile, ksi 65.0.
5. Use of external pressure charts for material in the form of barstock is permitted for stiffening rings only.

THERMAL EXPANSION

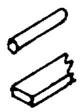
Linear Thermal Expansion between 70F and Indicated Temperature, Inches/100 Feet

THE DATA OF THIS TABLE ARE TAKEN FROM THE AMERICAN STANDARD CODE FOR PRESSURE PIPING. IT IS NOT TO BE IMPLIED THAT MATERIALS ARE SUITABLE FOR ALL THE TEMPERATURES SHOWN IN THE TABLE.

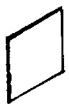
Temp. deg F	MATERIAL									
	Carbon Steel Carbon-Moly Low-Chrome (thru 3 Cr Mo)	5 Cr Mo thru 9 Cr Mo	Austenitic Stainless Steels 18 Cr 8 Ni	12 Cr 17 Cr 27 Cr	25 Cr 20 Ni	Monel 67 Ni 30 Cu	3½ Nickel	Aluminum	Gray Cast Iron	Bronze
−325	−2.37	−2.22	−3.85	−2.04		−2.62	−2.25	−4.68		−3.98
−300	−2.24	−2.10	−3.63	−1.92		−2.50	−2.17	−4.46		−3.74
−275	−2.11	−1.98	−3.41	−1.80		−2.38	−2.07	−4.21		−3.50
−250	−1.98	−1.86	−3.19	−1.68		−2.26	−1.96	−3.97		−3.26
−225	−1.85	−1.74	−2.96	−1.57		−2.14	−1.86	−3.71		−3.02
−200	−1.71	−1.62	−2.73	−1.46		−2.02	−1.76	−3.44		−2.78
−175	−1.58	−1.50	−2.50	−1.35		−1.90	−1.62	−3.16		−2.54
−150	−1.45	−1.37	−2.27	−1.24		−1.79	−1.48	−2.88		−2.31
−125	−1.30	−1.23	−2.01	−1.11		−1.59	−1.33	−2.57		−2.06
−100	−1.15	−1.08	−1.75	−0.98		−1.38	−1.17	−2.27		−1.81
− 75	−1.00	−0.94	−1.50	−0.85		−1.18	−1.01	−1.97		−1.56
− 50	−0.84	−0.79	−1.24	−0.72		−0.98	−0.84	−1.67		−1.32
− 25	−0.68	−0.63	−0.98	−0.57		−0.77	−0.67	−1.32		−1.25
0	−0.49	−0.46	−0.72	−0.42		−0.57	−0.50	−0.97		−0.77
25	−0.32	−0.30	−0.46	−0.27		−0.37	−0.32	−0.63		−0.49
50	−0.14	−0.13	−0.21	−0.12		−0.20	−0.15	−0.28		−0.22
70	0	0	0	0	0	0	0	0	0	0
100	0.23	0.22	0.34	0.20	0.32	0.28	0.23	0.46	0.21	0.36
125	0.42	0.40	0.62	0.36	0.58	0.52	0.42	0.85	0.38	0.66
150	0.61	0.58	0.90	0.53	0.84	0.75	0.61	1.23	0.55	0.96
175	0.80	0.76	1.18	0.69	1.10	0.99	0.81	1.62	0.73	1.26
200	0.99	0.94	1.46	0.86	1.37	1.22	1.01	2.00	0.90	1.56
225	1.21	1.13	1.75	1.03	1.64	1.46	1.21	2.41	1.08	1.86
250	1.40	1.33	2.03	1.21	1.91	1.71	1.42	2.83	1.27	2.17
275	1.61	1.52	2.32	1.38	2.18	1.96	1.63	3.24	1.45	2.48
300	1.82	1.71	2.61	1.56	2.45	2.21	1.84	3.67	1.64	2.79
325	2.04	1.90	2.90	1.74	2.72	2.44	2.05	4.09	1.83	3.11
350	2.26	2.10	3.20	1.93	2.99	2.68	2.26	4.52	2.03	3.42
375	2.48	2.30	3.50	2.11	3.26	2.91	2.47	4.95	2.22	3.74
400	2.70	2.50	3.80	2.30	3.53	3.25	2.69	5.39	2.42	4.05
425	2.93	2.72	4.10	2.50	3.80	3.52	2.91	5.83	2.62	4.37
450	3.16	2.93	4.41	2.69	4.07	3.79	3.13	6.28	2.83	4.69
475	3.39	3.14	4.71	2.89	4.34	4.06	3.35	6.72	3.03	5.01
500	3.62	3.35	5.01	3.08	4.61	4.33	3.58	7.17	3.24	5.33
525	3.86	3.58	5.31	3.28	4.88	4.61	3.81	7.63	3.46	5.65
550	4.11	3.80	5.62	3.49	5.15	4.90	4.04	8.10	3.67	5.98
575	4.35	4.02	5.93	3.69	5.42	5.18	4.27	8.56	3.89	6.31
600	4.60	4.24	6.24	3.90	5.69	5.46	4.50	9.03	4.11	6.64
625	4.86	4.47	6.55	4.10	5.96	5.75	4.74		4.34	6.96
650	5.11	4.69	6.87	4.31	6.23	6.05	4.98		4.57	7.29
675	5.37	4.92	7.18	4.52	6.50	6.34	5.22		4.80	7.62
700	5.63	5.14	7.50	4.73	6.77	6.64	5.46		5.03	7.95
725	5.90	5.38	7.82	4.94	7.04	6.94	5.70		5.26	8.28
750	6.16	5.62	8.15	5.16	7.31	7.25	5.94		5.50	8.62
775	6.43	5.86	8.47	5.38	7.58	7.55	6.18		5.74	8.96
800	6.70	6.10	8.80	5.60	7.85	7.85	6.43		5.98	9.30
825	6.97	6.34	9.13	5.82	8.15	8.16	6.68		6.22	9.64
850	7.25	6.59	9.46	6.05	8.45	8.48	6.93		6.47	9.99
875	7.53	6.83	9.79	6.27	8.75	8.80	7.18		6.72	10.33
900	7.81	7.07	10.12	6.49	9.05	9.12	7.43		6.97	10.68
925	8.08	7.31	10.46	6.71	9.35	9.44	7.68		7.23	11.02
950	8.35	7.56	10.80	6.94	9.65	9.77	7.93		7.50	11.37
975	8.62	7.81	11.14	7.17	9.95	10.09	8.17		7.76	11.71
1000	8.89	8.06	11.48	7.40	10.25	10.42	8.41		8.02	12.05
1025	9.17	8.30	11.82	7.62	10.55	10.75				12.40
1050	9.46	8.55	12.16	7.95	10.85	11.09				12.76
1075	9.75	8.80	12.50	8.18	11.15	11.43				13.11
1100	10.04	9.05	12.84	8.31	11.45	11.77				13.47
1125	10.31	9.28	13.18	8.53	11.78	12.11				
1150	10.57	9.52	13.52	8.76	12.11	12.47				
1175	10.83	9.76	13.86	8.98	12.44	12.81				
1200	11.10	10.00	14.20	9.20	12.77	13.15				
1225	11.38	10.26	14.54	9.42	13.10	13.50				
1250	11.66	10.53	14.88	9.65	13.43	13.86				
1275	11.94	10.79	15.22	9.88	13.76	14.22				
1300	12.22	11.06	15.56	10.11	14.09	14.58				
1325	12.50	11.30	15.90	10.33	14.39	14.94				
1350	12.78	11.55	16.24	10.56	14.69	15.30				
1375	13.06	11.80	16.58	10.78	14.99	15.66				
1400	13.34	12.05	16.92	11.01	15.29	16.02				
1425			17.30							
1450			17.69							
1475			18.08							
1500			18.47							

DESCRIPTION OF MATERIALS

When describing various vessel components and parts on drawings and in bill of materials, it is advisable that a standard method be followed. For this purpose it is recommended the use of the widely accepted abbreviations in the sequences exemplified below. For ordering material the requirements of manufacturers should be observed.

	PART	DESCRIPTION	MATERIAL SPECIFICATION
	BAR	Bar 2 x 1/4 x 3'-6 Bar 3/4 ∅ x 2'-0 Bar 1 ⌗ x 3'-0	SA-7
	BOLT	3/4 ∅ x 2-1/2 H. Hd. M. B. w/ (1) sq. nut 1 ∅ x 5-1/2 stud w/ (2) h. nuts	SA-193 B7 bolt SA-194 2H nut
	CAP	8" Std. Cap	
	Screwed COUPLING	1" – 6000 # Cplg. 2" – 3000 # Cplg. 1" - 6000 # Half Cplg. 1" - 6000 # 4-1/2 Lg. Cplg.	SA-105
	Welding ELBOW	6"- Std. 90° L. R. Ell. 4"- X Stg. 45° S. R. Ell. 6" x 4" Std. L. R. Red. Ell	SA-234 WPB
	FLANGE	4" - 300 # RF. So. Flg. 6" - 150 # RF. Wn. Flg. Std. Bore 6" - 600 # RTJ. Wn. Flg. X Stg. Bore 3" - 150 # FF. So. Flg. 8" - 150 # R.F. Bld. Flg.	SA-181 1
  	Screwed Socket Welding FORGED FITTING	1" - 6000 # 90° Scr'd. Ell. 1" - 3000 # 90° Scr'd. Street Ell. 2" - 3000 # S.W. Cplg. 1" - 3000 # Sq. Hd. Plug 2" - 6000 # Scr'd. Tee 2" - 3000 # 45° S. W. Ell.	SA-105
	GASKET	18 - 150 # 1/16" Serv. Sht. Gasket 18 - 300 # Spiral Wound ASB. Filled	ASB.
	HEAD	48" ID x 0.375 min. 2:1 ellip. head 2" S.F. 48" OD x 0.500" min. ASME F & D Head 2 S.F. L = 48" r = 3" 54" ID x 0.375" min. Hemis. Head	SA-285 C SA-515-70 SA-516-70

DESCRIPTION OF MATERIALS (cont.)

	Long Welding Neck	18" - 300 RF. LWN	SA-181 1
	PIPE	6" - Std. Pipe x 2' -1 8" - X Stg. Pipe x 1' - 6-1/2 4" - S. 160 Pipe x 2' -4 24" - 0.438" Wall Pipe x 1' - 0	SA-53 B
	PLATE	PL 96" x 3/8 x 12' - 6 PL 24" OD x 1/2 x 18" ID PL 18" OD x 1-1/2	SA-285 C
	Welding REDUCER	6" x 4" Std. Conc. Reducer 8" x 6" X Stg. Ecc. Reducer	SA-234 WPB
	Welding RETURN	6" - Std. 180° L. R. Return 4" - X Stg. 180° S. R. Return	SA-234 WPB
	Welding TEE	4" - Std. Tee 6" x 6" x 4" X Stg. Red. Tee	SA-234 WPB

EQUIVALENT AND COMPARABLE MATERIALS OF FOREIGN COUNTRIES

U.S.A.	France	Germany West (Fed. Rep.)	Germany East (D. Rep.)	Former Soviet Union	Japan
SA - 204 *B*	15 *D* 3	1.6415/15 *Mo* 3	15 *Mo* 3	—	—
SA - 283 *A*	≈ *A* 33	≈1.0035 / ≈ *St* 33	≈ *St* 33	CT O-2	—
SA - 283 *C*	*TS E* 24 *a*	≈1.0036 / *Ust* 37-2	*St* 38*u* - 2	*CT* 3 *kn* 2	—
SA - 284 *B*	≈ *E* 24 – 2	≈ 1,0038 / ≈ *Rst* 37-2	*St* 38 *b* - 2	*BCt* 3 *cn* 2	—
SA - 284 *B*	*E - 24 - 3*	1.0116 / *St* 37-3	*St* 38-3	≈181 *cn*	—
SA - 285 *C*	*A* 37	1.0345/*HI*	*Mb* 13	≈ 12 *K*	—
SA - 299					
SA - 455	*A* 52	1.0844 / 17 *Mn* 4	17 *Mn* 4	K47	
SA - 440	15 *CD* 2.05	1.7335/13 *CrMor*	13 *CrMor* 4.4	12 X *M*	—
SA - 440					
SA- 572-55	*A* 50-2	1.0050/*St* 50-2	*St* 50	*Ct* 5 *Cn* 3	*SS* 50
SA - 515 60	*A* - 42	1.0425 / H II	*Mb* 16	16 *k*	—
SA - 515 70	—	1.0435 / H III	*Mb* 19	18 *k*	—
SA - 516 60	*A* - 42	1.0425 / H II	*Mb* 16	16 *k*	—
SA - 516-70	—	1.0435 / H III	*Mb* 19	18 *k*	—
SA - 572-55	*A* 50-2	1.0050 / *St* 50-2	*St* 50	*Ct* 5 *Cn* 3	*SM* 53 *C*
SA - 240-304	—	1.4301 / X 5 *Cr Ni* 189	X5 *CrNi* 189	08 X 18 *H* 10	*SM* 53 *C*
SA - 240 -316*L*	≈*Z2 CNDIT*-12	≈1.4404/ X 2 *CrNiMo* 1810	X8*CrNiTi* 1810	03X17*H*14*M*2	316*L*

SPECIFICATION
FOR THE DESIGN AND FABRICATION OF PRESSURE VESSELS

NOTES

Pressure vessel users and manufacturers have developed certain standard practices which have proven advantageous in the design and construction of pressure vessels. This specification includes those practices which have become the most widely acceptable and followed.

These standards are partly references to the selected alternatives permitted by the ASME Code, and partly described design and construction methods not covered by the Code. The regulations of the Code are not quoted in this Specification.

A. GENERAL

1. This Specification together with the purchase order and drawings covers the requirements for the design and fabrication of pressure vessels.
2. In case of conflicts, the purchase order and drawings take precedence over this Specification.
3. Pressure vessels shall be designed, fabricated, inspected and stamped in accordance with the latest edition of the ASME Boiler and Pressure Vessel Code, Section VIII, Division 1, and its subsequent addenda.
4. Vessels and vessel appurtenances shall comply with the regulations of the Occupational Safety and Health Act (OSHA).
5. Vessel Manufacturers are invited to quote prices on alternate materials and construction methods if economics or other aspects make it reasonable to do so.
6. All deviations from this Specification, the purchase order, or the drawings shall have the written approval of the Purchaser.
7. Vessel fabricator, after receipt of purchase order, shall furnish to purchaser checked shop drawings for approval.

B. DESIGN

1. Pressure Vessels shall be designed to withstand the **loadings** exerted by internal or external pressure, weight of the vessel, wind, earthquake, reaction of supports, impact, and temperature.
2. The maximum allowable working **pressure shall be limited** by the shell or head, not by minor parts.
3. **Wind load and earthquake.** All vessels shall be designed to be free-standing. To determine the magnitude of wind pressure, the probability of earthquakes and seismic coefficients in various areas of the United States Standard ANSI/ASCE 7-93 (Minimum Design Loads in Buildings and Other Structures) shall be applied.

   It is assumed that wind and earthquake loads do not occur simultaneously, thus the vessel should be designed for either wind or earthquake loading, whichever is greater.
4. **Horizontal vessels supported by saddles** shall be designed according to the method of L. P. Zick, (Stresses in Large Horizontal Pressure Vessels on Two Saddle Supports).
5. The **deflection** of vertical vessels under normal operating conditions shall not exceed 6 inches per 100 feet of length.

Specification for the Design and Fabrication of Pressure Vessels (continued)

6. Stresses in skirts, saddles, or other supports and their attachment welds may exceed the maximum allowable stress values of materials given in Part UCS of the ASME Code by 33-1/3 percent.
7. Vessel manufacturers shall submit **designs for approval** when purchaser does not furnish a design or does not specify the required plate thickness.

C. **FABRICATION**

1. **Materials** shall be specified by purchaser and their designation indicated on the shop drawings. Materials shall not be substituted for those specified without prior written approval of purchaser.
2. The **thickness of plate** used for shell and heads shall be 1/4-inch minimum.
3. Manufacturer's **welding procedure and qualification records** shall be submitted for approval upon receipt of purchase order. Welding shall not be performed prior to purchaser's approval of welding procedure and qualification.

   All **welding** shall be done by the metallic shielded arc or the submerged arc welding process.

   Permanently installed **backing strips** shall not be used without written approval of purchaser. When used, backing strips shall be the same composition steel as that which they are attached to.

4. **Longitudinal seams** in cylindrical or conical shells, all seams in spherical shells and built-up heads shall be located to clear openings, their reinforcing pads, and saddle-wear plates. **Circumferential seams** of shell shall be located to clear openings, their reinforcing pads, tray and insulation support rings, and saddle wear plates. When the covering of circumferential seam by reinforcing pad is unavoidable, the seam shall be ground flush and examined prior to welding the reinforcing pad in place.

   No longitudinal joints shall be allowed within the downcomer area or at any other place where proper visual inspection of the weld is impossible.

   The minimum size of **fillet weld** serving as strength weld for internals shall be 1/4 inch.

5. **Skirt.** Vertical vessels shall be provided with a skirt which shall have an outside diameter equal to the outside diameter of the supported vessel . . The minimum thickness for a skirt shall be 1/4 inch.

   Skirts shall be provided with a minimum of two 2-inch vent holes located as high as possible 180 degrees apart.

   Skirts 4 feet in diameter and less shall have one access opening; larger than 4-foot diameter skirts shall have two 18-inch O.D. access openings reinforced with sleeves.

6. **Base rings** shall be designed for an allowable bearing pressure on concrete of 625 psi.
7. **Anchor bolt chairs** or lug rings shall be used where required and in all cases where vessel height exceeds 60 feet. The number of anchor bolts shall be in multiples of 4; a minimum of 8 is preferred.
8. **Saddle.** Horizontal vessels shall be supported by saddles, preferably by only two whenever possible.

   Saddles shall be welded to the vessel, except when specifically ordered to be shipped loose. Saddles to be shipped loose shall be fitted to the vessel and match-marked for field installation. The shop drawing shall bear detailed instruction concerning this.

Specification for the Design and Fabrication of Pressure Vessels (continued)

When temperature expansion will cause more than 3/8 inch change in the distance between the saddles, a slide bearing plate shall be used. Where the vessel is supported by concrete saddles 1/4 inch thick, corrosion plate 2 inches wider than the concrete saddle shall be welded to the shell with a continuous weld. The corrosion plate shall be provided with a 1/4 inch vent hole plugged with plastic sealant after the vessel has been pressure tested.

9. **Openings** of 2 inches and smaller shall be 6000 lb forged steel full or half coupling.

Openings 2-1/2 inches and larger shall be flanged.

Flanges shall conform to Standard ANSI B16.5-1973.

Flange faces shall be as follows:

Raised face. . . . . below rating 600 lb ANSI

Raised face. . . . . rating 600 lb ANSI, pipe size 3 inches and smaller

Ring type joint. . . . . . rating 600 lb ANSI, pipe size 4 inches and larger

Ring type joint. . . . . . above rating 600 lb ANSI.

Flange-bolt-holes shall straddle the principal centerlines of the vessel. Openings shall be flush with inside of vessel when used as drains or when located so that there would be interference with vessel internals. Internal edges of openings shall be rounded to a minimum radius of 1/8 inch or to a radius equal to one-half of the pipe wall thickness when it is less than 1/4 inch.

When the inside diameter of the nozzle neck and the welding neck flange or welding fitting differ by 1/16 inch or more, the part of smaller diameter shall be tapered at a ratio 1:4.

Openings shall be **reinforced** for new and cold, as well as for corroded condition.

The plate used for reinforcing pad shall be the same composition steel as that used for the shell or head to which it is connected.

Reinforcing pads shall be provided with a 1/4 inch tapped tell-tale hole located at 90° off the longitudinal axis of vessel.

The minimum outside diameter of the reinforcing pad shall be 4 inches plus the outside diameter of the opening's neck.

When covers are to be provided for openings according to the purchaser's requisition, manufacturer shall furnish the required gaskets and studs; these shall not be used for testing the vessel.

Manway covers shall be provided with **davits.**

Coupling threads must be clean and free from defects after installation.

10. **Internals.** Trays shall be furnished by tray fabricator and installed by vessel manufacturer. Tray support rings and downcomer bolting bars shall be furnished and installed by vessel manufacturer. The tray fabricator shall submit complete shop details, including installation instructions and packing list, to purchaser for approval and transmittal to vessel fabricator.

Trays shall be designed for a uniform live load of 10 psf or the weight of water setting, whichever is greater, and for a concentrated live load of 250 lb.

At the design loading the maximum deflection of trays shall not exceed

up to 10-foot diameter - 1/8 inch

larger than 10-foot diameter - 3/16 inch

Specification for the Design and Fabrication of Pressure Vessels (continued)

The minimum thickness of internal plateworks and support rings shall not be less than 1/4 inch.

Internal carbon steel **piping** shall be standard weight.

Internal flanges shall be ANSI 150-lb slip-on type or fabricated from plate.

Carbon steel **internal flanges** shall be fastened with carbon steel square-head machine bolts and square nuts tack-welded to the flanges to avoid loosening.

Removable internals shall be made in sections which can be removed through the manways.

Removable internals shall not be provided with corrosion allowance. For openings connected to pump suction, a vortex breaker shall be provided.

11. **Appurtenances.** Vessels provided with manways, liquid level controls or relief valves 12 feet above grade, shall be equipped with caged ladders and platforms.

    Ladder and platform lugs shall be shop-welded to the vessel. Where vertical vessels require insulation, fabricator shall furnish and install support rings. Reinforcing rings may also be utilized in supporting insulation.

    Insulation support rings shall be 1/2 inch less in width than the thickness of insulation and spaced 12 foot-1/2 inch clear starting at the top tangent line. The top ring shall be continuously welded to the head; all other rings may be attached by a 1-inch long fillet weld on 12-inch centers. The bottom head of insulated vertical vessel shall be equipped with 1/2-inch square nuts welded with their edges to the outside of the head on approximately 12-inch square centers.

12. **Fabrication tolerances** shall not exceed the limits indicated in the table beginning on page 170.

D. **INSPECTION**

1. Purchaser reserves the right to inspect the vessel at any time during fabrication to assure that the vessel materials and the workmanship are in accordance with this specification.
2. The approval of any work by the purchaser's representative and his release of a vessel shall not relieve the manufacturer of any responsibility for carrying out the provisions of this specification.

E. **MISCELLANEOUS**

1. **Radiographic examination** shall be performed when required by the ASME Code or when determined by the economics of design.
2. The completed vessel shall be provided with a **name plate** securely attached to the vessel by welding.
3. If the vessel is **post-weld heat-treated,** no welding is permitted after stress relieving.
4. **Removable internals** shall be installed after stress relieving.
5. The location of all vessel components openings, seams, internals, etc., of the vessel shall be indicated on the shop drawings by the distance to a common **reference line**. The reference line shall be permanently marked on the shell.
6. The **hydrostatic test pressure** shall be maintained for an adequate time to permit a thorough inspection, in any case not less than 30 minutes.
7. Vessels shall not be **painted** unless specifically stated on order.

Specification for the Design and Fabrication of Pressure Vessels (continued)

F. PREPARATION FOR SHIPMENT

1. After final hydrostatic test, vessel shall be dried and cleaned thoroughly inside and outside to remove grease, loose scale, rust and dirt.
2. All finished surfaces which are not protected by blind flanges shall be coated with rust preventative.
3. All flanged openings which are not provided with covers shall be protected by suitable steel plates.
4. Threaded openings shall be plugged.
5. For internal parts, suitable supports shall be provided to avoid damage during shipment.
6. Bolts and nuts shall be coated with waterproof lubricant.
7. Vessels shall be clearly identified by painting the order and item number in a conspicuous location on the vessel.
8. Small parts which are to be shipped loose shall be bagged or boxed and marked with the order and item number of the vessel.
9. Vessel fabricator shall take all necessary precautions in loading by blocking and bracing the vessel and furnishing all necessary material to prevent damages.

G. FINAL REPORTS

1. Before the vessel is ready for shipment the manufacturer shall furnish purchaser copies or reproducible transparency each of the following reports:
   a. Manufacturer's data report.
   b. Shop drawings showing the vessel and dimensions "as built".
   c. Photostatic copies of recording charts showing pressure during hydrostatic test.
   d. Photostatic copies of recording charts showing temperature during post-weld heat treatment.
   e. Rubbing of name plate.

H. GUARANTEE

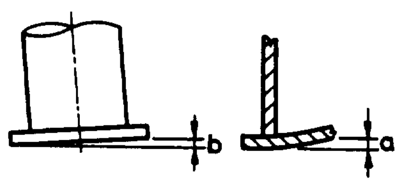
Manufacturer guarantees that the vessel fulfills all conditions as stated in this Specification and that it is free from fault in design, workmanship and material. Should any defect develop during the first year of operation, the manufacturer agrees to make all necessary alterations, repairs and replacements free of charge.

VESSEL FABRICATION TOLERANCES

The dimensional tolerances in this table - unless otherwise noted - are based on practice widely followed by users and manufacturers of pressure vessels.

All tolerances are inches, unless otherwise indicated.

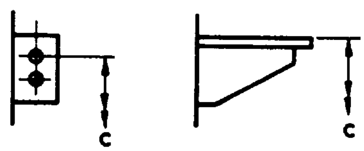
Tolerances not listed in this table shall be held within a practical limit.



Base Ring

a. Flatness . . . . ± 1/16

b. Out of level . . . . ± 1/8

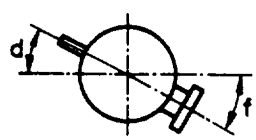


Clips, Brackets

c. Distance to the reference line . . . . ± 1/4

d. Deviation circumferentially measured at the joint of structure . . . . ± 1/4

Distance between two adjacent clips. ± 1/16

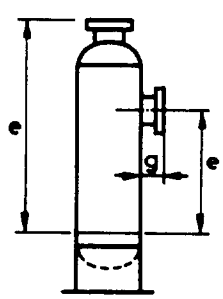


Manway

e. Distance from the face of flange or centerline of manway to reference line, vessel support lug, bottom of saddle, centerline of vessel, whichever is applicable . . . . ± 1/2

f. Deviation circumferentially measured on the outer surface of vessel . . . . ± 1/2

g. Projection; shortest distance from outside surface of vessel to the face of manway . . . . ± 1/2



h. Deviation from horizontal, vertical or the intended position in any direction . . . . ± 1°

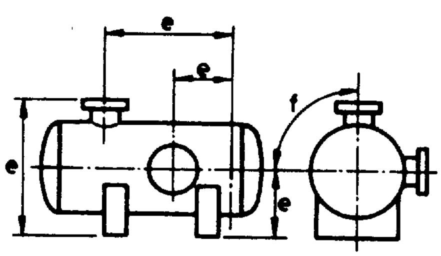
i. Deviation of bolt holes in any direction . . . . ± 1/4

Nozzle, Coupling which are not to be connected to piping.

The tolerances for manways shall be applied.

Nozzle, Coupling which are to be connected to piping.

Distance from the face of flange or centerline of opening to reference line, vessel support lug, bottom of saddle, centerline of vessel, whichever is applicable . . . . ± 1/4

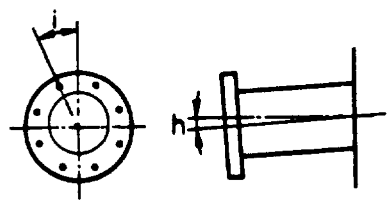


f. Deviation circumferentially measured on the outer surface of vessel . . . . ± 1/4

g. Projection; shortest distance from outside surface of vessel to the face of opening . . . . ± 1/4

VESSEL FABRICATION TOLERANCES
(continued)

Nozzles, (continued)



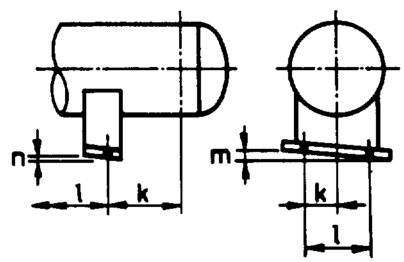
h. Deviation from horizontal, vertical or the intended position in any direction . . . . ± 1/2°

i. Deviation of bolt holes in any direction . . . . ± 1/8

Nozzles, Couplings used for level gage, level control, etc.

Distance between centerline of openings . . . . ± 1/16

Saddle



k. Distance centerline of boltholes to reference line . . . . ± 1/8

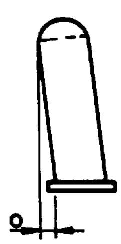
k. Distance centerline of boltholes to centerline of shell . . . . ± 1/8

l. Distance between boltholes in base plate or between boltholes or slots of two saddles. . . . . ± 1/8

m. Transverse tilt of base plate . . . . . ± 1/32 per Ft.

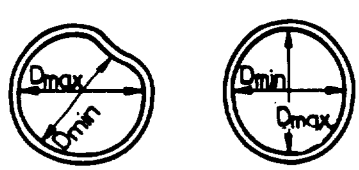
n. Longitudinal tilt of base plate . . . . ± 1/8

Shell



o. Deviation from verticallity for vessels of up to 30 ft overall length . . . . . ± 1/2

for vessels of over 30 ft overall length ± 1/8 per 10 ft. max. 1-1/2



$D_{max} - D_{min} = P$

p. Vessels for internal pressure. The difference between the maximum and minimum inside diameters at any cross section shall not exceed one percent of the nominal diameter at the cross section . . . . ± 1%

Deviation from nominal inside diameter as determined by strapping . . . . . ± 1/32 per Ft.

Out of roundness Code UG-80

External pressure. See Code UG-80

Formed Heads, Code UG-81

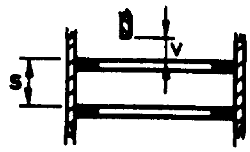
Tray Installation

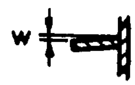
r. Out of level in any direction . . . . . ± 1/32 per Ft.

Tray Support

r. Out of level in any direction . . . . . ± 1/32 per Ft.

VESSEL FABRICATION TOLERANCES
(continued)





Tray Support (continued)

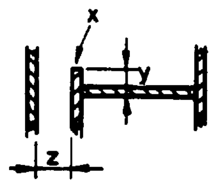
s. Distance between adjacent tray supports . . . . ± 1/8

t. Distance to reference line . . . . . . ± 1/4

s. Distance to seal pan . . . . ± 1/8

v. Distance to downcomer support . . . ± 1/8

w. Tilt for any width of support ring . . ± 1/16



Weir Plate

x. Out of level . . . . ± 1/16

y. Height . . . . ± 1/8

z. Distance to inside of vessel wall . . . ± 1/4

API Specification for

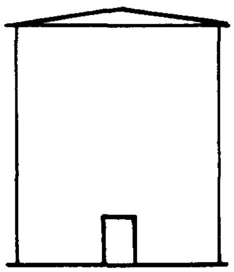
SHOP WELDED TANKS

Summary of Major Requirements of API. Standard 12F, Tenth Edition 1988

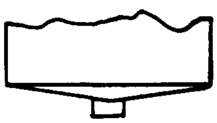
SCOPE

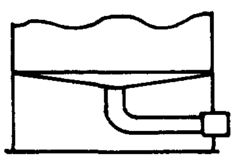
This specification covers material, design, and construction requirements for vertical, cylindrical, above ground, shop-welded, steel production tanks in nominal capacities of 90 to 500 bbl. (in standard sizes up to maximum diameter of 15 ft., 6 in.) for oil field service.

A



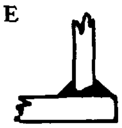
B



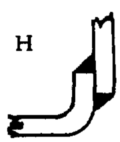


D

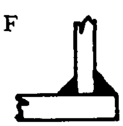
E



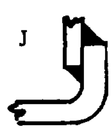
H



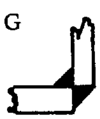
F



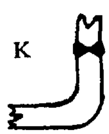
J



G



K



MATERIAL

Plates shall conform to the following ASTM Standards A36, A283 C or D, and A285 C.

MINIMUM PLATE THICKNESS

Shell and deck: 3/16 in., Bottom: 1/4 in. Sump: 3/8 in.

CONSTRUCTION

The bottom of the tank shall be flat or conical; the latter may be skirted or unskirted. Fig. A, B, C. The deck shall be conical. The slope of the bottom and deck cone = 1:12

WELDING

Bottom, shell and deck plate joints shall be double-welded butt joints with complete penetration. Fig. D. The bottom and the deck shall be attached to the shell by double-welded butt joint or 3/16 in. fillet welds, both inside and outside. Fig. E through K.

OPENINGS

Tanks shall be furnished with 24 in. x 36 in. extended neck cleanout. API Std. 12F Fig. 3.4

TESTING

Tanks in diameters up to and including 10 ft. shall be tested to 3 psi. air pressure; tanks in diameters larger than 10 ft. shall be tested to 1-1/2 psi. air pressure.

PAINTING

One coat primer.

TANK DIMENSIONS

Nominal Capacity, bbl.	Working Capacity, bbl.	Outside Diameter, ft. in.	Height ft.
90	72	7 - 11	10
100	79	9 - 6	8
150	129	9 - 6	12
200	166	12 - 0	10
210	200	10 - 0	15
250	224	11 - 0	15
300	266	12 - 0	15
400	366	12 - 0	20
500	466	12 - 0	25
500	479	15 - 6	16
750	746	15 - 6	24
Tolerance	—	±1/8 in.	±3/8 in.

WELDED STEEL TANKS FOR OIL STORAGE

API. Standard 650, Eighth Edition, 1988

APPENDIX A — OPTIONAL DESIGN BASIS FOR SMALL TANKS

(Summary of major requirements)

SCOPE

This appendix provides rules for relatively small capacity field-erected tanks in which the stressed components are limited to a maximum of ½ inch nominal thickness, including any corrosion allowance stated by the purchaser.

MATERIALS

The most commonly used plate materials of those permitted by this standard:
A 283 C, A 285 C, A 36, A 516-55, A 516-60
The plate materials shall be limited to ½ inch thickness

WELDED JOINTS

The type of joints at various locations shall be:

Vertical Joints in Shell
Butt joints with complete penetration and complete fusion as attained by double welding or by other means which will obtain the same quality of joint.

Horizontal Joints in Shell
Complete penetration and complete fusion butt weld.

Bottom Plates
Single-welded full-fillet lap joint or single-welded butt joint with backing strip.

Roof Plates
Single-welded full-fillet lap joint. Roof plates shall be welded to the top angle of the tank with continuous fillet weld on the top side only.

Shell to Bottom Plate Joint
Continuous fillet weld laid on each side of the shell plate. The size of each weld shall be the thickness of the thinner plate.

The bottom plates shall project at least 1 inch width beyond the outside edge of the weld attaching the bottom to shell plate.

INSPECTION

Butt Welds
Inspection for quality of welds shall be made by the radiographic method. By agreement between purchaser and manufacturer, the spot radiography may be deleted.

Fillet Welds
Inspection of fillet welds shall be made by visual inspection.

WELDED STEEL TANKS FOR OIL STORAGE

API. Standard 650, Eighth Edition, 1988

TESTING

Bottom Welds

1. Air pressure or vacuum shall be applied using soapsuds, linseed oil, or other suitable material for detection of leaks, or
2. After attachment of at least the lowest shell course water shall be pumped. underneath the bottom and a head of 6 inches of liquid shall be maintained inside a temporary dam.

Tank Shell

1. The tank shall be filled with water, or
2. Painting all joints on the inside with highly penetrating oil, and examining outside for leakage
3. Applying vacuum

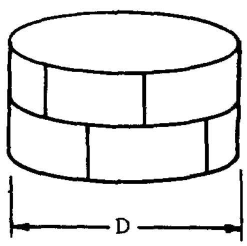
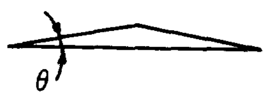
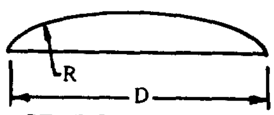
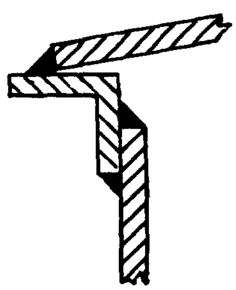
APPENDICES OF API STANDARD 650

Appendix A — Optional Design Basis for Small Tanks
Appendix B — Foundations
Appendix C — Floating Roofs
Appendix E — Seismic Design of Storage Tanks
Appendix F — Design for Small Internal Pressure
Appendix H — Internal Floating Roofs
Appendix J — Shop-Assembled Storage Tanks
Appendix K — Example of the application of variable design point procedure to Determine Shell-Plate Thicknesses
Appendix M — Tanks Operating at Elevated Temperatures
Appendix N — Use of Unidentified Materials
Appendix O — Under-Bottom Connections

WELDED STEEL TANKS, API. Std. 650 — APPENDIX A
FORMULAS

NOTATION

C.A. = corrosion allowance, in.
D = mean diameter of tank, ft.
E = joint efficiency, 0.85 when spot radiographed 0.70 when not radiographed
G = specific gravity of liquid to be stored, but in no case less than 1.0
H = height, ft.
t = minimum required plate thickness, in.
R = radius of curvature of roof, ft.
θ = angle of cone elements with the horizontal, deg.

 SHELL	$$t = \frac{(2.6)(D)(H-1)(G)}{(E)(21{,}000)} + \text{C.A.}$$ but in no case less than the following: Mean diameter of tank, ft — Plate thickness, in. Smaller than 50 .... $\frac{3}{16}$ 50 to 120, excl. .... $\frac{1}{4}$ 120 to 200, incl. .... $\frac{5}{16}$ Over 200 .... $\frac{3}{8}$
 SELF-SUPPORTING CONE ROOF	$$t = \frac{D}{400 \sin\theta}$$ but not less than $\frac{3}{16}$ in. Maximum t = 1/2 in. Maximum θ = 37 deg. 9:12 slope Minimum θ = 9 deg. 28 min. 2:12 slope
 SELF-SUPPORTING DOME AND UMBRELLA ROOF	$t = R/200$ but not less than $\frac{3}{16}$ in. Maximum $t = \frac{1}{2}$ in. R = radius of curvature of roof, in feet. Minimum $R = 0.8D$ (unless otherwise specified by the purchaser). Maximum $R = 1.2D$.
 TOP RING	The cross-sectional area of the top angle, in square inches, plus the cross-sectional areas of the shell and roof plates within a distance of 16 times their thicknesses, measured from their most remote point of attachment to the top angle, shall be minimum: **For Self-Supporting Cone Roofs:** $$\frac{D^2}{3{,}000 \sin\theta}$$ **For Self-Supporting Dome and Umbrella Roofs:** $$\frac{DR}{1{,}500}$$
BOTTOM	All bottom plates shall have a minimum nominal thickness of 1/4 in.

WELDED STEEL TANKS FOR OIL STORAGE

API. Standard 650, Eighth Edition, 1988

APPENDIX J — SHOP-ASSEMBLED STORAGE TANKS
(Summary of major requirements)

SCOPE
This appendix provides design and fabrication specifications for vertical storage tanks of such size as to permit complete shop assembly and delivery to the installation site in one piece. Storage tanks designed on this basis are not to exceed 20 feet in diameter within the scope of API Standard 650.

MATERIALS
The most commonly used plate materials of those permitted by this standard:
A 36, A 283 C, A 285 C, A 516-55, A 516-60

WELDED JOINTS
As described in Appendix A (see preceding page) with the following modifications:
Lap-welded joints in bottoms are not permissible
All shell joints shall be full penetration butt-welded without the use of backup bars.
Top angles shall not be required for flanged roof tanks.
Joints in bottom plates shall be full penetration butt welded.
Flat bottoms shall be attached to the shell by continuous fillet weld laid on each side of the shell plate.

BOTTOM DESIGN
All bottom plate shall have a minimum thickness of ¼ inch.
Bottoms may be flat or flat-flanged.
Flat bottoms shall project at least 1 inch beyond the outside diameter of the weld attaching the bottom to shell.

SHELL DESIGN
Shell plate thickness shall be designed with the formula:
(for notations see Appendix A on preceding page)

$$t = \frac{(2.6)\,(D)\,(H-1)\,(G)}{(E)\,(21{,}000)} + \text{C.A.}$$

,but in no case shall the nominal thickness less than:

Nominal Tank Diameter (feet)	Nominal Plate Thickness (inches)
Up to 10.5, incl.	$^3/_{16}$
Over 10.5	$^1/_4$

ROOF DESIGN
Roofs shall be self supporting cone or dome and umbrella roofs.
See Appendix A for design formulas.

TESTING
Apply 2 to 3 pounds per square inch internal air pressure.

Summary of Major Requirements of PIPING CODES pertaining to PIPE WALL THICKNESS AND ALLOWABLE PRESSURE

CODE & SCOPE	FORMULAS
ANSI B31.1-1992 **POWER PIPING** This Code prescribes minimum requirements for the design, materials, fabrication, erection, test, and inspection of power and auxiliary service piping systems for electric generation stations, industrial and institutional plants, central and district heating plants, and district heating systems, except as limited by Para. 100.1.3. These systems are not limited by plant or other property lines unless they are specifically limited in Para. 100.1.	**Internal Pressure** $t_m = \frac{PD_o}{2(SE + Py)} + A$ $t_m = \frac{Pd + 2SEA + 2yPA}{2(SE + Py - P)}$ $P = \frac{2SE(t_m - A)}{D_o - 2y(t_m - A)}$ $P = \frac{2SE(t_m - A)}{d - 2y(t_m - A) + 2t_m}$ VALUES OF, S, 1000 psi. For Materials ASTM A 53 B and A 106 B For Metal Temperatures not Exceeding Deg. F −20 to 650: 15.0; 700: 14.4; 750: 13.0; 800: 10.8 **External Pressure** For determining wall thickness and stiffening requirements the procedures outlined in Paras. UG-28, 29 and 30 of Section VIII, Division 1 of the ASME Boiler and Pressure Vessel Code shall be followed.
USAS B31.2-1968 **FUEL GAS PIPING** This Code covers the design, fabrication, installation, and testing of piping systems for fuel gases such as natural gas, manufactured gas, liquefied petroleum gas (LPG) - air mixtures above the upper combustible limit, liquefied petroleum gas (LPG) in the gaseous phase, or mixtures of these gases.	**Internal Pressure** $t_m = t + A$ $P = \frac{2SEt}{D}$ $t = \frac{PD}{2SE}$ (See notes 1, 3, 4, 5, 6, 8) VALUES OF, S, 1000 psi. For Materials ASTM A 53 B and A 106 B For Metal Temperatures Not Exceeding Deg. F −20 to 100: 20.00; 200: 19.10; 300: 18.15; 400: 17.25; 450: 16.80
ANSI B31.3-1993 **CHEMICAL PLANT AND PETROLEUM REFINERY PIPING** *(a)* This Code prescribes requirements for the materials, design, fabrication, assembly, erection, examination, inspection, and testing of piping systems subject to pressure or vacuum. *(b)* This Code applies to piping systems handling all fluids, including fluidized solids, and to all types of service, including raw, intermediate, and finished chemicals, oil and other petroleum products, gas, steam, air, water, and refrigerants, except as provided in 300.1.2 or 300.1.3. Only Category D and M fluid services as defined in 300.2 are segregated for special consideration.	**Internal Pressure** $t_m = t + c$ $t = \frac{Pd}{2[SE - P(1 - Y)]}$ $t = \frac{PD}{2(SE + PY)}$ (See notes 1, 7, 8) VALUES OF, S, 1000 psi For Materials ASTM A 53b and A 106b For Metal Temperatures not Exceeding Deg. F A 53B / A106B — −20 to 100: 20.00; 200: 20.00; 300: 20.00; 400: 20.00; 500: 18.90 **External Pressure** For determining wall thickness and stiffening requirements the procedures outlined in Paras. UG-28, 29 and 30 of Section VIII, Division 1 of the ASME Boiler and Pressure Vessel Code shall be followed.

Summary of Major Requirements of

PIPING CODES

(continuation from facing page)

NOTATION

A = an additional thickness, in inches to compensate for material removed in threading, grooving etc., and to provide for mechanical strength, corrosion and erosion.

For cast iron pipe the following values of A shall apply:

Centrifugally cast . . . . 0.14 in.
Statically cast . . . . 0.18 in.

c = the sum in inches of the mechanical allowances (thread or groove depth) plus corrosion and erosion allowance.

d = inside diameter of the pipe in corroded condition, inches

D & D_o = outside diameter of pipe, inches

E = efficiency factor of welded joint in pipe (see applicable code) For seamless pipe E = 1.0

F = for cast iron pipe casting quality factor F shall be used in place of E

P = internal design pressure, or maximum allowable working pressure, psig

S = maximum allowable stress in material due to internal pressure at the design temperature, psig.

t = thickness of pipe required for pressure, inches

t_m = minimum thickness of pipe in inches required for pressure and to compensate for material removed for threading, grooving, etc., and to provide for mechanical strength, corrosion and erosion.

y & *Y* = coefficients as tabulated below

Values of y & Y

Temperature F	900[1] and below	950	1000	1050	1100	1150 and above
Ferritic Steels	0.4	0.5	0.7	0.7	0.7	0.7
Austenitic Steels	0.4	0.4	0.4	0.4	0.5	0.7

Note: For intermediate temperatures the values may be interpolated. For nonferrous materials and cast iron, *y* equals 0.4.

[1] For pipe with a D_o/t_m ratio less than 6, the value of *y* for ferritic and austenitic steels designed for temperatures of 900 F and below shall be taken as:

$$y = \frac{d}{d + D_o}$$

NOTES

1. The minimum thickness for the pipe selected, considering manufacturer's minus tolerance, shall not be less than t_m. The minus tolerance for seamless steel pipe is 12.5% of the nominal pipe wall thickness.
2. Where steel pipe is threaded and used for steam service at pressure above 250 psi, or for water service above 100 psi with water temperature above 220 F the pipe shall be seamless having the minimum ultimate tensile strength of 48,000 psi and weight at least equal to Sch 80 of ANSI B36.10. (Code ANSI B31.1, Para. 104.1.2 C.1)
3. Piping systems installed in open easements, which are accesible to the general public or to individuals other than the owner of the piping system or his employee or agent, shall be designed in accordance with USAS B31.8. (Code USAS B31.02, Para. 201.1)
4. When not specifically required by a gas using process or equipment, the maximum working pressure for piping systems installed in buildings intended for human use and occupancy shall not exceed 10 psig. (Code USAS B31.2, Para 201.2.1)
5. Every piping system, regardless of anticipated service conditions shall have a design pressure of at least 10 psig between the temperatures of minus 20 F and 250 F. (Code USAS B31.2, Para. 201.2.2,b.)
6. Where the minimum wall thickness is in excess of 0.10 of the nominal diameter, the piping system shall meet the requirements of USAS B31.3. (Code USAS B31.2, Para. 203)
7. Pipe with t equal to or greater than D/6, or P/SE greater than 0.385, requires special consideration, taking into account design and material factors such as theory of failure, fatigue, and thermal stresses. (Code B31.3, Para. 304.1.2,b.)
8. Pipe bends shall meet the flattening limitations of the applicable Code.

Summary of Major Requirements of PIPING CODES pertaining to PIPE WALL THICKNESS AND ALLOWABLE PRESSURE

CODE & SCOPE	FORMULAS
ANSI B31.4-1992 **LIQUID PETROLEUM TRANSPORTATION PIPING SYSTEM** This Code prescribes minimum requirements for the design, materials, construction, assembly, inspection, and testing of piping transporting liquid petroleum such as crude oil, condensate, natural gasoline, natural gas liquids, liquefied petroleum gas, and liquid petroleum products between producers' lease facilities, tank farms, natural gas processing plants, refineries, stations, terminals, and other delivery and receiving points.	**Internal Pressure** $t_n = t + A$ $t = \frac{P_iD}{2S}$, where S = applicable allowable stress value, psi, in accordance with Code, Para. 402.3.1 a, b, c, or d. For pipe materials ASTM A 53 B and A 106 B, S = 25,200 psi. at −20 F to 250 F t = pressure design wall thickness, inches (see notes 1,2)
ANSI B31.5-1992 **REFRIGERATION PIPING** This Code prescribes minimum requirements for the materials, design, fabrication, assembly, erection, test, and inspection of refrigerant and brine piping for temperatures as low as −320°F (whether erected on the premises or factory assembled) except as specifically excluded in the following paragraphs. Users are advised that other piping Code Sections may provide requirements for refrigeration piping in their respective jurisdictions. This Code shall not apply to: *(a)* any self-contained or unit systems subject to the requirements of Underwriters' Laboratories or other nationally recognized testing laboratory; *(b)* water piping; *(c)* piping designed for external or internal gage pressure not exceeding 15 psi (103 kPa) regardless of size.	**Internal Pressure** $t_m = t + c$ $t = \frac{PD_o}{2(S + Py)}$ or $t = \frac{Pd}{2(S + Py - P)}$ $P = \frac{2St}{D_o - 2yt}$, where S = maximum allowable stress in material due to internal pressure at the design temperature, psi. For pipe materials ASTM A 53 B and A 106 B, S = 15,000 psi, at 100 F to 400 F. t = pressure design wall thickness, inches (See notes 1,2) **External Pressure** The pressure design thickness, t shall be determined in accordance with Code, Para. 504.1.3.
ANSI B31.8-1992 **GAS TRANSMISSION AND DISTRIBUTION PIPING SYSTEMS** This Code covers the design, fabrication, installation, inspection, testing, and the safety aspects of operation and maintenance of gas transmission and distribution systems, including gas pipelines, gas compressor stations, gas metering and regulating stations, gas mains, and service lines up to the outlet of the customer's meter set assembly. Also included within the scope of this section are gas storage equipment of the closed pipe type fabricated or forged from pipe or fabricated from pipe and fittings, and gas storage lines.	**Internal Pressure** $P = \frac{2St}{D} \times F \times E \times T$, where S = specified minimum yield strength, psi. For pipe materials ASTM A 53 B and A 106 B, S = 35,000 psi. t = nominal wall thickness, inches (See notes 1, 2, 3, 4, 5)

Summary of Major Requirements of

PIPING CODES

Continuation from facing page

NOTATION

A = sum of allowance, inches for threading and grooving as required under Code, Para 40. 4.2, corrosion as required under Code, Para. 402.4.1, and increase in wall thickness if used as protective measure under Code, Para. 402.1.

c = for internal pressure, the sum of allowances in inches thread and groove depth, manufacturers' minus tolerance, plus corrosion and erosion allowance.
for external pressure, the sum in inches of corrosion and erosion allowances, plus manufacturers' minus tolerance.

d = inside diameter of pipe, inches

D & D_o = outside diameter of pipe, inches

E = Longitudinal joint factor obtained from Code, table 841.12. For seamless pipe, E = 1.0

F = Values of Design Factor F

Construction Type (See Code 841.02)	Design Factor F
Type-A	0.72
Type–B	0.60
Type–C	0.50
Type–D	0.40

P & P_i = internal design pressure, psig

S = as described at the formulas, and in applicable code, psi.

t_t = as described at the formulas, inches

t_n = nominal wall thickness satisfying requirements for pressure and allowances, but not less than the nominal wall thickness listed in Code, Table 404.1.1, inches

t_{m_1} = minimum required thickness in inches satisfying requirements for design pressure and mechanical, corrosion and erosion allowances

T = Temperature Derating Factor for Steel Pipe

Temperature Degrees Fahrenheit	Factor T
250 F or less	1.000
300 F	0.967
350 F	0.933
400 F	0.900
450 F	0.867

Note: Interpolate for intermediate values

y = coefficient for materials indicated:

For ductile nonferrous materials, ferritic steels and austenitic steels y = 0.4

If D_o/t in range of 4-6, use

$$y = \frac{d}{d + D_o}$$

for ductile materials.

For brittle materials use y = 0.0

NOTES

1. In selection of pipe the manufacturers' minus tolerance shall be taken into consideration. The minus tolerance for seamless steel pipes is 12.5% of the nominal wall thickness. This tolerance may be used also when specification is not available.
2. Pipe bends shall meet the flattening limitations of the applicable Code.
3. Classification of Locations. In Code B31.8, Para. 841.01, four classes are described as a basis for prescribing the types of construction.
4. Limitation of Pipe Design Values, Code B31.8, Para. 841.14.
5. Least Nominal Wall Thickness, Code B31.8, Table 841.141.

The formulas and regulations are extracted from American National Standard Code for Pressure Piping with the permission of the publisher, The American Society of Mechanical Engineers.

PRESSURE VESSEL HANDBOOK

Tenth Edition

NOTE:
The CODE "does not contain rules - [as it states in Par. U-2 (g)] - to cover all details of design and construction. Where complete details are not given . . . the manufacturer . . . shall provide details . . ."

BUILD
BETTER VESSEL
FASTER
AND MORE
ECONOMICALLY

Design and construction details **not covered by the code,** have been selected from generally accepted sources, utilizing the most practical and economical methods.

PRESSURE VESSEL PUBLISHING, INC. P.O. BOX 35365 TULSA, OK 74153

RECTANGULAR TANKS
UNDER HYDROSTATIC PRESSURE

Flat-walled tanks due to their mechanically disadvantageous shape are used for low hydrostatic pressure only. The quantity of material required for rectangular tanks is higher than for cylindrical vessels of the same capacity. However, sometimes the application of rectangular tanks is preferable because of their easy fabrication and the good utilization of space.

MAXIMUM SIZE

Unstiffened tanks may be not larger than 30 cu. ft. and tanks with stiffenings, 140 cubic feet capacity.

For larger tanks, the use of stay rods is advisable for economic reasons.

RATIO OF SIDES

If all sides are equal, the length of one side: $B = \sqrt[3]{V}$; where V = volume cu. ft.

Preferable ratio: Longer side: 1.5 B; Shorter side : 0.667 B

DESIGN

The formulas on the following pages are based on maximum allowable deflection; $\Delta = t_a/2$, where t_a denotes the thickness of side-plate.

Values of α and β

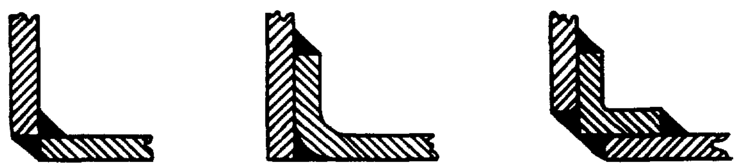
Ratio, $\frac{H}{L}$ or $\frac{H}{l}$	0.25	0.286	0.333	0.4	0.5	0.667
Constant, β	0.024	0.031	0.041	0.056	0.080	0.116
Constant, α	0.00027	0.00046	0.00083	0.0016	0.0035	0.0083

Ratio, $\frac{H}{L}$ or $\frac{H}{l}$	1.0	1.5	2.0	2.5	3.0	3.5	4.0
Constant, β	0.16	0.26	0.34	0.38	0.43	0.47	0.49
Constant, α	0.022	0.043	0.060	0.070	0.078	0.086	0.091

H = height of tank L = length of tank l = maximum distance between supports

WELDING OF PLATE EDGES

Some preferable welded joints of plate edges:



The stiffenings may be attached to the tank wall either by intermittent or continuous welding and may be placed inside or outside.

BIBLIOGRAPHY

Other design methods are offered in the following papers:

Vojtaszak, I. A.: Stress and Deflection of Rectangular Plates, ASME Paper A-71, Journal Appl. Mech., Vol. 3 No. 2, 1936.

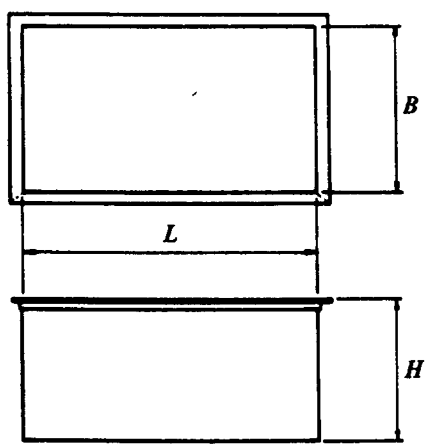
Timoshenko, S. and S. Woinowsky-Krieger: "Theory of Plates and Shells", 2nd edition, McGraw-Hill Book Company, 1959.

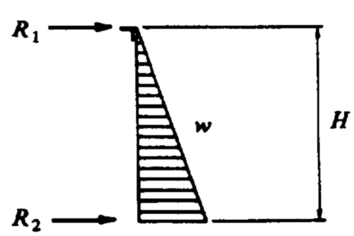
Kanti K. Mahajan: "Design of Process Equipment", Pressure Vessel Handbook Publishing, Inc. 1990.

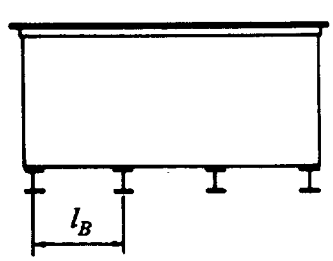
RECTANGULAR TANKS
UNDER HYDROSTATIC PRESSURE
WITH TOP-EDGE STIFFENING

NOTATION

α = factor depending on ratio of length and height of tank, H/L (See Table)
E = modulus of elasticity, psi.; 30,000,000 for carbon steel
G = specific gravity of liquid
H = height of tank, in
I = moment of inertia, $in.^4$
l = maximum distance between supports, inches
L = length of tank, nches
R = reaction with subscripts indicating the location, lb./in.
S = stress value of plate, psi. as tabulated in Code, Tables UCS - 23
t = required plate thickness, inches
t_a = actual plate thickness, inches
t_b = required plate thickness for bottom, inches
t_B = actual thickness of bottom, inches
w = load perunit of length lb./in.
y = deflection of plate, inches







REQUIRED PLATE THICKNESS

$$t = L\sqrt{\frac{\beta H\, 0.036\, G}{S}}$$

Thickness, t may be used also for the bottom plate if its entire surface is supported.

Thickness, t shall be increased in corrosive service.

Maximum deflection of plate:

$$\text{max} = \frac{\alpha\, 0.036\, GHL^4}{E t_a^3}$$

STIFFENING FRAME

$$w = \frac{0.036\, GH^2}{2} \qquad R_1 = 0.3w \qquad R_2 = 0.7w$$

Minimum required moment of inertia for top-edge stiffening:

$$I_{min} = \frac{R_1 L^4}{192\, E t_a}$$

BOTTOM PLATE
WHEN SUPPORTED BY BEAMS

$$t_b = \frac{l_B}{1.254\sqrt{\frac{S}{0.036\, G\, H}}}$$

Maximum spacing of supports for a given thickness of bottom:

$$l_B = 1.254\, t_B \sqrt{\frac{S}{0.036\, G\, H}}$$

RECTANGULAR TANKS
EXAMPLES

DESIGN DATA

Capacity of the tank: 600 gallon = 80 cu. ft. approximately
Content: water; G = 1
The side of a cube-shaped tank for the designed capacity: $\sqrt[3]{80} = 4.31$ ft.
Preferred proportion of sides:

L = 4.31 x 1.5 = 6.47 ft. = 78 inches
H = 4.31 x .667 = 2.87 ft. = 34 inches
Width of the tank 4.31 ft. = 52 inches

S = 13750, using SA 285 C material
Corrosion allowance: 1/16 in.
$H/L = 34/78 = 0.43;\ \beta = 0.063$

REQUIRED PLATE THICKNESS

$$t = 78\sqrt{\frac{0.063 \times 34 \times 0.036 \times 1}{13750}} = 0.18 \text{ in}$$

+0.0625 corr. allow = 1/4 in.

STIFFENING FRAME

$$w = \frac{0.036 \times 1 \times 34^2}{2} = 20.808 \text{ lb/in}$$

$$R_1 = 0.3 \times 20.808 = 6.24 \text{ lb/in}$$
$$R_2 = 0.6 \times 20.808 = 14.57 \text{ lb/in}$$

$$I_{min} = \frac{6.24 \times 78^4}{192 \times 30,000,000 \times 0.1875} = 0.214 \text{ in}^4$$

1-3/4 × 1-3/4 × 3/16 (.18 in^4) satisfactory for stiffening at the top of the tank

BOTTOM PLATE WHEN SUPPORTED BY BEAMS

if number of beams = 4; 1 = 26 inches

$$t_b = \frac{26}{1.254\sqrt{\dfrac{13750}{0.036 \text{x} 1 \text{x} 34}}} = 0.196 \text{ in.,}$$

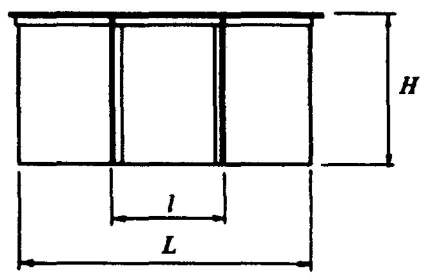
Or using the plate thickness 0.1875 as calculated above, the maximum spacing for supports:

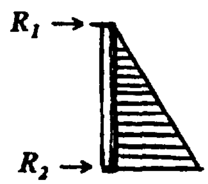
$$l_B = 1.254 \times 0.1875\sqrt{\frac{13750}{0.036 \text{ x } 1 \text{ x } 34}} = 24.9 \text{ in.}$$

RECTANGULAR TANKS WITH VERTICAL STIFFENINGS

NOTATION

β = Factor depending on ratio of length and height, H/l
(See Table on page 213)
E = modulus of elasticity, psi.
H = height of tank inches
I = moment of inertia, in^4
G = specific gravity of liquid
l = the maximum distance between stiffenings on the longer or shorter side of the tank, inches.
L = length of tank, inches
S = stress value of plate, psi.
t = required plate thickness, inches t_a = actual plate thickness, inches
w = load, lbs.
Z = section modulus, in^3





REQUIRED PLATE THICKNESS

$$t = l\sqrt{\frac{\beta H\, 0.036\, G}{S}}$$

LOADS, lb/in

$$W = \frac{0.036\, GH^2}{2} \qquad R_1 = 0.3_w \qquad R_2 = 0.7_w$$

STIFFENING FRAME

Required section modulus of vertical stiffening

$$Z = \frac{0.0642.\ 0.036\, GH^3 l}{S}$$

Minimum required moment of inertia for top-edge stiffening:

$$I_{min} = \frac{R_l\ L^4}{192\ E\ t_a}$$

RECTANGULAR TANKS
WITH VERTICAL STIFFENINGS
EXAMPLES

DESIGN DATA

$E = 30{,}000{,}000$ psi
$L = 78$ in
$H = 34$ in
$B = 52$ in
$S = 13570$ psi
$l = 26$ in

Content: Water
G = 1

$$H/l = \frac{34}{26} = 1.31;\ \beta = 0.22$$

REQUIRED PLATE THICKNESS

$$t = 26 \times \sqrt{\frac{0.22 \times 34 \times 0.036 \times 1}{13750}} = 0.115 \text{ in}$$

$+0.0625$ corr. allow $= 3/16$ in

STIFFENING FRAME

$$Z_{min} = \frac{0.0642 \times 0.036 \times 1 \times 34^3 \times 26}{13750} = 0.172 \text{ in}^3$$

$2 \times 2 \times 3/16$ (.19 in^3) satisfactory for vertical stiffening

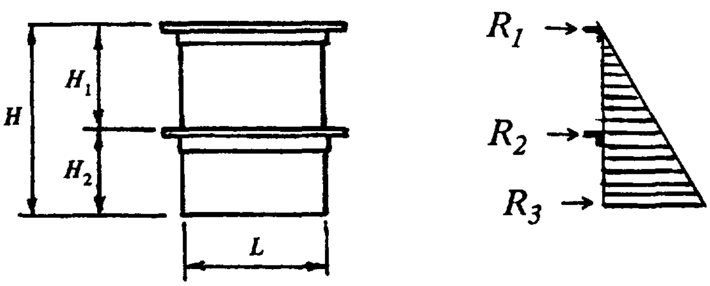
$$w = \frac{0.036 \times 1 \times 34^2}{2} = 20.8 \text{ lb/in} \qquad R1 = 0.3 \times 20.8 = 6.24 \text{ lb/in}$$

$$I_{min} = \frac{6.24 \times 78^4}{192 \times 30{,}000{,}000 \times 0.125} = 0.32 \text{ in}^4$$

RECTANGULAR TANKS
Under Hydrostatic Pressure
WITH HORIZONTAL STIFFENINGS

NOTATION

E = modulus of elasticity, psi.; 30,000,000 for carbon steel
G = specific gravity of liquid
H = height of tank, in
I = moment of inertia, in.^{4}
L = length of tank, inches
p = pressure of liquid, psi.
R = reaction with subscripts indicating the location, lb./in.
S = stress value of plate, psi.
t = required plate thickness, inches
t_a = actual plate thickness, inches
w = load per unit of length lb./in.



SPACING OF STIFFENINGS	$H_1 = 0.6H$ $\qquad$ $H_2 = 0.4H$
REQUIRED PLATE THICKNESS	$t = 0.3H\sqrt{\dfrac{0.036\ GH}{S}}$
LOAD lb./in.	$w = \dfrac{0.036\ GH^2}{2}$ $R_1 = 0.06\ w \quad R_2 = 0.3\ w \quad R_2 = 0.64\ w$
MINIMUM MOMENT OF INERTIA FOR STIFFENING	Minimum required moment of inertia for top-edge stiffening $I_1 = \dfrac{R_1\ L^4}{192\ E\ t_a}$ Minimum required moment of inertia for intermediate stiffening $I_2 = \dfrac{R_2\ L^4}{192\ E\ t_a}$

RECTANGULAR TANKS WITH INTERMEDIATE HORIZONTAL STIFFENINGS EXAMPLES

DESIGN DATA

Designed capacity = 1,000 gallon = 134 cu. ft. (approx.)
Content: water
S = 13750 psi., using SA 285 C material
Corrosion allowance = 1/16 in.

The side of a cube-shaped tank for the designed capacity: $\sqrt[3]{134} = 5.12$ ft.
Preferred proportion of sides:
width = 0.667 × 5.12 = 3.41 ft; approx. 42 inches
L = 1.500 × 5.12 = 7.68 ft; approx. 92 inches
H = 5.12 ft; approx. 60 inches

For height 60 in., intermediate stiffening is required.

SPACING OF STIFFENINGS:

$H_1 = 0.6\ H = 36$ in. $\qquad H_2 = 0.4H = 24$ in.

REQUIRED PLATE THICKNESS:

$$t = 0.3 \times 60 \sqrt{\frac{0.036 \times 1 \times 60}{13{,}750}} = 0.226 \text{ in.}$$

+ 0.0625 corr. allow = 5/16 in.

LOADS:

$$w = \frac{0.036 \times 1 \times 60^2}{2} = 64.8 \text{ lb/in.}$$

$R_1 = 0.06\ w = 3.89$ lb/in[1] $\qquad R_2 = 0.3\ w =$ 19.44 lb/in

MINIMUM MOMENT OF INERTIA FOR STIFFENINGS:

$$I_1 = \frac{3.89 \times 92^4}{192 \times 30{,}000{,}000 \times 0.25} = 0.4690 \text{ in}^4$$

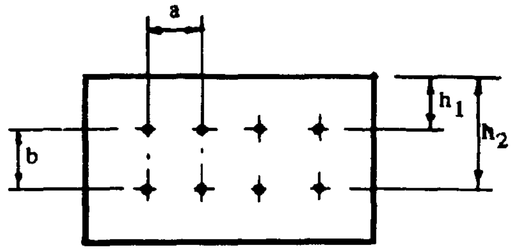
$$I_2 = \frac{19.44 \times 92^4}{192 \times 30{,}000{,}000 \times 0.25} = 0.967 \text{ in}^4$$

TIE ROD SUPPORT
FOR RECTANGULAR TANKS
Under Hydrostatic Pressure

To avoid the use of heavy stiffenings, the sides of large tanks may be supported most economically by tie rods.

NOTATIONS

A = Required cross sectional area of tie rod, sq. in.
a = horizontal pitch, in.
b = vertical pitch, in.
G = specific gravity of liquid
P = pressure of liquid, lb.
S = stress value of rod material, psi.
t = required plate thickness, in.
S_p = stress value of plate material, psi



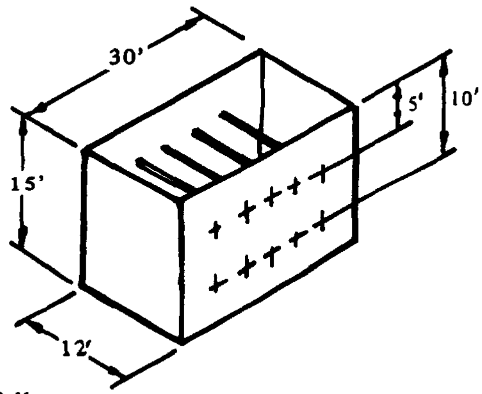
REQUIRED PLATE THICKNESS	when a≅b $t = 0.7b\sqrt{\frac{0.036\ G\ h}{S_p}}$
LOAD ON TIE ROD	$P = ab\ 0.036\ Gh$
REQUIRED CROSS SECTIONAL AREA OF TIE ROD	$A = \frac{P}{S}$

EXAMPLE

DESIGN DATA

Length=30 ft., width=12 ft., height=15 ft.

a = 60 in. $h_1 = 60$ in
b = 60 in. $h_2 = 120$ in
G = 1
S = 20,000 psi.
S = 20,000 psi.
S_p = 20,000 psi



$$t = 0.7 \times 60\sqrt{\frac{0.036 \times 1 \times 120}{20{,}000}}$$

$= \underline{0.625} \cong$ 5/8 in. plate

$P_2 = ab0.036Gh_2 = 60x60x0.036x120 = 15{,}552$ lb.

$A_2 = \frac{15{,}552}{20{,}000} = 0.778$ sq. in. = 1ϕ rods

$P_1 = ab0.036Gh_1 = 60x60x0.036x60 = 7{,}776$ lb.

$A_1 = \frac{7{,}776}{20{,}000} = 0.389$ sq. in. = 3/4 ϕ rods

CORROSION

Vessels or parts of vessels subject to thinning by corrosion, erosion or mechanical abrasion shall have provision made for the desired life of the vessel by suitable increase in the thickness of the material over that determined by the design formulas, or by using some other suitable method for protection (Code UG-25b).

The Code does not prescribe the magnitude of corrosion allowance except for vessels with a required minimum thickness of less than 0.25 in. that are to be used in steam, water or compressed air service, shall be provided with corrosion allowance of not less than one-sixth of the required minimum thickness. The sum of the required minimum thickness and corrosion allowance need not exceed 1/4 in. This requirement does not apply to vessel parts designed with no x-ray examination or seamless vessel parts designed with 0.85 joint efficiency. (Code UCS-25).

For other vessels when the rate of corrosion is predictable, the desired life of the vessel will determine the corrosion allowance and if the effect of the corrosion is indeterminated, the judgment of the designer. A corrosion rate of 5 mils per year (1/16 in. = 12 years) is usually satisfactory for vessels and piping.

The desired life time of a vessel is an economical question. Major vessels are usually designed for longer (15-20 years) operating life time, while minor vessels for shorter time (8-10 years).

The corrosion allowance need not be the same thickness for all parts of the vessel if different rates of attack are expected for the various parts (Code UG-25 c).

There are several different methods for measuring corrosion. The simplest way is the use of teltale holes (Code UG-25 e) or corrosion gauges.

Vessels subject to corrosion shall be supplied with drain-opening (Code UG-25 f).

All pressure vessels subject to iinternal corrosion, erosion, or mechanical abrasion shall be provided with inspection opening (Code UG-46).

To eliminate corrosion, corrosion resistant materials are used as lining only, or for the entire thickness of the vessel wall.

The rules of lining are outlined in the Code in Part UCL, Apendix F and Par. UG-26.

The vessel can be protected against mechanical abrasion by plate pads which are welded or fastened by other means to the exposed area of the vessel.

In vessels where corrosion occurs, all gaps and narrow pockets shall be avoided by joining parts to the vessel wall with continuous weld.

Internal heads may be subject to corrosion, erosion or abrasion on both sides.

SELECTION OF CORROSION RESISTANT MATERIALS

The tabular information on the following pages is an attempt to present a summarized analysis of existing test data. It is necessarily brief and, while the utmost precautions have been taken in its preparation, it should not be considered as infallible or applicable under all conditions. Rather, it should be looked upon as a convenient tool for use in determining the degree of safety which various materials are capable of providing and in narrowing down the field of investigation required for final selection. This particularly applies where failure due to corrosion may produce a hazardous situation or result in expensive down-time.

Footnotes have been generously used to explain and further clarify information contained in this table. It is most important that these notes be carefully read when using the table.

In rating materials, the letter "A" has been used to indicate materials which are generally recognized as satisfactory for use under the conditions given. The letter "F" signifies materials which are somewhat less desirable but which may be used where a low rate of corrosion is permissible or where cost considerations justify the use of a less resistant material. Materials rated under the letter "C" may be satisfactory under certain conditions. Caution should be exercised in the use of materials in this classification unless specific information is available on the corroding medium and previous experience justifies their use for the service intended. The letter "X" has been used to indicate materials generally recognized as not acceptable for the service.

Information on metals has been obtained from the International Nickel Company, the Dow Chemical Company, the Crane Company, the Haynes-Stellite Company, "Corrosion Resistance of Metals and Alloys" by McKay & Worthington, "Metals and Alloys Data Book" by Samuel L. White, "Chemical and Metallurgical Engineering" and "The Chemical Engineers' Handbook," Third Edition by McGraw-Hill.

NOTES - GASKET MATERIALS

I. The generally accepted temperature limit for a good grade compressed asbestos sheet, also called asbestos composition sheet, is 750°F. However, some grades are successfully used at considerable higher temperatures. This type of sheet is used for smooth flanges. For rough flanges, gaskets cut from asbestos-metallic sheet or formed by folding asbestos-metallic cloth are preferred. The latter ,and gaskets cut from felted asbestos sheet, are indicated for flanges when bolt pressures are necessarily limited because of the type of flange meterial.

II. Data from the Pfaulder Company are given from the special point of view of the suitability of the gasket material for use with glass-lined steel equipment.

III. Data in this column apply specifically to Silastic 181, a special silicone rubber for use in gasketing produced by Dow-Corning Corporation.

IV. Fiberglas fabric filled with Silastic silicone rubber (polysiloxane elastomer) has a usable compressibility of about 20 per cent and shows the chemical resistance cited here over the temperature range from -85 to 392°F. For Fiberglas fabric filled with chemically resistant synthetic rubber, the temperature range is approximately -40 to 257°F. Both the silicone rubber and the ordinary synthetic rubber are available as gasket materials in which the reinforcing fabric is a metal cloth (brass, aluminum, iron, stainless steel). The chemical properties of these constructions are the same as those given here for the Fiberglas-reinforced material, with the properties of the metal in the cloth imposed upon them. The metal-cloth construction for increased mechanical strength and electrical conductivity.

V. Teflon is the DuPont trade-name for polymerized tetrafluorethylene. It is completely inert in the presence of all known chemicals. It is not affected by any known solvent or combination of solvents. It is chemically stable up to 617°F but, being a plastic, it is not recommended for gasket applications above 392°F or for high pressures unless confined in a tongue-and-groove or similar joint.

* Sources of Data: A - Armstrong Cork Co.; C - Connecticut Hard Rubber Co.; D - Dow-Corning Corp.; E - E. I. DuPont de Nemours & Co.; J - Johns-Manville Corp.; P - The Pfaudler Co.; S - Stanco Distributors, Inc.; U - United States Rubber Co.

Information on gasket materials compiled by McGraw-Hill, "Chemical Engineers Handbook," Third Edition.

CHEMICAL RESISTANCE OF METALS

Caution: Do not use table without reading footnotes and text.

Resistance Ratings: A = Good; F = Fair; C = Caution – depends on conditions; X = Not recommended.

Chemical	Iron and Steel	Red Brass	Commercial Bronze	Lead	Copper	Aluminum	Nickel	Inconel	Monel Metal	Type 304 S.S.	Type 316 S.S.	Type 347 S.S.	Carpenter "20" S.S.	Hastelloy "B" or "C"
Acetic acid, crude	C	C	F	C	F	A	C	C	C	C	C	C	A	A
Pure	X	C	F	C	F	A	F	A	A	F	A_{0}	C	A	A
Vapors	X	C	F	C	F	C	C	C	C	C	X	C	A	A
150 lb/sq.in. @ 400°F	X	–	X	X	F	C	–	C	C	–	A	C	A	A
Acetic anhydride	C	F	F	A_{1}	F	A	A	A	A	F	A	A	A	A
Acetone	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Acetylene	A	X	X_{8}	A	X_{8}	A	A	–	A	A	A	A	A	A
Aluminum chloride	X	C	C	X	C	C	C	C	C	X	C	X	A_{2}	A_{2}
Aluminum sulfate	X	F	F	A	C	C	C	C	F	A	A	A	A	A
Alums	X	F	F	A	F	F	C	–	C	A	A	C	A	–
Ammonia gas, dry	F	A	A	A	A	A	–	A_{3}	–	A	A	A	A	A
Moist	F	X	X	A	X	C	C	A	C	A	A	A	A	–
Ammonium chloride	F	X	X	A	X	C	A	C	A	C	C	C	A	A_{6}
Ammonium hydroxide	A	X	X	A	X	A	C	A	C	A	A	A	A	A
Ammonium nitrate	F	X	X	X	X	A	–	–	C	A	A	–	A	A
Ammonium phosphate	C	C	C	A	C	C	A_{4}	A_{4}	A_{4}	A	A	A	A	A_{5}
Ammonium sulfate	F	C	C	A	C	A_{5}	F	A	A	C	C	A	A	A
Aniline, aniline oil	A	X	X	–	X	X	–	–	A	A	A	A	A	A
Aniline dyes	–	–	–	–	–	–	–	–	A	A	A	A	A	A
Barium chloride	–	–	–	–	–	–	A	–	–	C	C	–	F	A_{6}
Barium hydroxide	–	–	–	X	X	X	A	–	–	A	A	–	A	–
Barium sulfide	–	–	–	A	X	–	–	–	A	A	A	A	–	–
Beer	C	–	A	–	A	A	A	A	A	A	A	A	–	A
Beet sugar liquors	C	–	–	–	A	C	A	A	A	A	A	A	A	A
Benzene, benzol	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Benzine, petroleum ether, naphtha	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Black sulfate liquor	A	–	F	F	X	–	A	A	A	A	A	–	A	–
Boric acid	X	A	A	C	C	A	–	–	C	A	A	A	A	A
Bromine	X	C	C	–	C	X	C	C	C	X	X	X	C	A

Notes continued on opposite page

1. *In absence of oxygen.*
2. *125° maximum.*
3. *All percents; 70°.*
4. *To boiling.*
5. *5% room temperature.*
6. *To 122°.*
7. *Iron and steel may rust considerably in presence of water and air.*
8. *High copper alloys prohibited by Codes; yellow brass acceptable.*
9. *Hastelloy "C" recommended to 105°.*
10. *Where color is not important. Do not use with c.p. acid.*
11. *Room temperature to 212°. Moisture inhibits attack.*
12. *Gas; 70°.*
13. *To 500°.*
14. *Hastelloy "C" at room temperature.*
15. *Room temperature to 158°.*
16. *At room temperature.*
17. *Where discoloration is not objectionable.*
18. *5% maximum; 150° maximum.*
19. *Satisfactory vapors to 212°.*

CHEMICAL RESISTANCE OF GASKETS

(SEE CHEMICALS ON OPPOSITE PAGE)

Resistance Ratings: Same as facing page

Asbestos: White (comp. or woven) I	Asbestos: Blue (comp. or woven) I	Asbestos: Compressed sheet	Asbestos, Comp., Rubber Bonded: White (Buna-S) II	Asbestos, Comp., Rubber Bonded: White (Neoprene) II	Asbestos, Comp., Rubber Bonded: Blue (Butyl) II	Asbestos, Woven Rubber Frictioned: Blue (Neoprene) II	Asbestos, Woven Rubber Frictioned: White (Neoprene) II	Asbestos, Woven Rubber Frictioned: Blue (Butyl) II	Rubber: GR-S	Rubber: Neoprene	Rubber: Buna-N	Rubber: Butyl	Rubber: Thiokol	Rubber: Natural	Rubber: Silicone III	Miscellaneous: Glass Fabric and Silicone Elastomer IV	Miscellaneous: Glass Fabric and Synthetic Rubber IV	Miscellaneous: Cork Composition	Miscellaneous: Plant-Fiber Sheet	Miscellaneous: Teflon II
*J	J	U	P	P	P	P	P	P	U	A	U	U	U	U	D	C	C	A	A	P
C	A	C	A	A	A	A	A	A	C	C	F	F	F	C	–	A	A	C	X	A
C	A	C	A	A	A	A	A	A	C	C	F	F	F	C	A	A	A	C	X	A
C	A	C	A	A	A	A	A	A	C	A	F	F	F	C	–	A	A	C	X	A
C	A	F	–	–	–	–	–	–	X	X	F	X	X	X	–	A	X	X	X	–
C	A	–	A	A	A	A	A	A	–	A	–	–	–	–	–	C	C	X	X	A
A	–	A	X	X	X	X	X	X	A	A	X	A	C	F	F	A	A	A	A	A
A	–	A	–	–	–	–	–	–	A	A	A	A	C	A	–	X	X	A	A	–
A	–	A	A	A	A	A	A	A	A	A	A	A	–	A	–	F	A	F	C	A
A	–	–	A	A	A	A	A	A	A	A	A	A	–	A	–	A	A	F	F	A
A	–	A	A	A	A	C	C	C	A	A	A	A	–	A	–	A	A	F	F	A
A	–	A	A	A	A	A	A	A	A	A	A	A	A	A	–	A	A	X	X	A
A	–	A	–	–	–	–	–	–	C	C	C	C	X	C	–	A	A	X	X	A
C	A	A	A	A	A	A	A	A	–	A	–	A	C	A	–	F	A	F	F	A
A	–	A	A	A	A	A	A	A	C	F	C	A	X	C	A	A	A	X	X	A
C	A	–	F	F	F	F	F	F	A	A	A	A	–	A	–	–	A	F	F	A
C	A	–	A	A	A	A	A	A	A	A	A	A	–	A	–	–	A	F	F	A
C	A	A	A	A	A	A	A	A	A	A	A	A	–	A	A	–	A	F	F	A
A	–	A	–	–	–	–	–	–	X	X	X	A	A	X	–	X	C	X	A	A
A	–	A	–	–	–	–	–	–	F	–	F	A	C	F	–	X	C	C	C	A
C	A	A	A	A	A	A	A	A	A	A	A	A	–	A	A	–	A	F	F	A
A	–	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	F	F	A
A	–	–	–	–	–	–	–	–	A	A	A	A	A	A	–	–	A	F	F	A
A	–	A	A	A	A	X	X	X	A	A	X	A	X	A	–	A	A	A	A	A
A	–	A	A	A	A	A	A	A	A	A	A	A	X	A	–	A	A	A	A	A
A	–	C	X	X	X	X	X	X	X	X	X	X	C	X	X	X	X	A	A	A
A	–	C	X	X	X	X	X	X	X	F	X	X	C	X	X	X	C	A	A	A
A	–	A	–	–	–	–	–	–	A	A	A	A	X	A	–	–	–	A	A	–
A	–	–	A	A	A	A	A	A	A	Ĉ	A	A	X	A	A	A	A	A	A	A
X	C	X	X	X	X	X	X	X	X	X	X	X	F	X	–	X	X	X	X	A

*See text at the front page of these tables.

20. *Highly corrosive to nickel alloys at elevated temperatures. Recommendation applies to "dry" gas at ordinary temperatures.*
21. *48% — boil at 330°.*
22. *Room temperature — over 80%.*
23. *Not for temperatures over 390°F.*
24. *Up to 140°F.*
25. *Up to 200°F.*
26. *Up to 176°F.*
27. *10% maximum; boiling.*
28. *50%; 320°.*
29. *Do not use if iron contamination is not permissible.*
30. *10% — room temperature.*
31. *Hot.*
32. *Unsatisfactory for hot gases.*
33. *Hastelloy "C" to 158°.*
34. *Room temperature to 158°. Corrosion increases with increase in concentration as well as temperature.*
35. *Dilute at room temperature.*
36. *Attack increases when only partially submerged; fumes very corrosive.*
37. *Hastelloy "C" to 212°.*

CHEMICAL RESISTANCE OF METALS

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Resistance Ratings: A = Good; F = Fair; C = Caution – depends on conditions; X = Not recommended.

Chemical	Iron and Steel	Red Brass	Commercial Bronze	Lead	Copper	Aluminum	Nickel	Inconel	Monel Metal	Type 304 S.S.	Type 316 S.S.	Type 347 S.S.	Carpenter "20" S.S.	Hastelloy "B" or "C"
Butane	A	A	A	–	–	A	–	–	A	A	A	A	A	A
Butyl alcohol, butanol	A_{7}	A	A	A	A	A	A	A	A	A	A	A	A	A
Calcium chloride	F	F	F	X	F	C	A	A	A	C	C	C	A	A_{6}
Calcium hypochlorite	C	C	F	X	C	C	C	C	C	C	F	C	C	X_{9}
Carbolic acid, phenol	A_{10}	C	F	A	C	A_{11}	A	A	A	C	A	C	A	A
Carbon dioxide, dry	F	A	A	A	A	A	A	A	A	A	A	A	A	A
Wet	C	A	A	X	–	A	A	A	A	A	A	A	A	A
Carbon tetrachloride	C	C	F	F	C	F	A	A	A	C	A	C	A	A
Chlorine, dry	A	A	A	A	A	X	A	A	A	X	A_{12}	X	A_{13}	A
Wet	X	X	C	F	C	X	X	X	X	X	C	X	X	A_{14}
Chromic acid	C	X	X	A	X	C	C	C	C	C	C	X	C	A_{22}
Citric acid	X	A	A	A	C	F	F	A	A	A	A	A	A	A
Ethers	C	A	A	A	A	A	A	A	A	A	A	A	A	A
Ethylene glycol	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Ferric chloride	X	X	X	X	X	X	X	X	X	X	C	X	X	F_{24}
Ferric sulfate	X	X	X	A	X	F_{16}	C	C	X	A	A	A	A	A_{15}
Formaldehyde	F_{17}	A	A	–	A	C	A	A	A	C	C	C	A	A
Formic acid	X	A	A	–	C	X	F	F	F	A_{18}	A_{18}	C	A	A
Freon, dry	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Furfural	A	A	C	–	–	A	A	A	A	A	A	A	A	A
Gasoline, sour	C	X	X	A	X	A	A	A	C	A	A	A	A	A
Refined	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Glycerin, glycerol	A_{17}	A	A	A	A	A	A	A	A	A	A	A	A	A
Hydrochloric acid, <150°F	X	C	C	C	C	X	C	C	F	X	X	X	A_{25}	A
Hydrofluoric acid, cold, <65%	X	X	X	F	X	X	C	C	A	X	X	X	F	A_{26}
>65%	X	X	X	C	X	X	C	–	A	X	X	X	F	A_{26}
Hot <65%	X	X	X	X	X	X	X	X	A	X	X_{19}	X	X	A_{26}
>65%	X	X	X	X	X	X	C	C	A	X	X	X	C	A_{26}
Hydrogen gas, cold	A	A	A	A	A	A	A	A	A	A	A	A	A	A

Notes continued on opposite page

1. *In absence of oxygen.*
2. *125° maximum.*
3. *All percents; 70°.*
4. *To boiling.*
5. *5% room temperature.*
6. *To 122°.*
7. *Iron and steel may rust considerably in presence of water and air.*
8. *High copper alloys prohibited by Codes; yellow brass acceptable.*
9. *Hastelloy "C" recommended to 105°.*
10. *Where color is not important. Do not use with c.p. acid.*
11. *Room temperature to 212°. Moisture inhibits attack.*
12. *Gas; 70°.*
13. *To 500°.*
14. *Hastelloy "C" at room temperature.*
15. *Room temperature to 158°.*
16. *At room temperature.*
17. *Where discoloration is not objectionable.*
18. *5% maximum; 150° maximum.*
19. *Satisfactory vapors to 212°.*

CHEMICAL RESISTANCE OF GASKETS

(SEE CHEMICALS ON OPPOSITE PAGE)

Resistance Ratings: Same as facing page

Asbestos									Rubber							Miscellaneous				
			Comp., Rubber Bonded			Woven Rubber Frictioned														
White (comp. or woven) I	Blue (comp. or woven) I	Compressed sheet	White (Buna-S) II	White (Neoprene) II	Blue (Butyl) II	Blue (Neoprene) II	White (Neoprene) II	Blue (Butyl) II	GR-S	Neoprene	Buna-N	Butyl	Thiokol	Natural	Silicone III	Glass Fabric and Silicone Elastomer IV	Glass Fabric and Synthetic Rubber IV	Cork Composition	Plant-Fiber Sheet	Teflon II
*J	J	U	P	P	P	P	P	P	U	A	U	U	U	U	D	C	C	A	A	P
A	–	A	–	–	–	–	–	–	X	A	C	–	C	X	–	X	C	A	A	–
A	–	A	X	C	X	C	C	X	A	A	A	A	C	A	–	F	A	A	F	A
C	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	F	A	F	F	A
C	A	A	A	A	A	A	A	A	C	F	C	A	–	C	A	F	F	X	X	A
A	–	A	C	C	C	C	C	C	X	C	X	X	–	X	–	F	C	A	A	A
A	–	A	C	C	C	–	–	–	A	A	A	A	A	A	A	A	A	X	A	A
A	–	A	C	C	C	–	–	–	A	A	A	A	A	A	A	A	A	X	A	A
A	–	F	C	C	C	X	X	X	X	X	X	X	C	X	X	X	X	A	A	A
X	–	F	X	X	C	C	X	C	F	X	F	F	C	A	–	X	X	X	X	A
X	A	F	X	X	C	C	X	C	F	X	F	F	X	F	–	X	X	X	X	A
X	A	C	C	C	C	X	X	X	X	X	X	C	X	X	–	X	F	F	X	A
C	A	C	A	A	A	A	A	A	F	A	F	F	X	A	–	A	A	A	A	A
A	–	A	C	C	C	X	X	X	C	X	C	C	X	C	X	C	–	A	A	A
A	–	A	–	–	–	–	–	–	A	A	A	A	C	A	–	A	A	A	A	A
C	A	–	C	C	C	C	C	C	A	A	A	A	–	A	–	F	A	A	F	A
C	A	–	A	A	A	C	C	C	A	A	A	A	–	A	–	F	A	A	F	A
A	–	C	A	A	A	C	C	C	A	A	A	A	A	A	–	C	A	A	A	A
X	A	–	A	A	A	C	C	C	A	A	X	A	–	A	A	X	A	F	F	A
A	–	C	–	–	–	–	–	–	X	A	F	F	C	X	–	X	X	A	A	–
A	–	C	–	–	–	–	–	–	X	A	X	–	C	X	–	C	A	A	A	A
A	–	–	–	–	–	–	–	–	X	F	A	X	C	X	X	X	A	A	A	A
A	–	C	–	–	–	–	–	–	X	F	A	X	C	X	X	X	A	A	A	A
A	–	A	C	C	C	C	C	C	A	A	A	A	C	A	–	A	A	A	A	A
C	A	F	A	A	A	A	A	A	F	F	A	A	X	A	A	X	F	X	X	A
X	A	X	–	–	–	–	–	–	F	A	–	F	C	F	–	X	F	X	X	–
X	A	X	–	–	–	–	–	–	X	X	X	C	X	X	–	–	–	X	X	–
X	A	X	–	–	–	–	–	–	C	X	–	C	X	C	–	–	–	X	X	–
X	A	X	–	–	–	–	–	–	C	X	–	C	X	C	–	–	–	X	X	–
A	–	A	–	–	–	–	–	–	F	A	A	A	C	F	A	A	A	A	A	–

*See text at the front page of these tables.

20. *Highly corrosive to nickel alloys at elevated temperatures. Recommendation applies to "dry" gas at ordinary temperatures.*
21. *48% — boil at 330°.*
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23. *Not for temperatures over 390°F.*
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30. *10% — room temperature.*
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Chemical	Iron and Steel	Red Brass	Commercial Bronze	Lead	Copper	Aluminum	Nickel	Inconel	Monel Metal	Type 304 S.S.	Type 316 S.S.	Type 347 S.S.	Carpenter "20" S.S.	Hastelloy "B" or "C"
Hydrogen peroxide	C	C	F	C	C	C	C	C	C	A	A	C	A	A
Hydrogen sulfide, dry (20)	A	X	X	–	X	A	C	A	C	C	A	A	A	A
Wet	C	X	X	–	X	A	C	C	C	C	A	A	A	A
Lacquers (solvents)	C	C	C	A	C	A	A	A	A	A	A	A	A	A
Lactic acid	X	A	A	–	C	F	C	C	C	C	A	A	A	A
Lubricating oils, refined	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Magnesium chloride	F	F	F	X	F	F	A_{21}	A_{21}	A_{21}	C	C	C	A	A_{15}
Magnesium hydroxide	A	C	C	–	X	X	A	A	A	A	A	A	A	A
Magnesium sulfate	C	A	–	–	A	C	A	A	A	A	A	–	A	–
Mercury	A	X	X	–	X	X	A	–	A	A	A	–	–	–
Natural gas	A	C	C	A	C	X	A	A	A	A	A	A	A	A
Nitric acid, crude	X	X	X	X	X	A_{22}	X	C	X	A	A	A	A	C
Diluted	X	X	X	X	X	A_{22}	X	C	X	A	A	A	A	C_{33}
Concentrated	X	X	X	X	X	A_{22}	X	X	X	A	A	A	A	–
Oleic acid	C	A	A_{23}	X	C_{23}	A_{16}	A	A	A	A	A	A	A	A_{16}
Oxalic acid	C	A	A	X	C	C	F	A	A	C	F	C	A	A
Palmitic acid	C	C	A_{23}	C	C_{23}	A	A	A	A	A	A	A	A	A
Petroleum oils, <500°F–crude	A	C	C	A	C	A	C	A	C	C	F	–	A	A
Phosphoric acid	C	C	C_{24}	C	C_{24}	X	C	C	C	C	F	A	A_{26}	A
Potassium hydroxide	C	X	X	X	X	X	A	A	A	C	C	–	–	A
Potassium sulfate	C	A	–	A	A	A	A	A	A	F	F	–	–	A_{16}
Propane	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Sewage (gas)	C	X	X	A	C	A	C	A	C	A	A	–	–	–
Soda ash, (sodium carbonate)	A	F	F	A	C	C	A	A	A	A	A	A	A	A
Sodium bisulfate	X	F	F	A	F	C	–	–	–	A	A	A	A	A
Sodium chloride	F	F	F	A	C	C	A_{25}	A_{25}	A_{25}	C	C	C	A	A
Sodium cyanide	A	X	X	X	X	X	C	–	C	C	–	–	A	–
Sodium hydroxide	A	C	F	F	C	X	A	A	A	A	A	A	A	A
Sodium hypochlorite	X	C	F	X	C	X	C	C	C	C	C	C	F	A_9

Notes continued on opposite page

1. *In absence of oxygen.*
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3. *All percents; 70°.*
4. *To boiling.*
5. *5% room temperature.*
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7. *Iron and steel may rust considerably in presence of water and air.*
8. *High copper alloys prohibited by Codes; yellow brass acceptable.*
9. *Hastelloy "C" recommended to 105°.*
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Asbestos									Rubber							Miscellaneous				
			Comp., Rubber Bonded			Woven Rubber Frictioned														
White (comp. or woven) I	Blue (comp. or woven) I	Compressed sheet	White (Buna-S) II	White (Neoprene) II	Blue (Butyl) II	Blue (Neoprene) II	White (Neoprene) II	Blue (Butyl) II	GR-S	Neoprene	Buna-N	Butyl	Thiokol	Natural	Silicone III	Glass Fabric and Silicone Elastomer IV	Glass Fabric and Synthetic Rubber IV	Cork Composition	Plant-Fiber Sheet	Teflon II
*J	J	U	P	P	P	P	P	P	U	A	U	U	U	U	D	C	C	A	A	P
A	–	–	C	C	C	X	X	X	F	A	–	F	C	F	A	A	A	X	X	–
A	–	–	C	C	C	X	X	X	C	A	C	A	A	C	–	C	A	X	A	A
A	–	–	C	C	C	X	X	X	C	F	C	A	A	C	–	C	A	X	A	A
A	–	C	C	C	C	X	X	X	X	X	X	X	C	X	–	X	A	A	A	A
A	–	A	A	A	A	A	A	A	C	A	C	C	X	C	–	A	A	A	F	A
A	–	A	C	C	C	C	C	C	F	F	A	X	C	F	A	C	A	A	A	A
C	A	A	A	A	A	C	C	C	A	A	A	A	C	A	–	A	A	X	F	A
A	–	A	A	A	A	C	C	C	A	F	A	A	C	A	A	A	A	A	F	A
C	A	–	A	A	A	C	C	C	A	A	A	A	–	A	A	A	A	A	A	A
A	–	C	–	–	–	–	–	–	–	A	–	–	–	–	–	A	A	A	A	–
A	–	A	–	–	–	–	–	–	F	A	A	X	C	F	–	C	A	A	A	–
X	A	C	X	X	X	X	X	X	X	X	X	C	–	X	–	A	A	X	X	A
X	A	C	C	C	C	X	X	X	X	X	X	A	–	X	A	F	A	X	X	A
X	A	X	X	X	X	X	X	X	X	X	X	C	–	X	A	A	X	X	X	A
A	–	A	–	–	–	–	–	–	F	C	A	–	–	F	–	X	X	A	A	A
X	A	A	A	A	A	A	A	A	F	F	–	–	–	F	–	C	A	A	F	A
A	–	A	–	–	–	–	–	–	F	A	A	F	C	F	–	X	C	A	A	–
A	–	A	C	C	C	X	X	X	C	F	A	X	C	C	–	F	A	A	C	A
X	A	A	A	A	A	C	C	C	C	F	C	C	–	C	–	X	A	X	X	A
A	–	–	C	C	C	C	C	C	A	C	A	A	–	A	A	A	A	X	X	A
A	–	–	A	A	A	A	A	A	A	A	A	A	–	A	A	A	A	A	X	A
A	–	A	–	–	–	–	–	–	–	A	A	–	A	–	–	C	A	A	A	–
A	–	A	–	–	–	–	–	–	C	A	A	X	C	C	A	A	A	X	F	–
A	–	A	A	A	A	A	A	A	A	A	A	A	C	A	A	A	A	X	X	A
C	A	A	A	A	A	A	A	A	A	A	A	A	C	A	–	A	A	A	F	A
A	–	A	A	A	A	A	A	A	A	A	A	A	C	A	A	A	A	A	A	A
A	–	–	–	–	–	–	–	–	A	A	A	A	–	A	–	A	A	A	A	A
A	–	A	A	A	A	A	A	A	C	C	C	A	C	C	A	A	A	X	X	A
C	A	A	A	A	A	A	A	A	C	F	C	C	–	C	A	A	A	X	X	A

*See text at the front page of these tables.

20. *Highly corrosive to nickel alloys at elevated temperatures. Recommendation applies to "dry" gas at ordinary temperatures.*
21. *48% — boil at 330°.*
22. *Room temperature — over 80%.*
23. *Not for temperatures over 390°F.*
24. *Up to 140°F.*
25. *Up to 200°F.*
26. *Up to 176°F.*
27. *10% maximum; boiling.*
28. *50%; 320°.*
29. *Do not use if iron contamination is not permissible.*
30. *10% — room temperature.*
31. *Hot.*
32. *Unsatisfactory for hot gases.*
33. *Hastelloy "C" to 158°.*
34. *Room temperature to 158°. Corrosion increases with increase in concentration as well as temperature.*
35. *Dilute at room temperature.*
36. *Attack increases when only partially submerged; fumes very corrosive.*
37. *Hastelloy "C" to 212°.*

CHEMICAL RESISTANCE OF METALS

Caution: Do not use table without reading footnotes and text.

Resistance Ratings: A = Good; F = Fair; C = Caution – depends on conditions; X = Not recommended.

Chemical	Iron and Steel	Red Brass	Commercial Bronze	Lead	Copper	Aluminum	Nickel	Inconel	Monel Metal	Type 304 S.S.	Type 316 S.S.	Type 347 S.S.	Carpenter "20" S.S.	Hastelloy "3" or "C"
Sodium nitrate	A	A	A	A	A	A	A_{25}	A_{25}	A_{25}	C	A	A	A	C_{14}
Sodium peroxide	C	C	–	–	–	A	A	–	A	A	A	–	–	A_{37}
Sodium sulfate	A	A	A	A_{27}	A	A	A_{25}	A_{25}	A_{25}	A	A	A	A	A
Sodium sulfide	A	C	C	A	C	X	A_{28}	A_{28}	A_{28}	C	A	A	A	A_{16}
Sodium thiosulfate, "hypo"	A_{29}	C	C	A	C	C	–	–	–	A	A	A	A	–
Stearic acid	F	A	A	A	C_{23}	A_{11}	A_4	A_4	A_4	A	A	A	A	A_{25}
Sulfur	A	A	F	–	C	A	A	A	A	C	C	C	A	A
Sulfur dioxide, dry	A	A	A	A	A	A	A	A	A	C	A	C	A	A_{33}
Sulfur dioxide, wet	X	F	F	A	A	C	X	F	X	C	A	C	A	–
Sulfuric acid, <10%, cold	X	C	C	A	C	X	C	C	F	C	A	X	A	A
Hot	X	X	X	A	X	X	X	X	C	X	X	X	A	A
10-75%, cold	X	X	X	A	X	X	C	C	C	C	C	C	A	A
Hot	X	X	X	A	X	X	X	X	F	X	X	–	A_{26}	A_{15}
75-95%, cold	A	C	C	A	C	X	–	–	A	F	A	C	A	A
Hot	A	–	X	A	–	X	X	X	C	X	C	X	A_{26}	–
Fuming	A	–	–	A	C	A_{16}	X	–	–	–	A	–	A_{26}	–
Sulfurous acid	X	F	F	A	F	F	C	C	C	C	A	C	A	A_{14}
Tartaric acid	X	C	–	A	–	A	C	C	C	C	A	–	A	A_{30}
Toluene	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Trichloroethylene, dry	A	A	A	F	A	A	A	A	A	C	A	C	A	–
Wet	X	F	F	–	C	C	–	–	–	–	–	–	A	–
Turpentine	C	C	C	A	C	A	–	A	A	A	A	A	A	A
Water, fresh (tap, boiler feed, etc.)	A	A	A	A	A	X	A	A	A	A	A	A	A	A
Water, sea water	C	A	A	A	C	X	C	A	A	C	C	C	A	A
Whiskey and wines	X	C	C	–	A	C	A	A	C	A	A	–	A	–
Zinc chloride	X	X	X	A	X	X	–	–	A	X	C	–	A	A
Zinc sulfate	C	C	C	–	F	–	–	–	A	F	A	–	A	A

Notes continued on opposite page

1. *In absence of oxygen.*
2. *125° maximum.*
3. *All percents; 70°.*
4. *To boiling.*
5. *5% room temperature.*
6. *To 122°.*
7. *Iron and steel may rust considerably in presence of water and air.*
8. *High copper alloys prohibited by Codes; yellow brass acceptable.*
9. *Hastelloy "C" recommended to 105°.*
10. *Where color is not important. Do not use with c.p. acid.*
11. *Room temperature to 212°. Moisture inhibits attack.*
12. *Gas; 70°.*
13. *To 500°.*
14. *Hastelloy "C" at room temperature.*
15. *Room temperature to 158°.*
16. *At room temperature.*
17. *Where discoloration is not objectionable.*
18. *5% maximum; 150° maximum.*
19. *Satisfactory vapors to 212°.*

CHEMICAL RESISTANCE OF GASKETS

(SEE CHEMICALS ON OPPOSITE PAGE)

Resistance Ratings: Same as facing page

Asbestos									Rubber							Miscellaneous				
			Comp., Rubber Bonded			Woven Rubber Frictioned														
White (comp. or woven) I	Blue (comp. or woven) I	Compressed sheet	White (Buna-S) II	White (Neoprene) II	Blue (Butyl) II	Blue (Neoprene) II	White (Neoprene) II	Blue (Butyl) II	GR-S	Neoprene	Buna-N	Butyl	Thiokol	Natural	Silicone III	Glass Fabric and Silicone Elastomer IV	Glass Fabric and Synthetic Rubber IV	Cork Composition	Plant-Fiber Sheet	Teflon II
*J	J	U	P	P	P	P	P	P	U	A	U	U	U	U	D	C	C	A	A	P
C	A	C	A	A	A	A	A	A	C	A	C	A	–	C	–	A	A	A	A	A
A	–	C	–	–	–	–	–	–	C	F	C	A	–	C	–	C	A	X	X	A
A	–	A	A	A	A	A	A	A	A	A	A	A	–	A	A	A	A	A	F	A
A	–	A	–	–	–	–	–	–	A	A	A	A	–	A	–	A	A	X	X	A
A	–	A	A	A	A	A	A	A	A	A	A	A	–	A	A	A	A	A	F	A
A	–	A	C	C	C	X	X	X	C	A	A	C	–	C	A	X[31]	F[31]	A	A	A
A	–	A	–	–	–	–	–	–	F	A	F	F	A	F	–	A	C	A	A	–
A	–	–	C	C	C	–	–	–	C	C	C	C	–	C	–	F	C	F	X	A
–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
F	A	A	A	A	A	A	A	A	A	A	A	A	–	A	A	A	A	X	X	A
F	A	A	C	C	C	C	X	C	A	F	A	A	–	A	–	F	A	X	X	A
X	A	F	X	X	X	X	X	X	C	C	C	A	–	C	A	A	A	X	X	A
X	A	F	X	X	X	X	X	X	C	X	C	A	–	C	–	F	A	X	X	A
X	A	C	X	X	X	X	X	X	C	C	C	A	–	C	X	X	F	X	X	A
X	A	C	X	X	X	X	X	X	X	X	X	C	–	X	–	X	F	X	X	A
X	A	X	X	X	X	X	X	X	X	X	X	X	–	X	–	X	X	X	X	A
X	A	A	A	A	A	A	A	A	C	F	C	C	–	A	–	F	A	X	X	A
A	–	–	A	A	A	A	A	A	C	A	C	C	–	A	–	A	A	A	F	A
A	–	A	C	C	C	X	X	X	X	X	A	X	A	X	X	X	C	A	A	A
A	–	C	C	C	C	X	X	X	X	X	C	X	X	X	X	X	X	A	A	A
–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
A	–	A	C	C	C	X	X	X	C	C	A	X	C	C	–	C	C	A	A	A
A	–	A	A	A	A	A	A	A	A	A	A	A	C	A	A	A	A	F	A	A
A	–	A	A	A	A	A	A	A	A	A	A	A	C	A	A	A	A	F	F	A
A	–	A	C	C	C	X	X	X	A	A	A	A	X	A	–	A	A	A	A	A
X	A	C	A	A	A	A	A	A	C	A	C	A	–	C	–	A	A	F	X	A
X	A	A	A	A	A	A	A	A	A	A	A	A	–	A	–	A	A	F	F	A

*See text at the front page of these tables.

20. *Highly corrosive to nickel alloys at elevated temperatures. Recommendation applies to "dry" gas at ordinary temperatures.*
21. *48% — boil at 330°.*
22. *Room temperature — over 80%.*
23. *Not for temperatures over 390°F.*
24. *Up to 140°F.*
25. *Up to 200°F.*
26. *Up to 176°F.*
27. *10% maximum; boiling.*
28. *50%; 320°.*
29. *Do not use if iron contamination is not permissible.*
30. *10% — room temperature.*
31. *Hot.*
32. *Unsatisfactory for hot gases.*
33. *Hastelloy "C" to 158°.*
34. *Room temperature to 158°. Corrosion increases with increase in concentration as well as temperature.*
35. *Dilute at room temperature.*
36. *Attack increases when only partially submerged; fumes very corrosive.*
37. *Hastelloy "C" to 212°.*

FABRICATING CAPACITIES

THE TABLES BELOW ARE FOR DATA OF FABRICATING CAPACITIES OF THE SHOP WHICH HAVE TO BE KNOWN BY THE VESSEL DESIGNER. THE COLUMNS HAVE BEEN LEFT OPEN AND ARE TO BE FILLED IN BY THE USER OF THIS HANDBOOK ACCORDING TO THE FACILITIES OF THE SHOP CONSIDERED.

ROLLING PLATES	MAXIMUM WIDTH in.	MAXIMUM THICKNESS in.	MINIMUM DIAMETER in.
TENSILE STRENGTH OF PLATE psi.			
NOTE: FOR MATERIAL OF HIGHER STRENGTH THE THICKNESS OR WIDTH OF THE PLATE MUST BE REDUCED IN DIRECT PROPORTION TO THE HIGHER STRENGTH			

ROLLING ANGLES		MAXIMUM SIZE	MINIMUM DIAMETER in.
	 LEG IN		
	 LEG OUT		
		MINIMUM SIZE	MINIMUM DIAMETER in.
	 LEG IN		
	 LEG OUT		

ROLLING BEAMS		MAXIMUM SIZE	MINIMUM DIAMETER in.
	 ON FLANGES		

ROLLING CHANNELS		MAXIMUM SIZE	MINIMUM DIAMETER in.
	 FLANGES IN		
	 FLANGES OUT		

ROLLING FLAT BAR		MAXIMUM SIZE	MINIMUM DIAMETER in.
	 ON EDGE		

FABRICATING CAPACITIES

	NOMINAL PIPE SIZE	SCHEDULE	MINIMUM RADIUS in.
BENDING PIPES			

	PLATE THICKNESS in.	MINIMUM INSIDE RADIUS in.	PLATE THICKNESS in.	MINIMUM INSIDE RADIUS in.
BENDING PLATES WITH PRESS BRAKE				

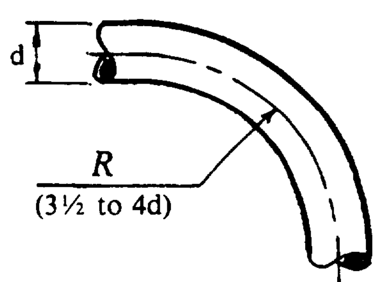
	PLATE THICKNESS in.	MAXIMUM DIAMETER OF HOLE in.	PLATE THICKNESS in.	MAXIMUM DIAMETER OF HOLE in.
PUNCHING HOLES				

MINIMUM INSIDE DIAMETER OF VESSEL ACCESSIBLE FOR INSIDE WELDING	inches
TYPES OF WELDINGS AVAILABLE	
FURNACES FOR STRESS RELIEVING	WIDTH ft. HEIGHT ft. LENGTH ft. MAX. TEMPERATURE F.

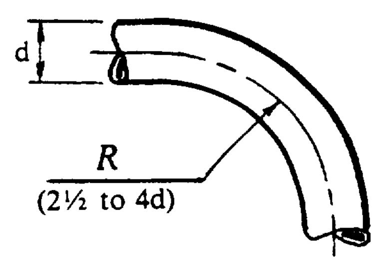
PIPE AND TUBE BENDING *

In bending a pipe or tube, the outer part of the bend is stretched and the inner section compressed, and as the result of opposite and unequal stresses, the pipe or tube tends to flatten or collapse. To prevent such distortion, the common practice is to support the wall of the pipe or tube in some manner during the bending operation. This support may be in the form of a filling material, or, when a bending machine or fixture is used, an internal mandrel or ball-shaped member may support the inner wall when required.

MINIMUM RADIUS: The safe minimum radius for a given diameter, material, and method of bending depends upon the thickness of the pipe wall, it being possible, for example, to bend extra heavy pipe to a smaller radius than pipe of standard weight. As a general rule, wrought iron or steel pipe of standard weight may readily be bent to a radius equal to five or six times the nominal pipe diameter. The minimum radius for standard weight pipe should, as a rule, be three and one-half to four times the diameter. It will be understood, however, that the minimum radius may vary considerably, depending upon the method of bending. Extra heavy pipe may be bent to radii varying from two and one-half times the diameter for smaller sizes to three and one-half to four times the diameter for larger sizes.



Standard Pipe

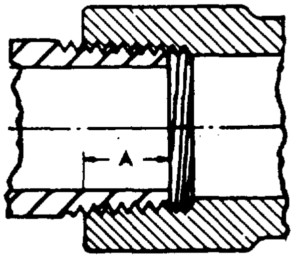


Extra Heavy Pipe

MINIMUM RADIUS

*From Machinery's Handbook, 1969 Industrial Press, Inc. - New York

PIPE ENGAGEMENT
LENGTH OF THREAD ON PIPE TO MAKE A TIGHT JOINT



Nominal Pipe Size	Dimension A inches	Nominal Pipe Size	Dimension A inches
1/8	1/4	3-1/2	1-1/16
1/4	3/8	4	1-1/8
3/8	3/8	5	1-1/4
1/2	1/2	6	1-5/16
3/4	9/16	8	1-7/16
1	11/16	10	1-5/8
1-1/4	11/16	12	1-3/4
1-1/2	11/16		
2	3/4		
2-1/2	15/16		
3	1		

DIMENSIONS DO NOT ALLOW FOR VARIATION
IN TAPPING OR THREADING

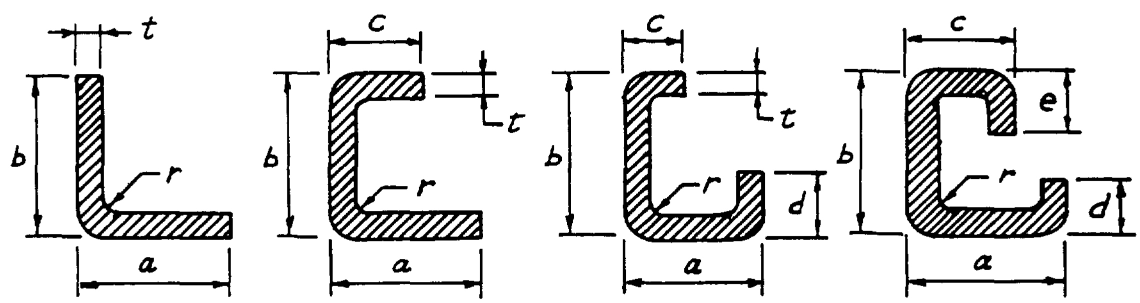
DRILL SIZES FOR PIPE TAPS

Nominal Pipe Size	Tap Drill Size in.	Nominal Pipe Size	Tap Drill Size in.
1/8	11/32	2	2-3/16
1/4	7/16	2-1/2	2-9/16
3/8	19/32	3	3-3/16
1/2	23/32	3-1/2	3-11/16
3/4	15/16	4	4-3/16
1	1-5/32	5	5-5/16
1-1/4	1-1/2	6	6-5/16
1-1/2	1-23/32		

BEND ALLOWANCES

For 90° Bends in Low-Carbon Steel

Metal Thickness (t) in.	Bend Allowance Inches With Inside Radius (r) in.					
	1/32	1/16	3/32	1/8	1/4	1/2
0.032	0.059	0.066	0.079	0.093	0.146	0.254
0.050	0.087	0.101	0.114	0.129	0.168	0.276
0.062	0.105	0.118	0.132	0.145	0.183	0.290
0.078	0.128	0.142	0.155	0.169	0.202	0.310
0.090	0.146	0.160	0.173	0.187	0.217	0.324
0.125	0.198	0.211	0.224	0.243	0.260	0.367
0.188	0.289	0.302	0.316	0.329	0.383	0.443
0.250	0.382	0.395	0.409	0.424	0.476	0.519
0.313	0.474	0.488	0.501	0.515	0.569	0.676
0.375	0.566	0.580	0.593	0.607	0.661	0.768
0.437	0.658	0.672	0.685	0.699	0.752	0.860
0.500	0.750	0.764	0.777	0.791	0.845	0.952



w = a + b − bend allowance   w = a + b + c − (2 x bend allowance)   w = a + b + c + d − (3 x bend allowance)   w = a + b + c + d + e − (4 x bend allowance)

Note: w = developed width (length) of blank, t = metal thickness, r = inside radius of bend.

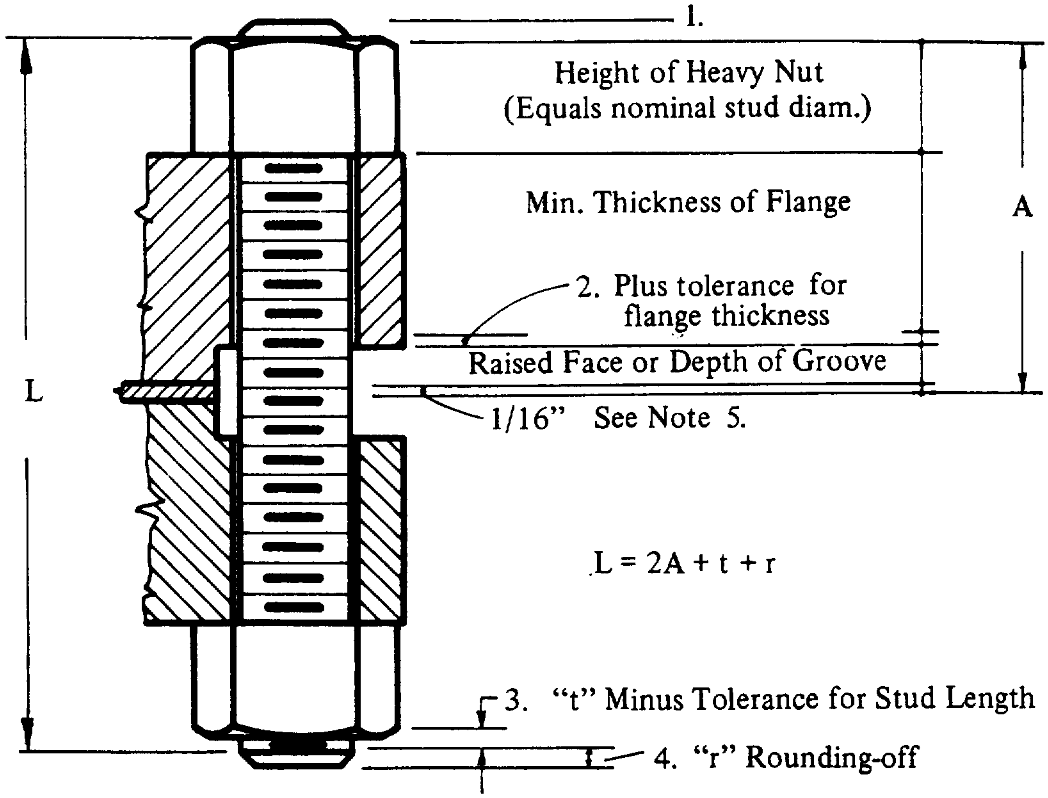
EXAMPLE: Carbon steel bar bent at two places.
The required length of a 1/4 in. thick bar bent to 90 degrees with 1/4 in inside radius as shown above when the sum of dimensions a, b and c equals 12 inches, is

12 - (2 x 0.476) = 11.048 inches

MINIMUM RADIUS FOR COLD BENDING:
The minimum permissible inside radius of cold bending of metals when bend lines are transverse to the direction of the final rolling, varies in terms of the thickness, t from 1-1/2 t up to 6 t depending on thickness and ductility of material.

When bend lines are parallel to the direction of the final rolling the above values may have to be approximately doubled.

LENGTH OF STUD BOLTS FOR FLANGES*



1. Length of the stud bolts do not include the heights of the point. (1.5 times thread pitch)

2. Plus tolerance of flg. thk's.

   Sizes 18 in. & smaller 0.12 in.
   Sizes 20 in. and larger 0.19 in.

3. Minus tolerance of stud length

   For lengths up to 12" incl. 0.06 in.
   For lengths over 12" to 18" incl. 0.12 in.
   For lengths over 18" 0.25 in.

4. Rounding-off to the next larger 0.25 in. increment.

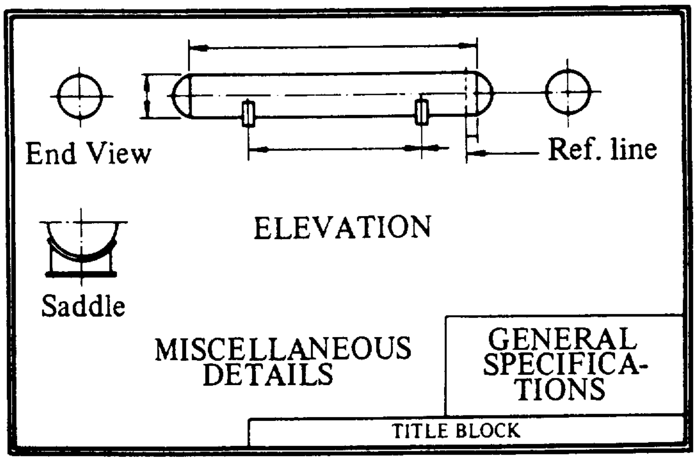
5. Gasket thickness for raised face, M & F and T & G flanges 0.12 in. For ring type joint see table page 346 and take half of the dimensions shown, since in dimension "A" only half of the gasket thickness is included.

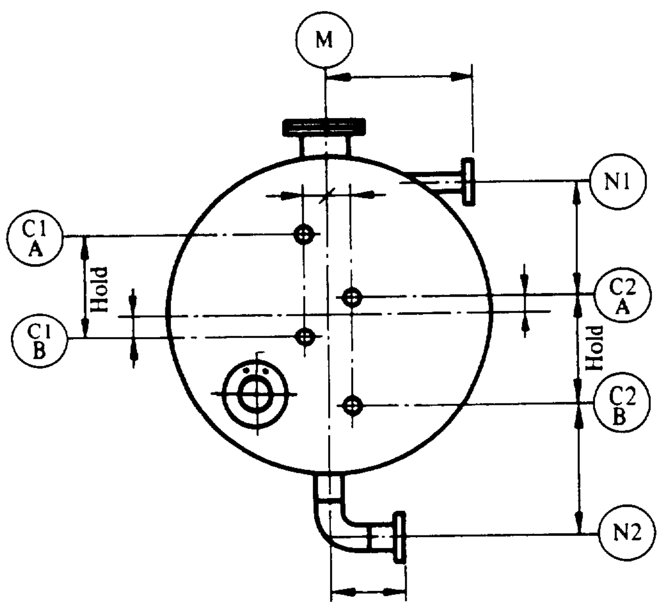
*Extracted from American National Standard :
ANSI B16.5 - 1973 Steel Pipe Flanges and Flanged Fittings.

PRESSURE VESSEL DETAILING

IN THE PRACTICE THERE ARE SEVERAL DIFFERENT WAYS OF DETAILING PRESSURE VESSELS. BY MAKING THE DRAWINGS ALWAYS WITH THE SAME METHOD, CONSIDERABLE TIME CAN BE SAVED AND ALSO THE POSSIBILITIES OF ERRORS ARE LESS. THE RECOMMENDED METHOD IN THE FOLLOWING PROVED PRACTICAL AND GENERALLY ACCEPTED.

HORIZONTAL VESSELS





END VIEW

A. Select the scale so that all openings, seams, etc., can be shown without making the picture overcrowded or confusing.

B. Show right-end view if necessary only for clarity because of numerous connections, etc., on heads. In this case it is not necessary to show on both views the connections etc., in shell.

C. Show the saddles separately, if showing them on the end view would overcrowd the picture. On elevation show only a simple picture of saddle and the centerlines.

D. Locate davit.

E. Locate name plate.

F. Locate seams, after everything is in place on elevation. The seams have to clear nozzles, lugs and saddles.

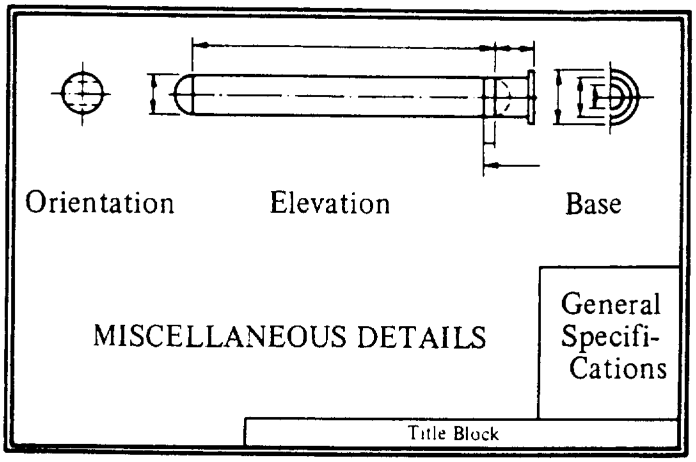
G. Show on the elevation and end view a simple picture of openings, internals, etc., if a separate detail has to be made for these.

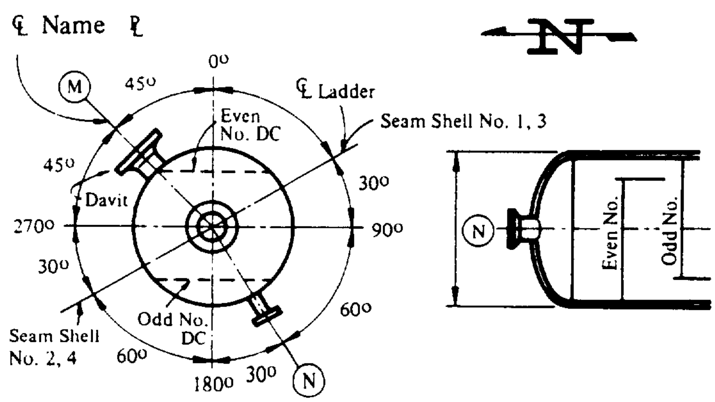
H. Dimensioning on the elevation drawing. All locations shall be shown with tailed dimensions measured from the reference line. The distance from ref. line to be shown for one saddle only. The other saddle shall be located showing the dimension between the anchor bolt holes of the saddles.

I. Two symbolic bolt holes shown in flanges make clear that the holes are straddling the parallel lines with the principal centerlines of vessel.

PRESSURE VESSEL DETAILING (cont.)

VERTICAL VESSELS





ORIENTATION PLAN

A. Select the scale so that all openings, trays, seams, etc., can be shown without making the picture overcrowded or confusing.

B. If the vessel diameter is unproportionally small to the length, draw the width of the vessel in a larger scale to have space enough for all details.

C. The orientation is not a top view, but a schematic information about the location of nozzles, etc.

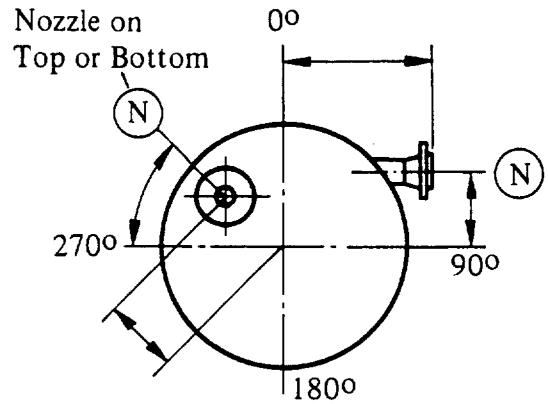
D. Show the orientation so rotated that the downcomers on the elevation can be shown in their true position.

E. Dimensioning. All locations on the elevation drawing shall be shown with tailed dimensions measured from the reference line.

F. Locate long seams, after everything is in place on elevation.

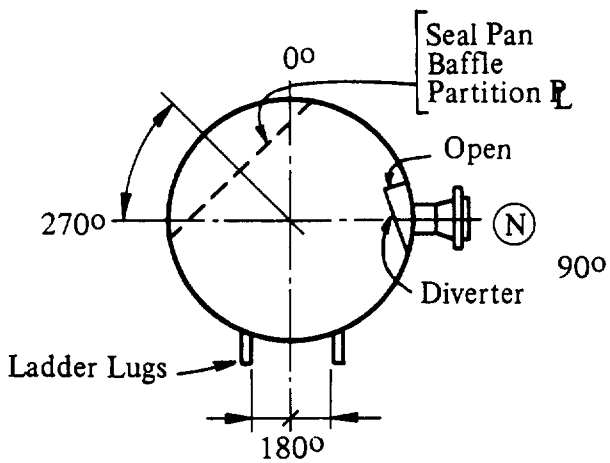
G. Mark vessel centerlines w/ degrees: 0°, 90°, 180°, 270° and use it in the same position on all other orientations.

PRESSURE VESSEL DETAILING (cont.)



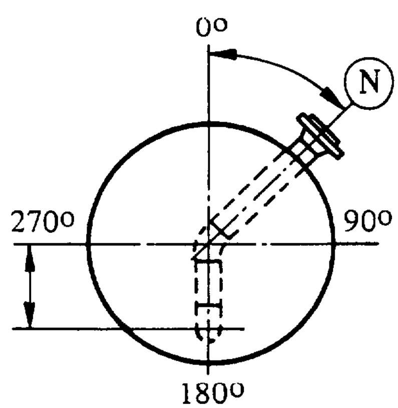
H. It is not necessary to show internals on vessel orientation if their position is clear from detail drawings or otherwise.

J. Draw separate orientations for showing different internals, lugs, etc. if there is not space enough to show everything on one.

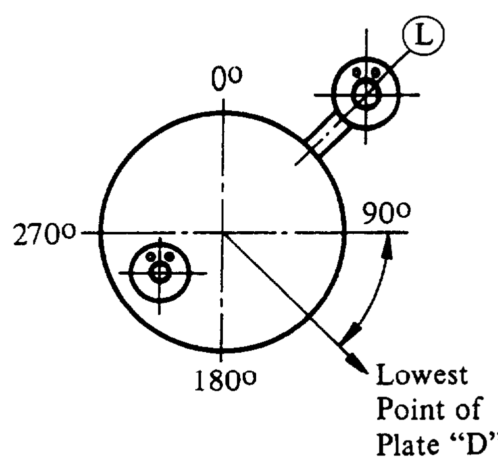


K. For vessels with conical sections, show 2 orientations if necessary, one for the upper section, one for the lower section.

L. Two, symbolic bolt holes shown in flanges make clear that the holes are straddling the lines parallel with the principal centerlines of vessel.

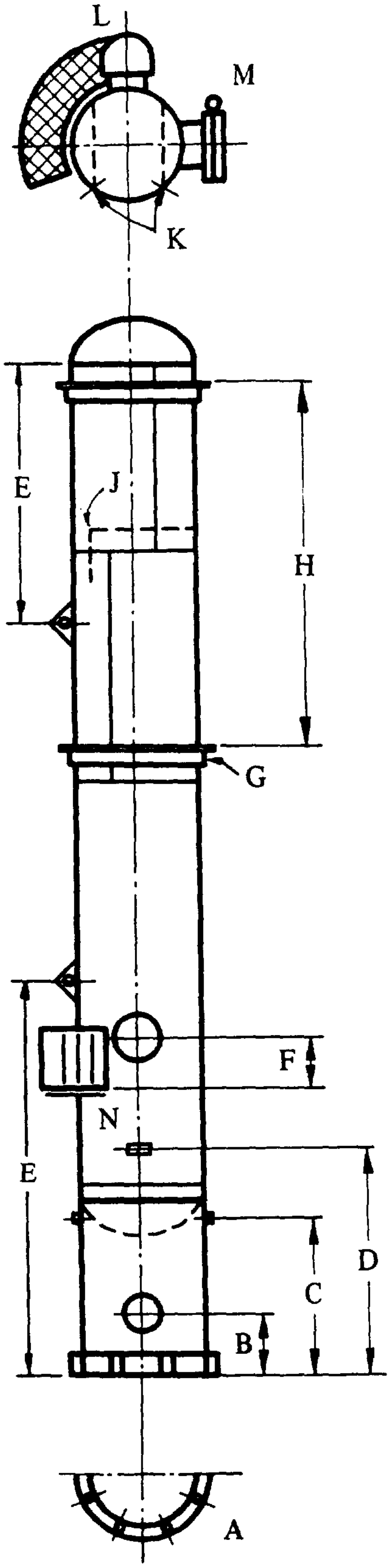


M. If there is a sloping tray, partition plate, coil, etc., in the vessel, show in the orientation the direction of slope.



ORIENTATIONS

PREFERRED LOCATIONS
Of Vessel Components and Appurtenances



A. Anchor bolts straddle principal centerlines of vessel.

B. Skirt access openings above base minimum to clear anchor lugs, maximum 3'-0".

C. Skirt vent holes as high as possible.

D. Name plate above manway or liquid level control, or level gauge. If there is no manway, 5'-0" above base.

E. Lifting lugs - if the weight of the vessel is uniform, "E" dimension is equal .207 times the overall length of vessel.

F. Manway 3'-0" above top of platform-floor plate.

G. Insulation ring must clear girth seam and shall be cut out to clear nozzles, etc.

H. Insulation ring spacing 8 - 12 feet (approx. length of metal jacket sheet).

J. Girth seams shall clear trays, nozzles, lugs.

K. Long seams to clear nozzles, lugs, tray downcomers. Do not locate long seams behind downcomers. Seams shall be located so that visual inspection can be made with all internals in place. Longitudinal seams to be staggered 180° if possible.

L. Ladder and platform relation.

M. Davit and hinge to be located as the manway is most accessible, or right hand side.

N. Ladder rung level with top of platform floor plate. The height of first rung above base varies, minimum 6", maximum 1'-6".

COMMON ERRORS
in detailing pressure vessels

A. Interferences

Openings, seams, lugs, etc. interfere with each other. This can occur:

1. When the location on the elevation and orientation is not checked. The practice of not showing openings etc. on the elevation in their true position, may increase the probability of this mistake.

2. The tail dimensions or the distances between openings on the orientation do not show interference, but it is disregarded, that the nozzles, lugs etc., have certain extension. Thus it can take place that:

   a. Skirt access opening does not clear the anchor lugs.
   b. Ladder lug interferes with nozzles.
   c. The reinforcing pads of two nozzles overlap each other.
   d. Reinforcing pad covers seam.
   e. Vessel-davit interferes with nozzles. This can be overlooked especially if the manufacturer does not furnish the vessel-davit itself, but the lugs only.
   f. Lugs, openings, etc. are on the vessel seam.
   g. There is no room on perimeter of the skirt for the required number of anchor lugs.

Particular care should be taken when ladder, platform, vessel-davit etc., are shown on separate drawings, or more than one orientations are used.

B. Changes.

Certain changes are necessary on the drawing which are carried out on the elevation, but not shown on the orientation or reversed. Making changes, it is advisable to ask the question: "What does it affect?"

For example:

The change of material affects:	Bill of material Schedule of openings General specification Legend
The change of location affects:	Orientation Elevation Location of internals Location of other components.

C. Showing O.D. (outside diameter) instead of I.D. (inside diameter) or reversed.

D. Dimensions shown erroneously:
   1'-0" instead of 10"
   2'-0" instead of 20" etc.

E. Overlooking the requirement of special material

PRESSURE VESSEL DETAILING (cont.)

GENERAL SPECIFICATIONS

VESSEL TO BE CONSTRUCTED IN STRICT ACCORDANCE WITH THE LATEST EDITION OF THE ASME CODE SECTION VIII. DIV. I. FOR PRESSURE VESSELS AND IS TO BE SO STAMPED. INSPECTION BY COMMERCIAL UNION INSURANCE CO. OF AMERICA.

DESIGN DATA

	DESIGN	MAX. A. WORKING.	MAX. A. N. & C.	HYDRO. TEST
PRESSURE PSIG. @				
TEMPERATURE °F.				
LIMITED BY				
WIND PRESS. LBS/SQ. FT.		CORROSION ALLOW. IN.		
SEISMIC COEFFICIENT		RADIOGRAPHIC EXAMINATION		
ERECTION (SHIPPING) WEIGHT LBS.		LONGITUDINAL JOINT EFFICIENCY		
WEIGHT FULL W/ WATER LBS.		POST WELD HEAT TREATMENT @ 1100°F		
OPERATING WEIGHT LBS.				

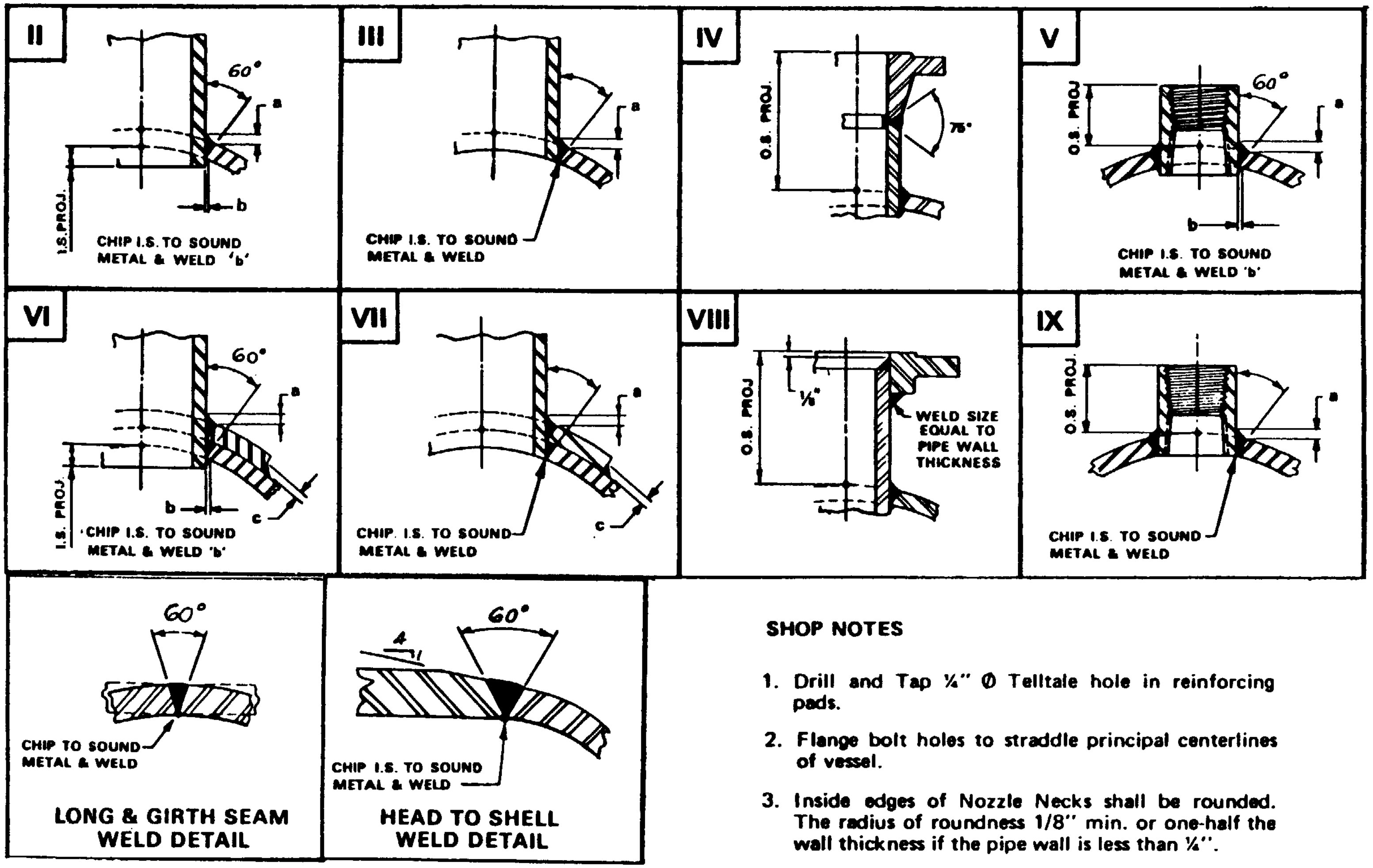
DATA NOT SHOWN ARE NOT FACTOR OF DESIGN

MATERIAL

SHELL	SA.	**HEAD**	SA.
			TYPE
	THK.		THK
FLANGE		SKIRT	
NOZZLE NECK		BASE	
BOLTING		ANCH. BOLT	
COUPLING		SADDLES	
WELDED FITTING			
GASKET			

PAINT

VESSELS REQUIRED:	APPROX. SHIPPING WEIGHT LBS.



SHOP NOTES

1. Drill and Tap ¼" Ø Telltale hole in reinforcing pads.
2. Flange bolt holes to straddle principal centerlines of vessel.
3. Inside edges of Nozzle Necks shall be rounded. The radius of roundness 1/8" min. or one-half the wall thickness if the pipe wall is less than ¼".

Detailing openings as shown on the opposite page with data exemplified in the schedule of openings below, eliminates the necessity of detailing every single opening on the shop drawing.

MARK	SERVICE	SIZE	RATING	TYPE	BORE	NECK				REPAD		PROJ.		WELD DETAIL DWG.		WELD SIZE		
						SCH.	WALL	LG.	MAT'L.	O.D.xTHK.	MAT'L.	O.S.	I.S.			a	b	c
C-1	DRAIN	2"	6000#	CPLG.	-	-	-	-	-	-	-	2½"	MIN.	V	-	3/8"	MIN.	-
N-1	INLET	3"	300#	W.N.	XH.	XH	.300	5½	SA 53 B	—	—	8"	MIN.	II	IV	3/8"	MIN.	-
M-1	MANWAY	18"	300#	W.N.	XH	XH.	.500	6¼"	SA 53-B	24"x½"	SA 515-70	10"	2"	VI	IV	3/8"	MIN.	3/8"

SCHEDULE OF OPENINGS

TRANSPORTATION OF VESSELS

Shipping capabilities and limitations.

1. TRANSPORTATION BY TRUCK.

The maximum size of loads which may be carried without special permits

a. weight approximately 40.000 lbs.

b. width of load 8 ft., 0 in.

c. height above road 13 ft., 6 in. (height of truck 4 ft., 6 in. to 5 ft., 0 in.)

d. length of load 40 ft., 0 in.

Truck shipments over 12 ft., 0 in. width require escort. It increases considerably the costs of transportation.

2. TRANSPORTATION BY RAILROAD.

Maximum dimensions of load which may be carried without special routing.

a. width of load 10 ft., 0 in.

b. height above bed of car 10 ft., 0 in.

With special routing, loads up to 14 ft., 0 in. width and 14 ft., 0 in. height may be handled.

PAINTING

OF STEEL SURFACES

PURPOSE
The main purpose of painting is the preservation of a steel surface. The paint retards the corrosion 1., by preventing the contact of corrosive agents from the vessel surface and 2., by rust inhibitive, electro-chemical properties of the paint material.

The paints must be suitable to resist the effects of the environment, heat, impact, abrasion and action of chemicals.

SURFACE PREPARATION
The primary requisite for a successful paint job is the removal of mill scale, rust, dirt, grease, oil and foreign matter. Mill scale is the bluish-gray, thick layer of iron oxides which forms on structural steel subsequent to the hot rolling operation. If the mill scale is intact and adheres tightly to the metal, it provides protection to the steel, however, due to the rolling and dishing of plates, completely intact mill scale is seldom encountered in practice.

If mill scale is not badly cracked, a shop primer will give long life in mild environments, provided that the loose mill scale, rust, oil, grease, etc. are removed.

ECONOMIC CONSIDERATIONS
The selection of paint and surface preparation beyond the technical aspects is naturally a problem of economics.

The cost of paint is normally 25-30% or less of the cost of painting a structure, thus the advantage of using high quality paint is apparent. Sixty percent or more of the total expense of a paint job lies in the surface preparation and the cost of preparation to different degrees is varying in a proportion of 1 to 10-12. For example, the cost of sandblasting is about 10-12 times higher than that of the hand wire brushing. The cost of surface preparation should be balanced against the increased life of the vessel.

SELECTION OF PAINT SYSTEMS
The tables on the following pages serve as guides to select the proper painting system and estimate the required quantity of paint for various service conditions. The data tabulated there have been taken from the Steel Structures Painting Council's specifications and recommendations.

Considering the several variables of painting problems, it is advisable to request the assistance of paint manufacturers.

SPECIAL CONDITIONS

ABRASION
When the painting must resist abrasion, the good adhesion of the coating is particularly important. For maximum adhesion, blast cleaning is the best and also pickling is satisfactory. Pretreatments such as hot phosphate or wash primer are excellent for etching and roughening the surface.

Urethane coatings, epoxies and vinyl paints have very good abrasion resistance. Zinc-rich coating, and phenolic paints are also good. Oleoresinous paints may develop much greater resistance by incorporation of sand reinforcement.

HIGH TEMPERATURE

Below temperatures of 500-600^{o}F to obtain a good surface for coating, hot phosphate treatment is satisfactory. Above 500-600^{o}F a blast cleaned surface is desirable.

Recommended Paints:

Up to	200 - 250 F	Oil base paints limited period
	200 - 300 F	An alkyd or phenolic vehicle
	300 - 400 F	Specially modified alkyds
	300 - 550 F	Colored silicones
	700 - 800 F	Inorganic zinc coatings above 550 F Black or Aluminum silicones
	800 - 1200 F	Aluminum silicones up to 1600-1800 F Silicone ceramic coatings

CORROSIVE CHEMICALS

See tables I and V for the selection of paint systems.

THE REQUIRED QUANTITY OF PAINT

Theoretically, one gallon of paint covers 1600 square feet surface with 1 mil (0.001 inch) thick coat when it is wet.

The dry thickness is determined by the solid (non volatile) content of the paint, which can be found in the specification on the label, or in the supplier's literature.

If the content of solids by volume is, for example, 60%, then the maximum dry coverage (spreading rate) theoretically will be 1600 x .60 = 960 square feet.

THE CONTENT OF SOLIDS OF PAINTS BY VOLUME %

Spec. No.	Paint	%	Spec. No.	Paint	%
1	Red Lead and Raw linseed Oil Primer	96	12	Cold Applied Asphalt Mastic (Extra Thick Film)	50
2	Red Lead, Iron Oxide, Raw Linseed Oil and Alkyd Primer	82	13	Red or Brown One-Coat Shop Paint	60
3	Red Lead, Iron Oxide, and Fractionated Linseed Oil Primer	96	14	Red Lead, Iron Oxide & Linseed Oil Primer	96
4	Extended Red Lead, Raw and Bodied Linseed Oil Primer	70	15	Steel Joist Steel Shop Paint	70
5	Zinc Dust, Zinc Oxide, and Phenolic Varnish Paint	60	16	Coal Tar Epoxy-Polyamide Black (or Dark Red) Paint	75
			101	Aluminum Alkyd Paint	40
6	Red Lead, Iron Oxide, and Phenolic Varnish Paint	47	102	Black Alkyd Paint	37
			103	Black Phenolic Paint	57
8	Aluminum Vinyl Paint	14	104	White or Tinted Alkyd Paint, Types I, II, III, IV	47 - 50
9	White (or Colored) Vinyl Paint	17			
11	Red Iron Oxide, Zinc Chromate, Raw Linseed Oil and Alkyd Primer	70	106	Black Vinyl Paint	13
			107	Red Lead, Iron Oxide and Alkyd Intermediate Paint	60

In practice, especially with spray application, the paint never can be utilized at 100 percent. Losses due to overspray, complexity of surface (piping, etc.) may decrease the actual coverage to 40-60%, or even more.

PAINTING

TABLE I, PAINT SYSTEMS

System Number SSPC-PS	CONDITION	Surface Preparation Table II	Pretreatment Table III	1st Coat	2nd Coat	3rd Coat	4th Coat	5th Coat	Total Thickness
				Paint and Dry Thickness, mils See Table IV					
1.01	Condensation, chemical fumes, brine drippings and other extremely corrosive conditions are not present	2 or 3	Not Req'd	14 (1.7)	104 (1.3)	104 (1.0)			4.0
1.02				14 (1.7)	14	104	104		5.0
1.03				1 (1.7)	104 (1.3)	104 (1.0)			4.0
1.05				2 (1.7)	104	104			4.0
1.06				A (1.7)	104	104			4.0
2.01	Steel surfaces exposed to the weather, high humidity, infrequent immersion in fresh or salt water or to mild chemical atmospheres	6 or 8	Not Req'd	C (1.5)	C (1.5)	104	104		5.0
2.02				D (1.5)	104 (1.5)	104 (1.0)			4.0
2.03				B (1.5)	104 (1.5)	104 (1.0)			4.0
2.04				E (1.5)	104	104			3.5
3.00	Steel surfaces exposed to alternate immersion, high humidity and condensation or to the weather or moderately severe chemical atmospheres or immersed in fresh water	5, 6, 8, or 10	1, 2, 3, or 4	5, or 6 (1.5)	5, or 6 (1.5)	103 (1.0)	5, 6 or 103 *		4.0 or 5.0
4.01	Immersion in salt water or in many chemical solutions, condensation, very severe weather exposure or chemical atmospheres	10	3 **	G (1.5)	G	9	9		5.5
4.02	Fresh water immersion, condensation, very severe weather or chemical atmospheres	10	Not Req'd	H (1.5)	H	H	H		6.0
4.03	Complete or alternate immersion in salt water, high humidity, condensation, and exposure to the weather	6 or 8	3 **	G (1.5)	9	8			4.0
4.04	Condensation, or very severe weather exposure, or chemical atmospheres	6 or 8	Not Req'd	9 (1.2)	9	9	9		4.5
4.05	Condensation, severe weather, mild chemical atmospheres	6 or 8	3 **	G (1.5)	F	F			4.0
6.01	Steel vessels and floating structures exposed to fresh or salt water, fouling water and weather	10	3	G (1.5)	G	G	G	I (2.0)	7.0
6.02		6 or 8	3	G (1.5)	G	G	J	J	7.0
6.03		6 or 8	3	G (1.5)	G	G	L	K	6.25
7.01	Dry, non corrosive environment, inside of buildings or temporary weather protection	nominal cleaning	Not Req'd	13 (1.0)					1.0
8.01	Longtime protection in sheltered or inaccessible places, short term or temporary protection in corrosive environments	1 and 2 or 3	Not Req'd	M 31 (wet)					31 (wet)
9.01	Corrosive or chemical atmospheres, but should not be used in contact with oils, solvents, or other agents	6	Not Req'd	12 63					63
10.01	Underground and underwater steel structures	6	Not Req'd	N (.5-2)	N (31)	N (31)			63-100
10.02	Underground, underwater or for damp, corrosive environments. Not recommended for potable water or for high temperature	6	Not Req'd	0 (15-18)	0 (25)	P (8-15)			35

*Four coats are recommended in severe exposures

**The dry film thickness of the wash coat 0.3-0.5 mils.

TABLE I, PAINT SYSTEMS (continued)

System Number SSPC-PS	CONDITION	Surface Preparation Table II	Pretreatment Table III	Paint and Dry Thickness, mils See Table IV 1st Coat	2nd Coat	3rd Coat	4th Coat	5th Coat	Total Thickness
11.01	Fresh or sea water immersion, tidal and splash zone exposure, condensation, burial in soil and exposure of brine, crude oil, sewage and alkalies, chemical fumes, mists	6 or 10	Not Req'd	16 (16)	16 (16)				32
12.00	High humidity or marine atmospheric exposures, fresh water immersion. With proper topcoating in brackish and seawater immersion and exposure to chemical acid and alkali fumes		Zinc-rich coatings comprise a number of different commercial types such as: chlorinated rubber, styrene, epoxies, polyesters, vinyls, urethanes, silicones, silicate esters, silicates, phosphates.						
13.00	Industrial exposure, marine environment fresh and salt water immersion, and areas subject to chemical exposure such as acid and alkali.		Epoxy Paint System						

TABLE III, PRETREATMENT SPECIFICATIONS

Reference to Table I	Title and Purpose	Specification Number
1	**WETTING OIL TREATMENT** Saturation of the surface layer of rusty and scaled steel with wetting oil that is compatible with the priming paint, thus improving the adhesion and performance of the paint system to be applied.	SSPC-PT 1-64
2	**COLD PHOSPHATE SURFACE TREATMENT** Converting the surface of steel to insoluble salts of phosphoric acid for the purpose of inhibiting corrosion and improving the adhesion and performance of paints to be applied.	SSPC-PT 2-64
3	**BASIC ZINC CHROMATE-VINYL BUTYRAL WASHCOAT (Wash Primer)** Pretreatment which reacts with the metal and at the same time forms a protective vinyl film which contains an inhibitive pigment to help prevent rusting.	SSPC-PT 3-64
4	**HOT PHOSPHATE SURFACE TREATMENT** Converting the surface of steel to a heavy crystaline layer of insoluble salts of phosporic acid for the purpose of inhibiting corrosion and improving the adhesion and performance of paints to be applied.	SSPC-PT 4-64

PAINTING

TABLE II, SURFACE PREPARATION SPECIFICATIONS

Reference to Table I	Title and Purpose	Specification Number
1	**SOLVENT CLEANING** Removal of oil, grease, dirt, soil, salts, and contaminants with solvents, emulsions, cleaning compounds, or steam.	SSPC-SP 1-63
2	**HAND TOOL CLEANING** Removal of loose mill scale, loose rust, and loose paint by hand brushing, hand sanding, hand scraping, hand chipping or other hand impact tools, or by combination of these methods.	SSPC-SP 2-63
3	**POWER TOOL CLEANING** Removal of loose mill scale, loose rust, and loose paint with power wire brushes, power impact tools, power grinders, power sanders, or by combination of these methods.	SSPC-SP 3-63
4	**FLAME CLEANING OF NEW STEEL** Removal of scale, rust and other detrimental foreign matter by high-velocity oxyacetylene flames, followed by wire brushing.	SSPC-SP 4-63
5	**WHITE METAL BLAST CLEANING** Removal of all mill scale, rust, rust-scale, paint or foreign matter by the use of sand, grit or shot to obtain a gray-white, uniform metallic color surface.	SSPC-SP 5-63
6	**COMMERCIAL BLAST CLEANING** Removal of mill scale, rust, rust-scale, paint or foreign matter completely except for slight shadows, streaks, or discolorations caused by rust, stain, mill scale oxides or slight, tight residues of paint or coating that may remain.	SSPC-SP 6-63
7	**BRUSH-OFF BLAST CLEANING** Removal of all except tightly adhering residues of mill scale, rust and paint by the impact of abrasives. (Sand, grit or shot)	SSPC-SP 7-63
8	**PICKLING** Complete removal of all mill scale, rust, and rust-scale by chemical reaction, or by electrolysis, or by both. The surface shall be free of unreacted or harmful acid, alkali, or smut.	SSPC-SP 8-63
10	**NEAR-WHITE BLAST CLEANING** Removal of nearly all mill scale, rust, rust-scale, paint, or foreign matter by the use of abrasives (sand, grit, shot). Very light shadows, very slight streaks, or slight discolorations caused by rust stain, mill scale oxides, or slight, tight residues of paint or coating may remain.	SSPC-SP 10-63T

PAINTING

TABLE IV, PAINTS

Reference to Table I	Material	Number
1	Red Lead and Raw Linseed Oil Primer	1-64T No. 1
2	Red Lead, Iron Oxide, Raw Linseed Oil and Alkyd Primer	2-64 No. 2
3	Red Lead, Iron Oxide, and Fractionated Linseed Oil Primer	3-64T No. 3
4	Extended Red Lead, Raw and Bodied Linseed Oil Primer	4-64T No. 4
5	Zinc Dust, Zink Oxide, and Phenolic Varnish Paint	5-64T No. 5
6	Red Lead, Iron Oxide, and Phenolic Varnish Paint	6-64T No. 6
8	Aluminum Vinyl Paint	8-64 No. 8
9	White (or Colored) Vinyl Paint	9-64 No. 9
11	Red Iron Oxide, Zinc Chromate, Raw Linseed Oil and Alkyd Primer	11-64T No. 11
12	Cold Applied Asphalt Mastic (Extra Thick Film)	12-64 No. 12
13	Red or Brown One-Coat Shop Paint	13-64 No. 13
14	Red Lead, Iron Oxide & Linseed Oil Primer	14-64T No. 14
15	Steel Joist Shop Paint	15-68T No. 15
16	Coal Tar Epoxy-Polyamide Black (or Dark Red) Paint	16-68T No. 16
102	Black Alkyd Paint	102-64 No. 102
103	Black Phenolic Paint	103-64T No. 103
104	White or Tinted Alkyd Paint, Types I, II, III, IV	104-64 No. 104
106	Black Vinyl Paint	106-64 No. 106
107	Red Lead, Iron Oxide and Alkyd Intermediate Paint	107-64T No. 107
	Paint; Red-Lead Base, Ready-Mixed	
A	Type I red lead-raw and bodied linseed oil	TT-P-86c
B	Type II red lead, iron oxide, mixed pigment-alkyd-linseed oil	TT-P-86c
C	Type III red lead alkyd	TT-P-86c
D	Primer; Paint; Zinc Chromate, alkyd Type	TT-P-645
E	Paint; Zinc Yellow-Iron Oxide Base, Ready Mixed, Type II-yellow, alkyd	MIL-P-15929B
F	Paint; Outside, White, Vinyl, Alkyd Type	MIL-P-16738B
G	Primer; Vinyl-Red Lead Type	MIL-P-15929B
H	Vinyl Resin Paint	VR-3
I	Paint; Antifouling, Vinyl Type	MIL-P-15931A
J	Paints; Boottopping, Vinyl-Alkyd, Bright Red Undercoat and Indian Red Finish Coat	MAP-44
K	Enamel, Outside, Gray No. 11 (Vinyl-Alkyd)	MIL-E-15935B
L	Enamel, Outside, Gray No. 27 (Vinyl-Alkyd)	MIL-E-15936B
M	Compounds; Rust Preventive	52-MA-602a
N	Coal Tar Enamel and Primers	MIL-P-15147C
O	Coal Tar Base Coating	MIL-C-18480A
P	Coating, Bituminous Emulsion	MIL-C-15203c

SSPC SPECIFICATIONS (items 1–107)

MIL = Military, TT = Federal Spec., MAP or MA = Mari-time Admin., VR = Bureau of Reclamations.

PAINTING

TABLE V, CHEMICAL RESISTANCE OF COATING MATERIAL

	Natural Rubber	Butadiene-Styrene Rubber	Neoprene	Phenolics	Furanes	Epoxys	Oleoresinous	Vinyls	Vinylidene Chloride	Chlorinated Rubber	Styrene-Butadiene	Polyethylene	Bitumens
Acetaldehyde	1	2	1	1	1	1	3	2	2	3	3	2	3
Acetic acid, 10%	1	2	1	1	1	1	4	3	3	4	4	3	4
Acetic acid, glacial	1	2	1	1	1	1	4	3	3	4	4	3	4
Acetone	3	3	3	1	1	1	4	4	4	4	4	3	4
Alcohol, amyl	1	1	1	1	1	1	4	3	3	3	3	2	3
Alcohol butyl, normal	1	1	1	1	1	1	3	2	2	2	2	1	3
Alcohol, ethyl	1	1	1	1	1	1	2	1	1	1	1	1	2
Alcohol, isopropyl	1	1	1	1	1	1	2	1	1	1	1	1	2
Alcohol, methyl	1	1	1	1	1	1	2	1	1	1	1	1	2
Aluminum chloride	1	1	1	2	2	2	4	1	1	3	3	1	3
Aluminum sulphate	1	1	1	1	1	1	4	1	1	2	2	1	2
Ammonia, liquid	1	1	1	3	2	2	3	1		3	3	1	3
Ammonium chloride	1	1	1	1	1	1	3	1	1	3	3	1	2
Ammonium hydroxide	1	1	1	3	2	2	3	1		3	3	1	3
Ammonium nitrate	1	1	1	1	1	1	3	1	1	3	3	1	2
Ammonium sulphate	1	1	1	1	1	1	3	1	1	3	3	1	2
Aniline			2	3	2	2	4	4		4	4	2	4
Benzene	4	4	4	1	1	1	3	3	3	4	4	3	4
Boric acid	1	1	1	1	1	1	1	1	1	1	1	1	1
Butyl acetate	1	1	1	1	1	1	3	4	4	3	3	1	3
Calcium chloride	1	1	1	1	1	1	2	1	1	2	2	1	2
Calcium hydroxide	1	1	1	2	1	1	2	1	1	2	2	1	2
Calcium hypochlorite	1	2	2	3	2	2	4	1	1	2	2	1	3
Carbon disulphide	4	4	4	1	1	1	4	4	4	4	4	3	4
Carbon tetrachloride	4	4	4	1	1	1	4	4	4	4	4	4	4
Chlorine gas	1	2	2	4	4	4	4	2	1	4	4	3	4
Chlorobenzene	4	4	4	1	1	1	4	4	4	4	4	4	4
Chloroform	4	4	4	1	1	1	4	4	4	4	4	4	4
Chromic acid, 10%	2	2	2	4	3	3	4	2	2	4	4	2	4
Chromic acid, 60%	2	2	2	4	3	3	4	2	2	4	4	2	4
Citric acid	1	1	1	1	1	1	2	1	1	2	2	1	2
Copper sulphate	1	1	1	1	1	1	1	1	1	1	1	1	1
Diethyl ether	4	4	4	1	1	1	4	4	4	4	4	4	4
Ethylene glycol	1	1	1	1	1	1	2	1	1	1	1	1	2
Ferric chloride	1	1	1	1	1	1	3	1	1	3	3	1	3
Ferric sulphate	1	1	1	1	1	1	2	1	1	2	2	1	2
Formaldehyde, 40%	1	1	1	1	1	1	3	1	1	2	2	1	3
Formic acid, 20%	1	1	1	1	1	1	3	1	1	2	2	1	3
Formic acid, conc.	1	1	1	1	1	1	3	1	1	2	2	1	3
Gasoline	4	4	1	1	1	1	2	1	1	4	4	2	4
Glycerine	1	1	1	1	1	1	2	1	1	1	1	1	2
Hydrochloric acid, 10%	1	1	1	1	1	1	3	1	1	3	3	1	3
Hydrochloric acid, 30%	1	2	2	1	1	1	3	1	1	3	3	1	3
Hydrochloric acid, conc.	1	2	2	1	1	1	3	1	1	3	3	1	3
Hydrofluoric acid, 10%	1	2	1	1	1	1	3	2	2	2	2	1	2
Hydrofluoric acid, 40%	1	2	1	1	1	1	3	2	2	2	2	1	3

CLASSES OF EXPOSURE (Numbers in the table refer to most severe class of exposure for general use.)

Class 1. Continual and direct contact with the corrosive

Class 2. High concentration of corrosive fumes and under frequent splash and spillage

Class 3. Relatively high concentrations of fumes, but with little or no splash or spillage or direct contact with the corrosive

Class 4. Mild concentrations of corrosive fumes. Weathering.

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PAINTING

TABLE V, CHEMICAL RESISTANCE OF COATING MATERIAL (continued)

	Natural Rubber	Butadiene-Styrene Rubber	Neoprene	Phenolics	Furanes	Epoxys	Oleoresinous	Vinyls	Vinylidene Chloride	Chlorinated Rubber	Styrene-Butadiene	Polyethylene	Bitumens
Hydrofluoric acid, 75% . .	1	2	1	1	1	1	3	2	2	2	2	2	3
Hydrogen peroxide, 3% . .	1	1	1	3	2	2	3	1	1	3	3	1	4
Hydrogen perioxide, 30%.	2	2	1	3	2	2	3	2	2	3	3	3	4
Hydrogen sulphide	1	1	1	1	1	1	2	1	1	2	2	1	2
Hypocholorous acid	1	2	1	4	3	3	4	1	1	3	3	1	4
Kerosene	4	4	1	1	1	1	2	1	1	4	4	2	4
Lubricating oil.	4	4	1	1	1	1	2	1	1	4	4	2	4
Magnesium sulphate	1	1	1	1	1	1	2	1	1	2	2	1	2
Methyl ethyl ketone	1	1	2	1	1	1	4	4	4	3	3	1	3
Mineral oil	4	4	1	1	1	1	2	1	1	4	4	2	4
Nitric acid, 5%.	1	1	1	4	2	2	4	1	1	3	3	1	3
Nitric acid, 10%	2	2	1	4	2	2	4	2	2	3	3	1	3
Nitric acid, 40%.	2	2	2	4	3	3	4	2	2	4	4	2	4
Nitric acid, conc.	3	3	2	4	3	3	4	2	2	4	4	2	4
Nitrobenzene.	4	4	4	1	1	1	3	3	3	4	4	3	4
Oleic acid	3	3	2	1	1	1	3	2	2	4	4	2	4
Oxalic acid	1	1	1	1	1	1	2	1	1	2	2	1	2
Phenol, 15-25%			3	1	1	1							4
Phenol			3										4
Phosphoric acid, 10% . . .	1	1	1	1	1	1	3	1	1	3	3	1	3
Phosphoric acid, 60% . . .	1	1	1	1	1	1	3	1	1	3	3	1	3
Phosphoric acid, conc. . .	1	1	1	1	1	1	3	1	1	3	3	1	3
Potassium alum	1	1	1	1	1	1	2	1	1	2	2	1	2
Potassium hydroxide, 20%	1	2	1	4	2	2	4	1	1	2	2	1	3
Potassium hydroxide, 95%	1	2	1	4	2	2		1	1	2	2	1	3
Potassium permanganate .	2	2	1	3	2	2	3	2	2	3	3	3	4
Potassium sulphate	1	1	1	1	1	1	2	1	1	2	2	1	2
Sea water	1	1	1	1	1	1	1	1	1	1	1	1	1
Silver nitrate	1	1	1	1	1	1	2	1	1	1	1	1	2
Sodium bisulphate	1	1	1	1	1	1	3	1	1	2	2	1	2
Sodium carbonate.	1	1	1	4	2	2	4	1	1	2	2	1	4
Sodium chloride.	1	1	1	1	1	1	1	1	1	1	1	1	1
Sodium hydroxide, 10%. .	1	2	1	4	2	2	4	1	1	1	1	1	3
Sodium hydroxide, 20% .	1	2	1	4	2	2	4	1	1	2	2	1	3
Sodium hydroxide, 40% .	1	2	1	4	2	2	4	1	1	2	2	1	3
Sodium hypochlorite. . . .	1	2	1	4	3	3	4	1	1	3	3	1	4
Sodium nitrate.	1	1	1	1	1	1	2	1	1	2	2	1	2
Sodium sulphate.	1	1	1	1	1	1	2	1	1	2	2	1	2
Sodium sulphite.	1	1	1	1	1	1	2	1	1	2	2	1	2
Sulphur dioxide	1	1	1	1	1	1	2	1	1	2	2	1	2
Sulphuric acid, 10%	1	1	1	1	1	1	3	1	1	2	2	1	2
Sulphuric acid, 30%	1	1	1	1	1	1	3	1	1	3	3	1	3
Sulphuric acid, 60%	1	1	1	1	1	1	3	1	1	3	3	1	3
Sulphuric acid, conc	2	2	2	1	1	1	3	2	2	3	3	1	3
Toluene	4	4	4	1	1	1	3	3	3	4	4	3	4
Trichloroethylene	4	4	4	1	1	1	4	4	4	4	4	4	4

CLASSES OF EXPOSURE (Numbers in the table refer to most severe class of exposure for general use.)

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CHECK LIST FOR INSPECTORS

	QC	AI
1. Codes and Addenda		
2. Drawings:		
a) All info & details required by QC Manual shown on drawing		
b) Heads correctly identified		
c) All metal correctly identified		
d) Name plate facsimilie stamped correctly: MAWP, MDMT and RT		
e) Approval by fabricator (on drawing)		
f) Revisions or metal substitution shown and approved		
3. Bill of Material:		
a) All material identified as SA or SB		
b) Requirements of UCS 79 (d) specified were applicable		
c) Required material test reports specified		
d) Shop order, serial number, and/or job number shown		
e) Material revision or substitution approved and shown when applicable		
4. Calculations:		
a) Dimensions used match drawing		
b) Correct stress values and joint efficiencies (S & E) used.		
c) Correct formula & dimensions used for heads		
d) Do nozzle necks comply with UG-45?		
e) Required reinforcement calculations available for all openings		
f) Special flange or structural loading calculations available		
g) Identification with S/O or S/N and approved by fabricator		
h) External design pressure correct - template calculations & template available		
i) MAWP & MDMT matches drawing and specifications. MDMT correct for materials used (UCS-66, UHA-51)		
5. Purchase Orders:		
a) Is job number shown (when applicable)?		
b) Correct specification (SA or SB) used		
c) USC 79(d) & UG 81 requirements specified as applicable		
d) Material Test Reports requested		
e) Is material ordered identical to Bill of Material or drawing requirements?		
6. Welding:		
a) Are correct WPS(s) shown on drawings?		
b) Are complete weld details for all welds shown on drawing?		
c) Are copies of WPS(s) available to shop supervisor for instruction?		

CHECK LIST FOR INSPECTORS *(continued)*

	QC	AI
d) Is a Welder's Log and Qualification Directory kept up-to-date and available?		
e) Are WPS, PQR, & WPQ forms correct and signed?		
f) Are welders properly qualified for thickness, position, pipe diameter and welding with no backing (when required)?		
g) Is sub-arc flux, electrodes and shielding gas(es) used the same as specified on applicable WPS?		
h) Do weld sizes (fillet & butt weld reinforcement) comply with drawing and Code requirements?		
i) Is welder identification stamped or recorded per QC Manual and/or Code requirements?		
7. Non-Destructive Examination & Calibration:		
a) Are SNT-TC-1A qualification records with current visual examination available for all RT technicians used?		
b) Do film reader sheets or check off records show film interpretation by a SNT-TC Level I or II examiner or interpreter?		
c) Are the required number of film shots in the proper locations for the joint efficiency and welders used (UW-11, 12, & 52)?		
d) Is an acceptable PT and/or MT procedure and personnel qualified and certified in accordance with Sec. VIII, Appendix 6 or 8 available?		
e) Is the PT material being used the same as specified in the PT procedure?		
f) Do all radiographs comply with identification, density, penetrameter, and acceptance requirements of Sect. VIII and V?		
g) For B31.1 fabrication, is a visual examination procedure and certified personnel available?		
h) Are tested gases marked or identified and calibrated as stated in QC Manual?		
i) Is a calibrated gage size per UG-102 available for demo vessel?		

ABBREVIATIONS:

AI	Authorized Inspector
MAWP	Maximum Allowable Working Pressure
MDMT	Maximum Design Metal Temperature
QC	Quality Control
RT	Radiographic Examination
S/N	Serial Number
S/O	Shop Order
WPS	Welding Procedure Specification

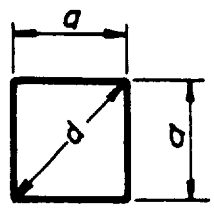
PART II.

GEOMETRY AND LAYOUT OF PRESSURE VESSELS

GEOMETRICAL FORMULAS

(See examples on the facing page)

SQUARE



A = Area

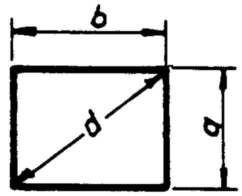
$A = a^2$

$d = 1{,}414\ a$

$A = \frac{d^2}{2}$

$a = 0{,}7071\ d$ or $a = \sqrt{A}$

RECTANGLE



A = Area

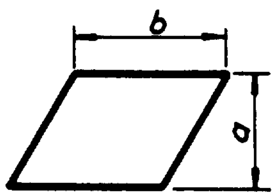
$A = a \times b$

$d = \sqrt{a^2 + b^2}$

$a = \sqrt{d^2 - b^2}$ or $a = \frac{A}{b}$

$b = \sqrt{a^2 - a^2}$ or $b = \frac{A}{a}$

PARALLELOGRAM



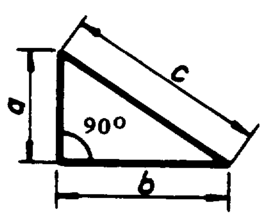
A = Area

$A = a \times b$

$a = \frac{A}{b}$

$b = \frac{A}{a}$

RIGHT-ANGLED TRIANGLE



A = Area

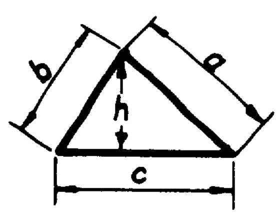
$A = \frac{a \times b}{2}$

$a = \sqrt{c^2 - b^2}$

$b = \sqrt{c^2 - a^2}$

$c = \sqrt{a^2 + b^2}$

ACUTE ANGLED TRIANGLE



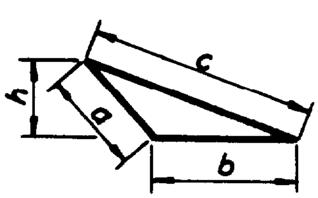
A = Area

$A = \frac{C \times h}{2}$

$A = \sqrt{s(s-a) \times (s-b) \times (s-c)}$

$s = \frac{1}{2}(a + b + c)$

OBTUSE ANGLED TRIANGLE



A = Area

$A = \frac{b \times h}{2}$

$A = \sqrt{s(s-a) \times (s-b) \times (s-c)}$

$s = \frac{1}{2}(a + b + c)$

EXAMPLES

(See Formulas on the Facing Page)

SQUARE

Given: Side $a = 8$ inches

Find: Area $A = a^2 = 8^2 = 64$ sq. in.

Diagonal $d = 1.414\ a = 1.414 \times 8 = 11.312$ in.

Area $A = d^2/2 = 11.312^2/2 = 64$ sq.-in.

Side $a = 0.7071\ d = 0.7071 \times 11.312 = 8$ in.

Side $a = \sqrt{A} = \sqrt{64} = 8$ in.

RECTANGLE

Given: Side $a = 3$ in., and $b = 4$ in.

Find: Area $A = a \times b = 3 \times 4 = 12$ sq.-in.

Diagonal $d = \sqrt{a^2 + b^2} = \sqrt{3^2 + 4^2} = \sqrt{9 + 16} = \sqrt{25} = 5$ in.

Side $a = A/b = 12/4 = 3$ in.

Side $b = A/a = 12/3 = 4$ in.

PARALLELOGRAM

Given: Height $a = 8$ in., and the side $b = 12$ in.

Find: Area $A = a \times b = 8 \times 12 = 96$ sq.-in.

Height $a = A/b = 96/12 = 8$ in.

Side $b = A/a = 96/8 = 12$ in.

RIGHT ANGLED TRIANGLE

Given: Side $a = 6$ in., and side $b = 8$ in.

Find: Area $A = \frac{a \times b}{2} = \frac{6 \times 8}{2} = 24$ sq.-in.

Side $c = \sqrt{a^2 + b^2} = \sqrt{6^2 + 8^2} = \sqrt{36 + 64} = \sqrt{100} = 10$ in.

Side $a = \sqrt{c^2 - b^2} = \sqrt{10^2 - 8^2} = \sqrt{100 - 64} = \sqrt{36} = 6$ in.

Side $b = \sqrt{c^2 - a^2} = \sqrt{10^2 - 6^2} = \sqrt{100 - 36} = \sqrt{64} = 8$ in.

ACUTE ANGLED TRIANGLE

Given: Side $a = 6$ in. Side $b = 8$ in., and side $c = 10$ in.

Find: Area $A = s = ½(a + b + c) = ½(6 + 8 + 10) = 12$

$A = \sqrt{s(s-a) \times (s-b) \times (s-c)} = \sqrt{12(12-6) \times (12-8) \times (12-10)} =$ 24 sq. in.

OBTUSE ANGLED TRIANGLE

Given: Side $a = 3$ in., $b = 4$ in., and $c = 5$ in.

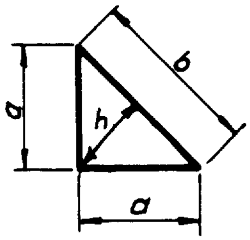
Find: Area $A = s = ½(a + b + c) = ½(3 + 4 + 5) = 6$

$A = \sqrt{6(6-3) \times (6-4) \times (6-5)} = \sqrt{36} = 6$ sq.-in.

GEOMETRICAL FORMULAS

(See examples on the facing page)

RIGHT TRIANGLE WITH 2 45° ANGLES



A = Area

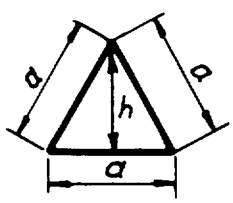
$A = \frac{a^2}{2}$

$b = 1.414\ a$

$h = 0.7071\ a$

$a = 1.414\ h$

EQUILATERAL TRIANGLE

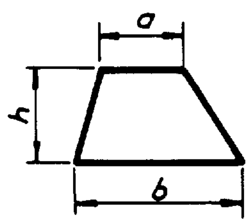


A = Area

$A = \frac{a \times h}{2}$

$h = 0.866\ a \qquad a = 1.155\ h$

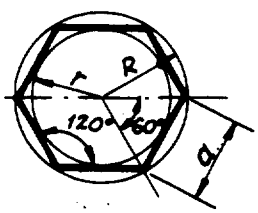
TRAPEZOID



A = Area

$A = \frac{(a+b)\,h}{2}$

REGULAR HEXAGON



A = Area

R = Radius of circumscribed circle

r = Radius of inscribed circle

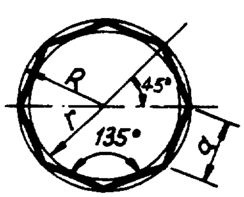
$A = 2.598\ a^2 = 2.598\ R^2 = 3.464\ r^2$

$R = a = 1.155\ r$

$r = 0.866\ a = 0.866\ R$

$a = R = 1.155\ r$

REGULAR OCTAGON



A = Area

R = Radius of circumscribed circle

r = Radius of inscribed circle

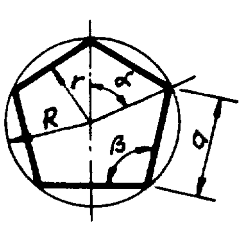
$A = 4.828\ a^2 = 2.828\ R^2 = 3.314\ r^2$

$R = 1.307\ a = 1.082\ r$

$r = 1.207\ a = 0.924\ R$

$a = 0.765\ R = 0.828\ r$

REGULAR POLYGON



A = Area

n = Number of sides

$\alpha = \frac{360^\circ}{n}$

$\beta = 180^\circ - \alpha$

$A = \frac{nra}{2}$

$r = \sqrt{R^2 - \frac{a^2}{4}} \qquad a = 2\sqrt{R^2 - r^2}$

$R = \sqrt{r^2 + \frac{a^2}{4}}$

EXAMPLES

(See Formulas on the Facing Page)

RIGHT TRIANGLE WITH 2 45° ANGLES

Given: Side $a = 8$ in.

Find: Area $A = \frac{a^2}{2} = \frac{8^2}{2} = \frac{64}{2} = 32$ sq.-in.

Side $b = 1.414\ a = 1.414 \times 8 = 11.312$ in.

$h = 0.7071\ a = 0.7071 \times 8 = 5.6568$ in.

EQUILATERAL TRIANGLE

Given: Side $a = 8$ in.

Find: $h = 0.866 \times a = 0.866 \times 8 = 6.928$ in.

Area $A = \frac{a \times h}{2} = \frac{8 \times 6.928}{2} = \frac{55.424}{2} = 27.712$ sq.-in.

TRAPEZOID

Given: Side $a = 4$ in., $b = 8$ in., and height $h = 6$ in.

Find: Area $A = \frac{(a + b)\,h}{2} = \frac{(4 + 8) \times 6}{2} = 36$ sq.-in.

REGULAR HEXAGON

Given: Side $a = 4$ in.

Find: Area $A = 2.598 \times a^2 = 2.598 \times 4^2 = 41.568$ sq.-in.

$r = 0.866 \times a = 0.866 \times 4 = 3.464$ in.

$R = a = 1.155\ r = 1.155 \times 3.464 = 4$ in.

REGULAR OCTAGON

Given: $R = 6$ in., radius of circumscribed circle

Find: Area $A = 2.828\ R^2 = 2.828 \times 6^2 = 101.81$ sq.-in.

Side $a = 0.765\ R = 0.765 \times 6 = 4.59$ in.

REGULAR POLYGON

Given: Number of sides $n = 5$, side $a = 9.125$ in.

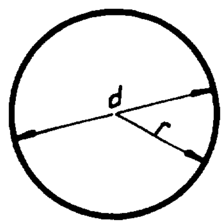
Radius of circumscribed circle, $R = 7.750$

Find: $r = \sqrt{R^2 - \frac{a^2}{4}} = \sqrt{7.750^2 - \frac{9.125^2}{4}} = 6.25$ in.

Area $A = \frac{nra}{2} = \frac{5 \times 6.25 \times 9.125}{2} = 142.58$ sq.-in.

GEOMETRICAL FORMULAS

(See examples on the facing page)



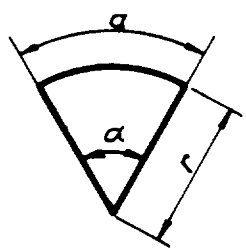
CIRCLE

A = Area   C = Circumference

$A = r^2 \times \pi = r^2 \times 3.1416 = d^2 \times 0.7854$

$C = d \times \pi = d \times 3.1416$

Length of arc for angle α = $0.008727\ d \times \alpha$



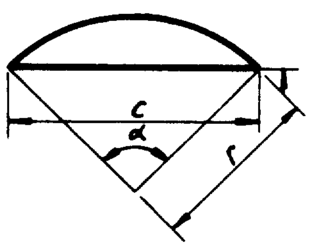
CIRCULAR SECTOR

A = Area   a = Arc α = Angle

$A = r^2\ \pi \times \frac{\alpha}{360}$

$a = \frac{r \times \alpha \times 3.1416}{180}$

$\alpha = \frac{57.296\ a}{r}$ $r = \frac{2A}{a}$

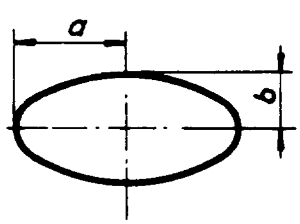


CIRCULAR SEGMENT

A = Area α = Angle   c = Cord

A = Area of sector minus area of triangle

$c = 2r \times \sin\frac{\alpha}{2}$



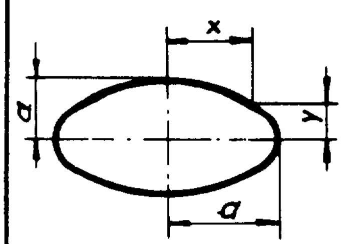
ELLIPSE

A = Area   P = Perimeter

$A = \pi \times a \times b = 3.1416 \times a \times b$

An approximate formula for perimeter

$P = 3.1416\sqrt{2\ (a^2 + b^2)}$



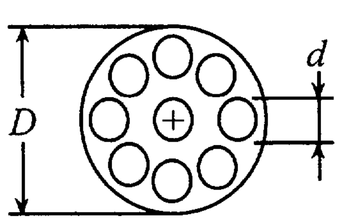
ELLIPSE

Locating points on ellipse

$\frac{a}{b}$ = C = Ratio of minor axis to major axis

$x = \sqrt{a^2 - (2C \times y^2)}$

$y = \frac{\sqrt{a^2 - x^2}}{C}$



$N = \left(\frac{D}{d}\right)^2$, where

N = the required number of holes (diam, d) of which total area equals area of circle diam. D.

EXAMPLES

(See Formulas on the Facing Page)

CIRCLE

Given: Radius $r = 6$ in.

Find area $A = r^2 \times \pi = 6^2 \times 3{,}1416 = 113.10$ sq. in. or

$A = d^2 \times 0.7854 = 12^2 \times 0.7854 = 113.10$ sq. in.

Circumference $C = d \times \pi = 12 \times 3.1416 = 37.6991$ in.

The length of arc for angle if $\alpha = 60^o$

Arc $= 0.008727\ d \times \alpha = 0.008727 \times 12 \times 60 = 6.283$ in.

CIRCULAR SECTOR

Given: Radius $r = 6$ in., Angle $= 60^o$

Find: Area $A = r^2\ \pi \times \frac{\alpha}{360} = 6^2 \times \pi \times \frac{60}{360} = 18.85$ sq. in.

Arc $a = \frac{r \times \alpha \times 3.1416}{180} = \frac{6 \times 60 \times 3.1416}{180} = 6.283$ in.

Angle $\alpha = \frac{57.296 \times a}{r} = \frac{57.296 \times 6.283}{6} = 60^o$

CIRCULAR SEGMENT

Given: Radius $r = 6$ in., Angle $\alpha = 90^o$

Find: Area A

Area of sector $= r^2 \times \pi \times \frac{\alpha}{360} = 6^2 \times 3.1416 \times \frac{90}{360} =$ 28.274 sq. in.

Minus area of triangle 18.000 sq. in.

Area of segment A = 10.274 sq. in.

Chord $c = 2r \times \sin\frac{\alpha}{2} = 2 \times 6 \times \sin\frac{90}{2} = 2 \times 6 \times 0.7071 = 8.485$ in.

ELLIPSE

Given: Half axis, $a = 8$ in. and $b = 3$ in.

Find: Area $A = \pi \times a \times b = 3.1416 \times 8 \times 3 = 75.398$ in.

Perimeter $P = 3.1416\sqrt{2\,(a^2 + b^2)} = 3.1416\sqrt{2 \times (8^2 + 3^2)} =$

$3.1416\sqrt{146} = 37.96$ in.

ELLIPSE

Given: Axis $a = 8$ in. and $b = 4$ in., then $C = \frac{a}{b} = \frac{8}{4} = 2$, $x = 6$ in.

Find: $Y = \frac{\sqrt{a^2 - x^2}}{C} = \frac{\sqrt{8^2 - 6^2}}{2} = \frac{\sqrt{64 - 36}}{2} = \frac{\sqrt{28}}{2} = \frac{5.2915}{2} = 2.6457$ sq. in.

$X = \sqrt{a^2 - (2C \times y^2)} = \sqrt{8^2 - (2 \times 2 \times 2.6457^2)} = \sqrt{64 - 4 \times 7} = \sqrt{36} = 6$ in.

EXAMPLE:

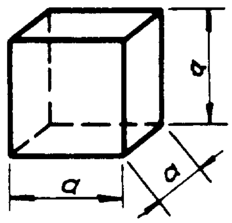
How many ¼ in. ϕ holes have same areas as a 6 in. diam. pipe?

$N = (D/d)^2 =$ $(6/0.25)^2 = 24^2 = 576$ holes =

Area of 6 in. ϕ pipe = 28,274 in.^{2}

Area of 576 ¼ in. ϕ holes = 28,276 in.^{2}

GEOMETRICAL FORMULAS
(See examples on the facing page)

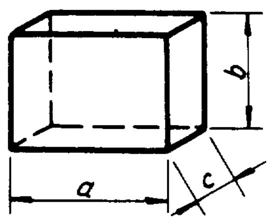


CUBE

V = Volume

$V = a^3$

$a = \sqrt[3]{V}$

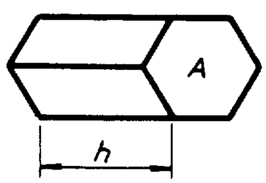


SQUARE PRISM

V = Volume

$V = a \times b \times c$

$a = \frac{V}{bc}$ $b = \frac{V}{ac}$ $c = \frac{V}{ab}$

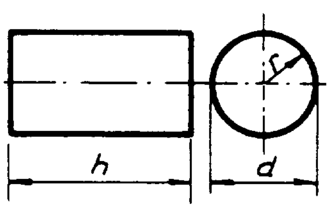


PRISM

V = Volume   A = Area of end surface

$V = h \times A$

This formula can be applied for any shape of end surface if h is perpendicular to end surface.

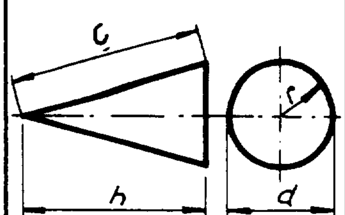


CYLINDER

V = Volume   S = Area of cylindrical surface

$V = 3.1416 \times r^2 \times h = 0.785 \times d^2 \times h$

$S = 3.1416 \times d \times h$



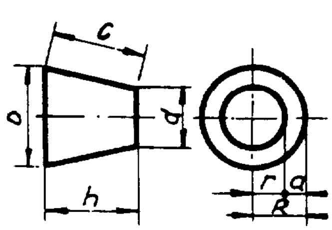
CONE

V = Volume   S = Area of conical surface

$V = \frac{3.1416 \times r^2 \times h}{3} = 1.0472 \times r^2 \times h$

$c = \sqrt{r^2 + h^2}$

$S = 3.1416\, rc = 1.5708\, dc$



FRUSTUM OF CONE

V = Volume   S = Area of conical surface

$V = 0.2618\, h\,(D^2 + Dd + d^2)$ $a = R - r$ $c = \sqrt{a^2 + h^2}$

$S = 1.5708\, c\,(D + d)$

EXAMPLE

(See Formulas on the Facing Page)

CUBE

Given: Side $a = 8$ in.

Find: Volume $V = a^3 = 8^3 = 512$ cu.-in.

Side $a = \sqrt[3]{512} = 8$ in.

SQUARE PRISM

Given: Side $a = 8$ in., $b = 6$ in., and $c = 4$ in.

Find: Volume $V = a \times b \times c = 8 \times 6 \times 4 = 192$ cu.-in.

$$a = \frac{V}{b \times c} = \frac{192}{6 \times 4} = 8 \text{ in.}; \quad b = \frac{V}{a \times c} = \frac{192}{8 \times 4} = 6 \text{ in.}$$

$$c = \frac{V}{a \times b} = \frac{192}{2 \times 6} = 4 \text{ in.}$$

PRISM

Given: End surface $A = 12$ sq.-in., and $h = 8$ in.

Find: Volume $V = h \times A = 8 \times 12 = 96$ cu.-in.

CYLINDER

Given: $r = 6$ in., and $h = 12$ in.

Find: Volume $V = 3.1416 \times r^2 \times h = 3.1416 \times 6^2 \times 12 = 1357.2$ cu.-in.

Area of Cylindrical Surface: $S = 3.1416 \times d \times h =$

$= 3.1416 \times 12 \times 12 = 452.389$ sq.-in.

CONE

Given: $r = 6$ in., and $h = 12$ in.

Find: Volume $V = 1.0472 \times r^2 \times h = 1.0472 \times 6^2 \times h = 452.4$ cu.-in.

$$c = \sqrt{r^2 + h^2} = \sqrt{36 + 144} = \sqrt{180} = 13.416 \text{ in.}$$

Area of Conical Surface: $S = 3.1416\ r \times c =$

$= 3.1416 \times 6 \times 13.416 = 252.887$ sq.-in.

FRUSTUM OF CONE

Given: Diameter $D = 24$ in., and $d = 12$ in., $h = 10.375$ in.

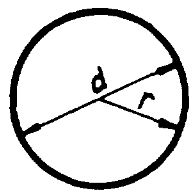
Find: Volume $V = 0.2618\ h\,(D^2 + Dd + d^2) =$

$0.2618 \times 10.375\,(24^2 + 24 \times 12 + 12^2) = 2737.9$ cu.-in.

Surface $S = 1.5708\ c\,(D + d) = 1.5708 \times 12\,(24 + 12) =$

678.586 sq.-in.

GEOMETRICAL FORMULAS
(See examples on the facing page)

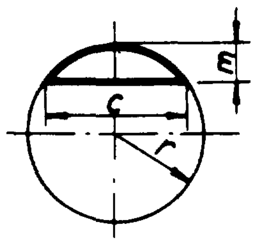


SPHERE

V = Volume A = Area of surface

$$V = \frac{4\pi x r^3}{3} = \frac{\pi x d^3}{6} = 4.1888\ r^3 = 0.5236\ d^3$$

$$A = 4\ \pi\ x\ r^2 = \pi d^2$$

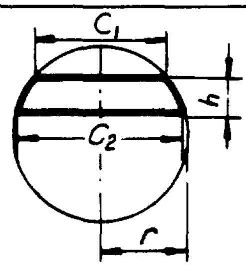


SPHERICAL SEGMENT

V = Volume A = Area of spherical surface

$$V = 3.1416\ x\ m^2\ (r - \frac{m}{3})$$

$$A = 2\pi\ x\ r\ x\ m$$

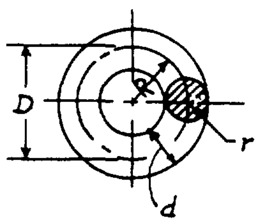


SPHERICAL ZONE

V = Volume A = Area of spherical surface

$$V = 0.5236h\left(\frac{3C_1^2}{4} + \frac{3C_2^2}{4} + h^2\right)$$

$$A = 2\pi\ rh = 6.2832\ rh$$



TORUS

V = Volume A = Area of surface

$$V = 19.739\ Rr^2$$
$$= 2.4674\ Dd^2$$
$$A = 39.478\ Rr$$
$$= 9.8696\ Dd$$

See tables for volume and surface of cylindrical shell, spherical, elliptical and flanged and dished heads beginning on page 416.

EXAMPLES

(See Formulas on the Facing Page)

SPHERE

Given: Radius $r = 6$ in.

Find: Volume $V = 4.1888\ r^3 = 4.1888 \times 216 = 904.78$ cu.-in.

or $V = 0.5236\ d^3 = 0.5236 \times 1728 = 904.78$ cu.-in.

Area $A = 4\ \pi\ r^2 = 4 \times 3.1416 \times 6^2 = 452.4$ sq.-in.

or $A = \pi\ d^2 = 3.1416 \times 12^2 = 452.4$ sq. in.

SPHERICAL SEGMENT

Given: Radius $r = 6$ in. and $m = 3$ in.

Find: Volume $V = 3.1416 \times m^2\ (r - \frac{m}{3}) =$

$= 3.1416 \times 3^2\ (6 - \frac{3}{3}) = 141.37$ cu.-in.

Area $A = 2\ \pi \times r \times m = 2 \times 3.1416 \times 6 \times 3 = 113.10$ sq.-in.

SPHERICAL ZONE

Given: Radius $r = 6$ in., $C_1 = 8$ in., $C_2 = 11.625$ in., and $h = 3$ in.

Find: Volume $V = 0.5236 \times 3 \times \left(\frac{3 \times 8^2}{4} + \frac{3 \times 11.625^2}{4} + 3^2 \right) = 248.74$ cu. in.

Area $A = 6.2832 \times 6 \times 3 = 113.10$ sq.-in.

TORUS

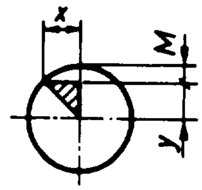
Given: Radius $R = 6$ in. and $r = 2$ in.

Find: Volume $V = 19.739\ R \times r^2 = 19.739 \times 6 \times 2^2 = 473.7$ cu.-in.

Area $A = 39.478\ Rr = 39.478 \times 6 \times 2 = 473.7$ sq.-in.

GEOMETRICAL PROBLEMS AND CONSTRUCTIONS

A — LOCATING POINTS ON A CIRCLE



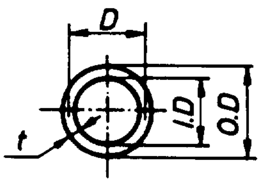
$$Y = \sqrt{R^2 - X^2}$$
$$X = \sqrt{R^2 - Y^2}$$

EXAMPLE

R = 5 in. X = 3 in.

Find Y $= \sqrt{5^2 - 3^2} = \sqrt{25 - 9}$
$= \sqrt{16} = 4$ in.

B — LENGTH OF PLATE FOR CYLINDER



L = π x D

L = Length of plate

D = Mean diameter

EXAMPLE

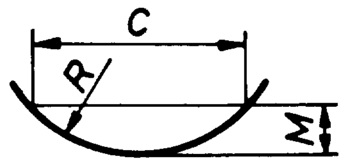
Inside diameter = 24 in.

Thickness of plate : 1 in.

The length of plate

L = 25 x 3.1416 = 78.5398 in.

C — TO FIND THE RADIUS OF A CIRCULAR ARC



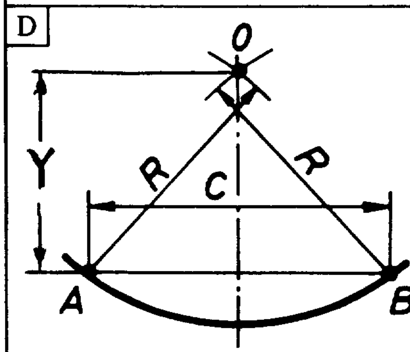
$$R = \frac{\left(\frac{c}{2}\right)^2 + M^2}{2M}$$

EXAMPLE

c = 6 in., M = 2 in.

Find R $= \frac{(6/2)^2 + 2^2}{2 \times 2} = 3.25$ in.

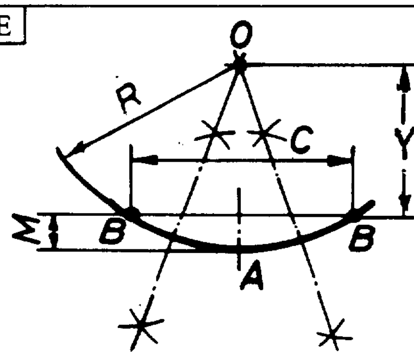
D — TO FIND THE CENTER OF A CIRCULAR ARC



When the Radius, R, and Chord, C are known, strike an arc from point A and from point B with the given length of the Radius. The intersecting point, O of the two arcs is the center of the circular arc.

$$Y = \sqrt{R^2 - \left(\frac{C}{2}\right)^2}$$

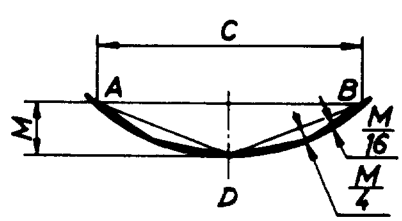
E — TO FIND THE CENTER OF A CIRCULAR ARC



When the Chord, C, and Dimension, M, are known, strike an arc from point A and from point B on both sides of the arc. Connect the intersecting points with straight lines. The intersecting point of the straight lines, O is the center of the circular arc.

$$R = \frac{C^2 + 4M^2}{8M} \quad ; \quad Y = R - M$$

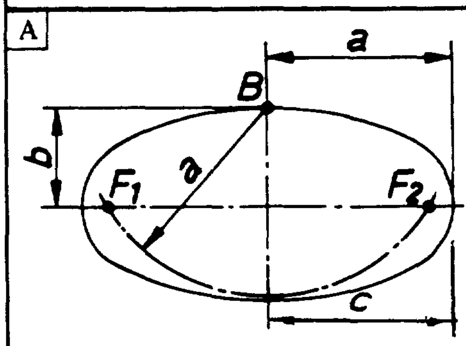
F — CONSTRUCTION OF A CIRCULAR ARC



The Radius is known, but because of its extreme length it is impossible to draw the arc with a compass. Determine the length of Chord and Dimension M. Draw at the center of the Chord a perpendicular line. Measure on this line Dimension M. Connect points AD and BD. Bisect lines AD and BD and measure M/4 dimension perpendicular. Repeating this procedure to the requested accuracy, M will be at each bisection 4 times less. The vortices of the triangles are the points of the circular arc.

GEOMETRICAL PROBLEMS AND CONSTRUCTIONS

A

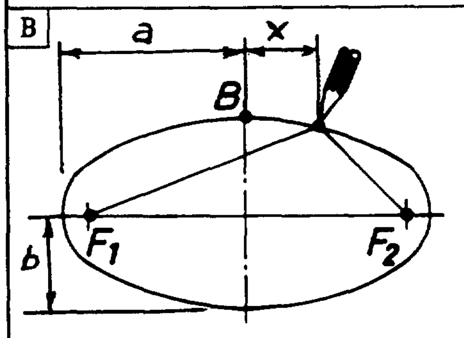


TO FIND THE FOCUS OF AN ELLIPSE

Given the minor and major axis of the ellipse. Find the focus.
Strike an arc with radius, a (one half of the major axis) with center at B. The intersecting points of the arc and major axis are the two foci of the ellipse.

$$c = \sqrt{a^2 - b^2}$$

B

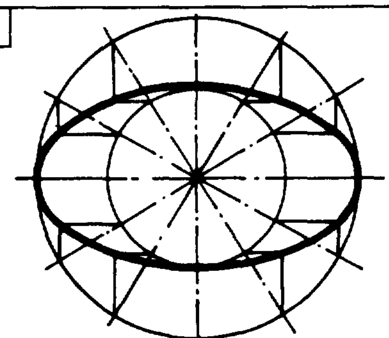


THE CONSTRUCTION OF ELLIPSE

Place a looped string around points F_1, B and F_2. Draw the ellipse with a pencil moving it along the maximum orbit of the string while it is kept taunt.

$$Y = b\sqrt{1 - \frac{x^2}{a^2}}$$

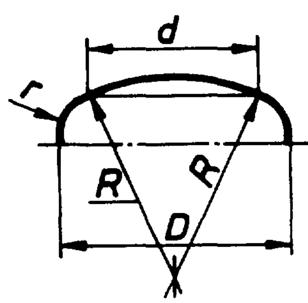
C



THE CONSTRUCTION OF ELLIPSE

Describe a circle of which diameter is equal to the major axis of the ellipse and with the same center a circle of which diameter is equal to the minor axis. Draw a number of diameters. From the intersecting points of the large circle draw perpendicular lines to the major axis and from the intersections of the small circle draw lines parallel with the minor axis. The intersections of these parallel and perpendicular lines are points of the elliptical curve.

D

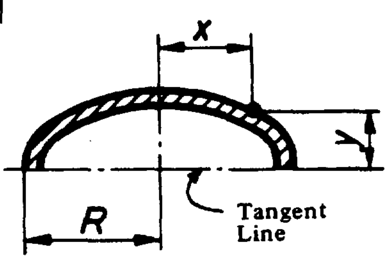


PROPERTIES OF 2:1 ELLIPTICAL HEAD

d = 0.8 D (approx.)
R = 0.9 D (approx.)
r = 0.173 D (approx.)

The upper portion of the head within diameter, d is a spherical segment with negligible deviation.

E

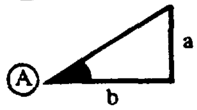
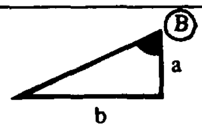
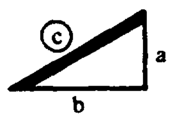
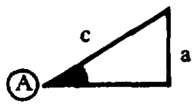
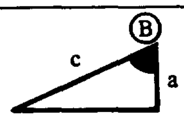
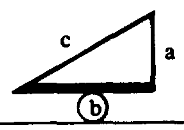
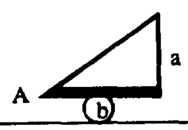
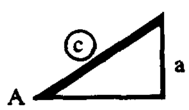
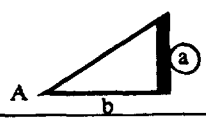
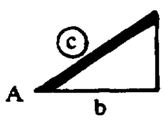
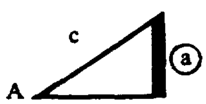
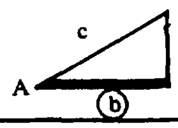


LOCATING POINTS ON A 2:1 ELLIPTICAL HEAD

$X = \sqrt{R^2 - 4Y^2}$ $\quad$ $Y = \dfrac{\sqrt{R^2 - X^2}}{2}$

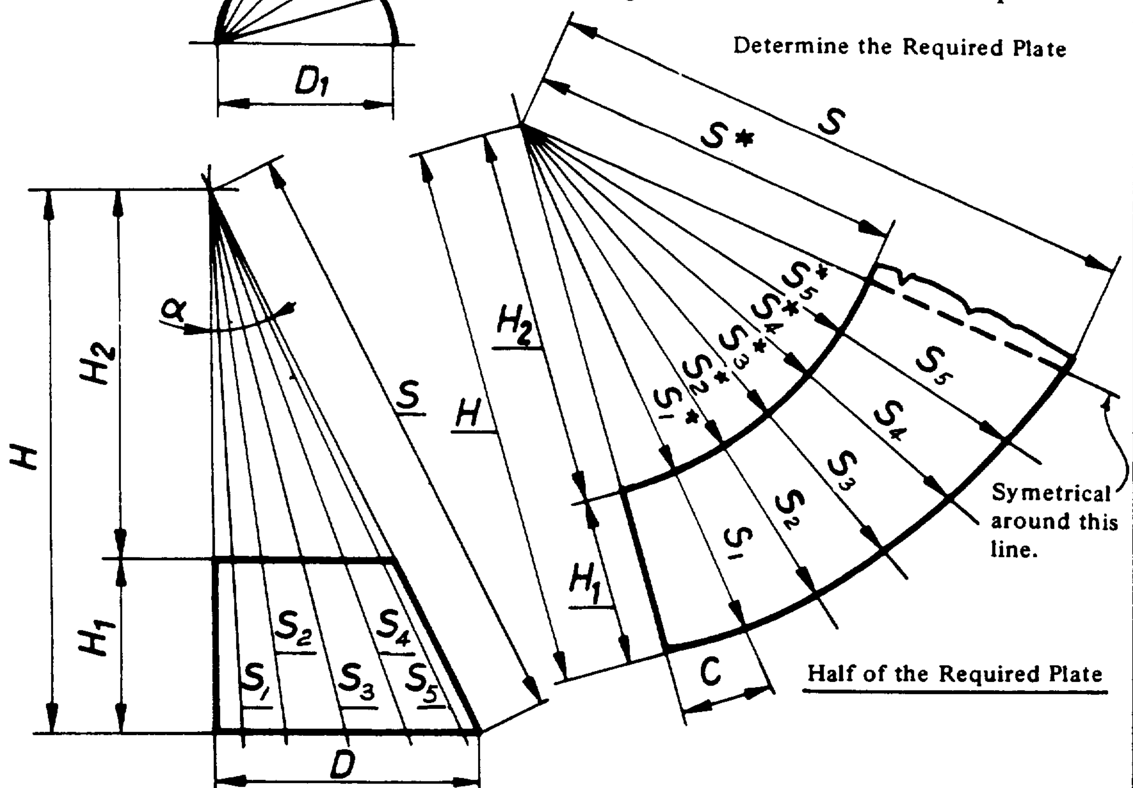
Note: The curvature of an elliptical head on one side only is a true ellipse (inside or outside). The opposite parallel curve is geometrically undetermined. To locate points on this curve especially in the case of heavy walled head is possible by means of layout only. See tables on page 285.

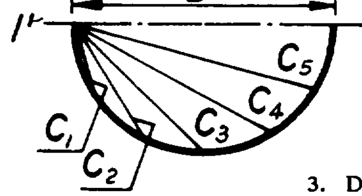
SOLUTION OF RIGHT TRIANGLES

KNOWN	REQUIRED SIDE OR ANGLE (ENCIRCLED)	FORMULAS	EXAMPLES
a, b		$\tan A = \frac{a}{b}$	Side a = 6 in. b = 12.867 in. Find Angle A = $\frac{6}{12.867}$ = 0.4663 tan 0.4663 = 25°
a, b		$\tan B = \frac{b}{a}$	Side a = 6 in. b = 12.867 in. Find Angle B = $\frac{12.867}{6}$ = 2.1445 tan 2.1445 = 65°
a, b		$c = \sqrt{a^2 + b^2}$	Side a = 3 in. b = 4 in. Find side c = $\sqrt{3^2 + 4^2}$ = $\sqrt{9 + 16}$ = $\sqrt{25}$ = 5 in.
a, c		$\sin A = \frac{a}{c}$	Side a = 6 in. c = 12 in. Find Angle A = $\frac{6}{12}$ = 0.500 sin 0.500 = 30°
a, c		$\cos B = \frac{a}{c}$	Side a = 6 in. c = 12 in. Find Angle B = $\frac{6}{12}$ = 0.500 cos 0.500 = 60°
a, c		$b = \sqrt{c^2 - a^2}$	Side a = 3 in. c = 5 in. Find side b = $\sqrt{5^2 - 3^2}$ $\sqrt{25 - 9}$ = $\sqrt{16}$ = 4 in.
A, a		b = a x cot A	Angle A = 25°, side a = 6 in. Find side b = 6 x cot 25° = 6 x 2.1445 = 12.867 in.
A, a		$c = \frac{a}{\sin A}$	Angle A = 30°, side a = 6 in. Find side c = $\frac{6}{\sin 30°}$ = $\frac{6}{0.500}$ = 12 in.
A, b		a = b x tan A	Angle A = 25°, side b = 12.867 in. Find side a = 12.867 x tan 25° = 12.867 x 0.4663 = 6 in.
A, b		$c = \frac{b}{\cos A}$	Angle A = 30°, side b = 12 in. Find side c = $\frac{b}{\cos 30°}$ = $\frac{12}{0.866}$ = 13.856 in.
A, c		a = c x sin A	Angle A = 30°, side c = 12 in. Find side a = 12 x sin 30° = 12 x 0.500 = 6 in.
A, c		b = c x cos A	Angle A = 30°, side c = 12 in. Find side b = 12 x cos 30° 12 x 0.866 = 10.392 in.

Frustum of ECCENTRIC CONE
EXAMPLE

Given: Mean diameter at the large end, $D = 36$ in.
Mean diameter at the small end, $D_1 = 24$ in.
Height of frustum, $H_1 = 24$ in.





1. $\tan\alpha = \frac{D - D_1}{H_1} = \frac{36 - 24}{24} = 0.500 = 26^{0} \cdot 34'$
2. $H = \frac{D}{\tan\alpha} = \frac{36}{0.500} = 72$ in., $H_2 = H - H_1 = 72 - 24 = 48$ in.
3. Divide the base circle into 12 equal parts.
4. Draw chords C_1, C_2, C_3, etc. to the dividing points.
5. Calculate the length of the chords C_1, C_2, C_3, etc. using Factor, C from table "Segments of Circles for Radius = 1 on page 290".
6. Calculate the lengths of S_1, S_2, etc. and S_1^*, S_2^*, etc.

	At The Bottom		At The Top	
	Factor c times mean radius = Chords, C_1 C_2... in.	$\sqrt{H^2 + C_{1,2}^2} = S_{1,2...}$ ft.-in.	Factor c times mean radius = Chords, C_1 C_2 etc. in.	$\sqrt{H_2^2 + C_{1,2}^2} = ... S_{1,2...}^*$ ft.-in.
30^0	$C_1 =$ 9.317″	$S_1 =$ 6'-0 5/8	$C_1 =$ 6.212″	$S_1^* =$ 4'-0 3/8
60^0	$C_2 =$ 18.000″	$S_2 =$ 6'-2 3/16	$C_2 =$ 12.000″	$S_2^* =$ 4'-1 1/2
90^0	$C_3 =$ 25.452″	$S_3 =$ 6'-4 3/8	$C_3 =$ 16.968″	$S_3^* =$ 4'-2 15/16
120^0	$C_4 =$ 31.176″	$S_4 =$ 6'-6 7/16	$C_4 =$ 20.784″	$S_4^* =$ 4'-4 5/16
150^0	$C_5 =$ 34.776″	$S_5 =$ 6'-7 15/16	$C_5 =$ 23.184″	$S_5^* =$ 4'-5 5/16

$S_6 = \sqrt{H^2 + D^2} = 6' \cdot 8\frac{1}{2}$

$S_6^* = \sqrt{H_2^2 + D_1^2} = 4' \cdot 5\frac{11}{16}$

OPTIMUM VESSEL SIZE*

To build a vessel of a certain capacity with the minimum material, the correct ratio of length to diameter shall be determined.
The optimum ratio of length to the diameter can be found by the following procedure: (The pressure is limited to 1000 psi and ellipsoidal heads are assumed)

$F = \frac{P}{CSE}$, where
P = Design pressure, psi.
C = Corrosion allowance, in.
S = Stress value of material, psi.
E = Joint efficiency

Enter chart on facing page at the left hand side at the desired capacity of the vessel. Move horizontally to the line representing the value of F.
From the intersection move vertically and read the value of D.

The length of vessel = $\frac{4V}{\pi D^2}$, where
V = Volume of vessel, cu. ft.
D = Inside diameter of vessel, ft.

EXAMPLE

Design Data:
P = 100 psi, V = 1,000 cu. ft., S = 16,000 psi., E = 0.80, C = 0.0625 in.
Find the optimum diameter and length

$$F = \frac{100}{0.0625 \times 16{,}000 \times 0.8} = 0.125 \text{ in.}^{-1}$$

From chart D = 5.6 ft., say 5 ft. 6 in.

$$\text{Length} = \frac{4 \times 1{,}000}{3.14 \times 5.5^2} = 42.1, \text{ say 42 ft. 1 in.}$$

*FROM:

"Nomographs Gives Optimum Vessel Size," by K. Abakians, Originally published in HYDROCARBON PROCESSING, Copyrighted Gulf Publishing Company, Houston. Used with permission.

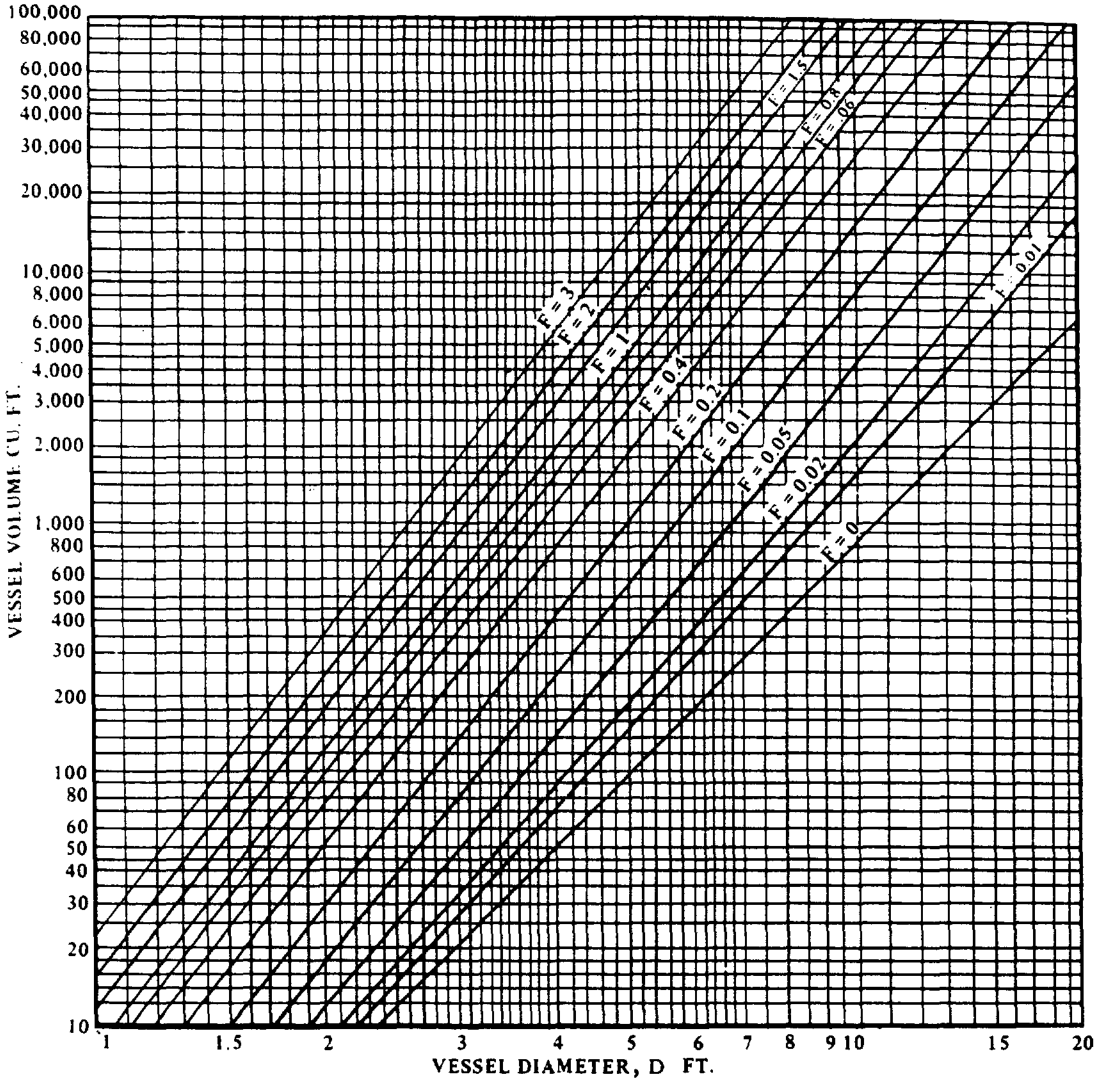
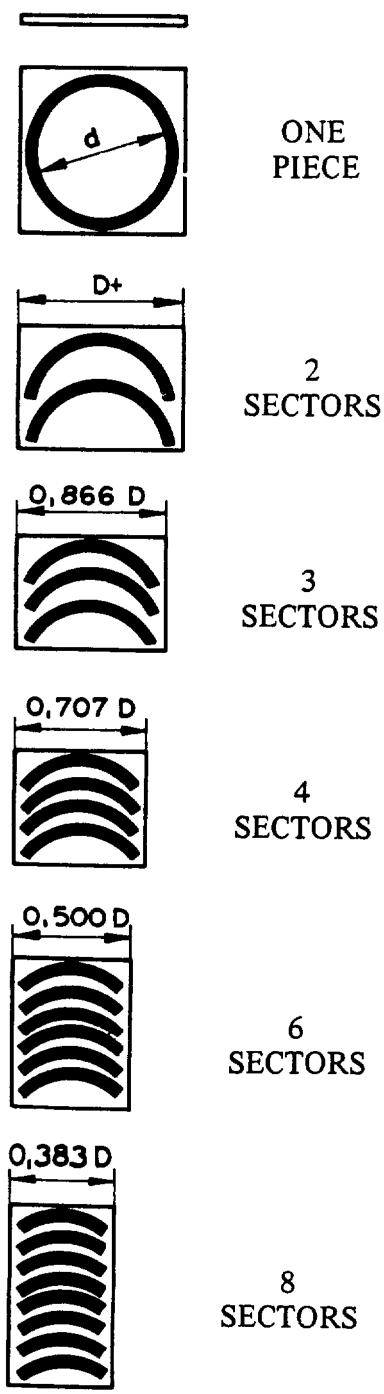


CHART FOR DETERMINING THE OPTIMUM VESSEL SIZE
(See facing page for explanation)

FLAT RINGS MADE OF SECTORS



THE REQUIRED WIDTH OF PLATE FOR RINGS MADE OF SECTORS

Making flat rings for base, stiffeners etc., by dividing the ring into a number of sectors, less plate will be required.

Since the sectors shall be welded to each other, the welding will be increased by increasing the number of sectors.

The cost of the welding must be balanced against the saving in plate cost.

The chart on facing page shows the total plate area required when a ring is to be divided into sectors. This area is expressed as a percentage of the square that is needed to cut out the ring in one piece. The figures at the left of this page show the width of the required plate using different number of sectors.

D = Outside diameter of ring.
d = Inside diameter of ring.

DETERMINATION OF THE REQUIRED PLATE SIZE

1. Determine D/d and D^2 (the area of square plate would be required for the ring made of one piece)

2. Read from chart (facing page) the percentage of the required area when the ring divided into the desired number of sectors

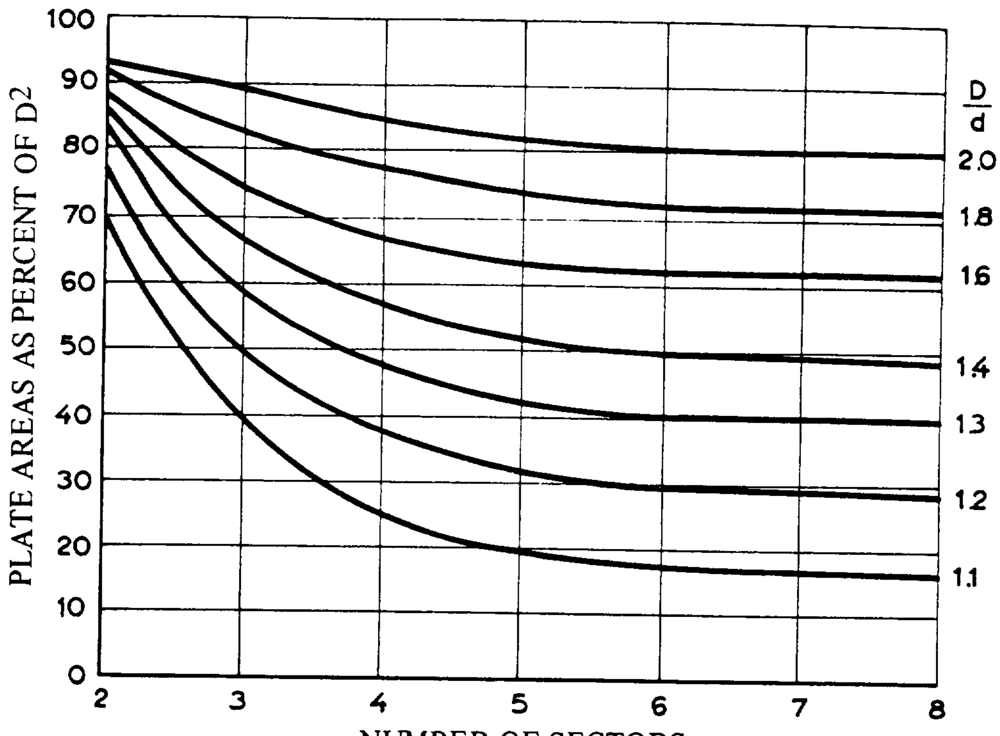
3. Determine the required area of plate

4. Divide the area by the required width of plate as shown at the left of this page to obtain the length of the plate.

5. Add allowance (max. 1 inch) for flame cutting between sectors and at the edges of the plate

See Example On Facing Page.

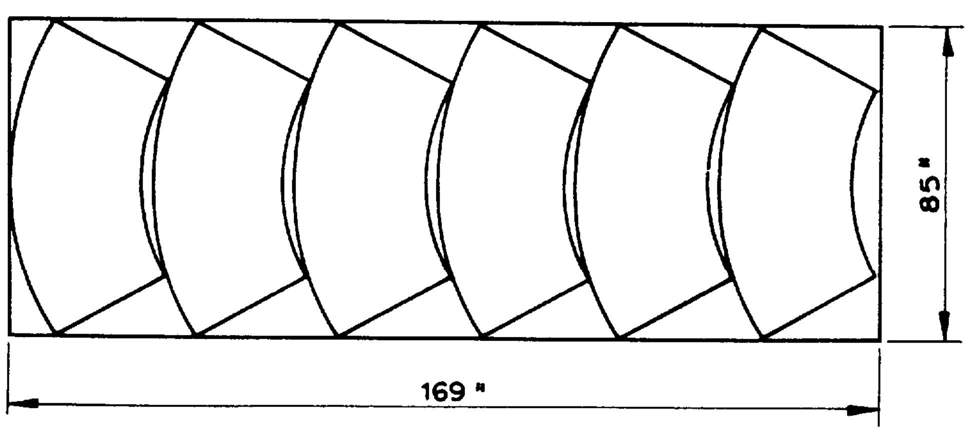
FLAT RINGS MADE OF SECTORS (cont.)



EXAMPLE

Determine the required plate size for a 168 in. O.D., 120 in. I.D. ring made of 6 sectors

1. D/d = 1.4; D^2 = 28,224 sq. in.
2. From chart (above) the required area of plate is 50% of the area that would be required for the ring made of one piece.
3. Area required 28.224 x 0.50 = 14,112 sq. in.
4. Divide this area by the required width of plate (facing page). Width = 0.5 x 168 = 84   14,112/84 = 167.9 inches, the length of plate.
5. Add allowance for flame cut.

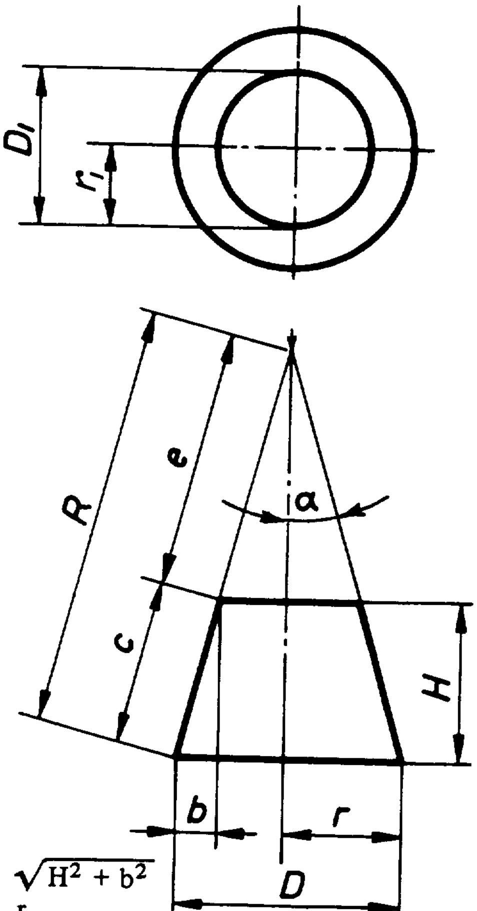


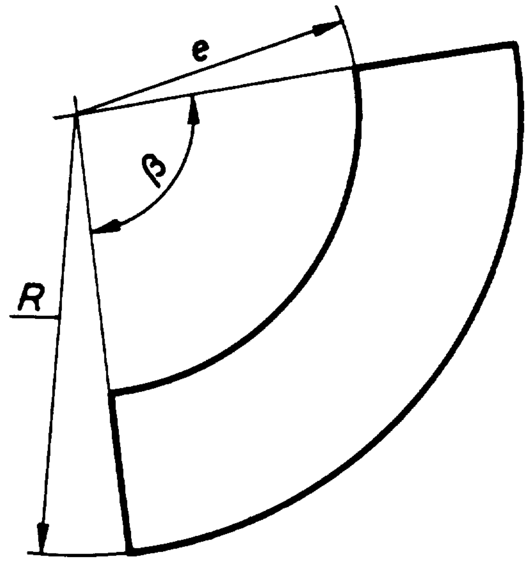
Frustum of CONCENTRIC CONE

Given:

D = Mean diameter at the large end.
D_1 = Mean diameter at the small end.
H = Height of the frustum.

Determine the Required Plate.





The Required Plate

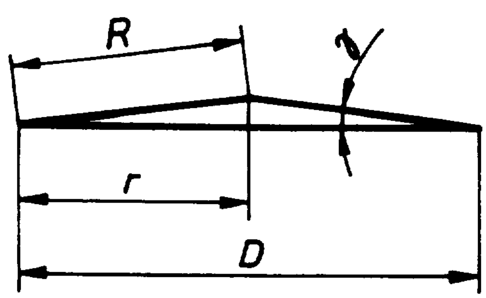
$c = \sqrt{H^2 + b^2}$

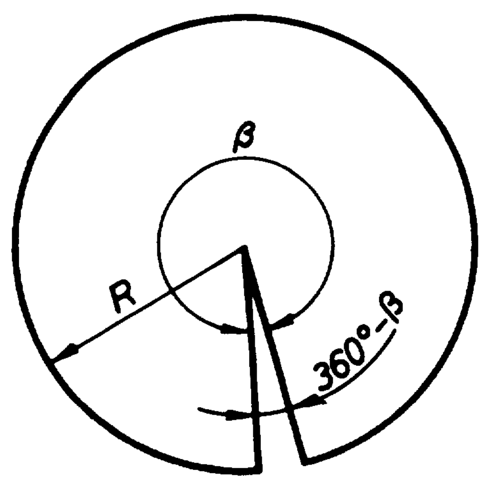
$\beta = \frac{r}{R} \times 360$

$b = \frac{D - D_1}{2}$, $\tan \alpha = \frac{b}{H}$, $r_1 = \frac{D_1}{2}$

$e = \frac{r_1}{\sin \alpha}$ $R = c + e$

Conical Tank Roof



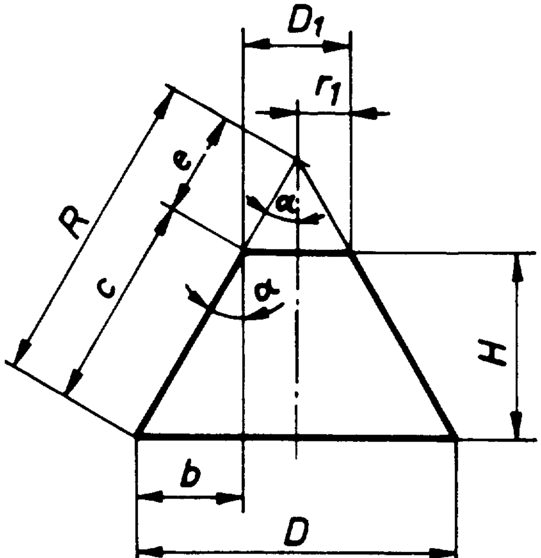


$R = \frac{r}{\cos \gamma}$ $\beta = \frac{r}{R} \times 360$

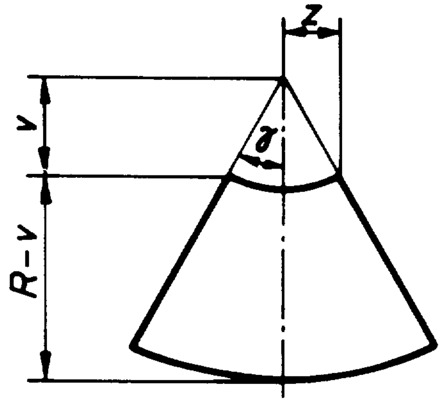
The Required Plate

Frustum of CONCENTRIC CONE

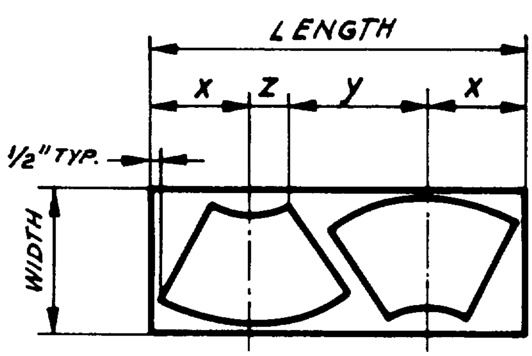
Made from two or more Plates



Elevation



One Sector of Plate



Required Plate

Given:

D = Mean diameter at the large end.

D_1 = Mean diameter at the small end.

H = Height of the frustum

n = Number of plates (sector)

Determine the Required Plate

$$b = \frac{D - D_1}{2}$$

$$\tan \alpha = \frac{b}{H}$$

$$c = \sqrt{b^2 + H^2}$$

$$r_1 = D_1/2$$

$$e = \frac{r_1}{\sin\alpha} \qquad R = c + e$$

$$\gamma = \frac{D \times \pi \times 57.296}{2Rn}$$

X = $R \times \sin\gamma + \frac{1}{2}$"

Y = $R \times \tan\gamma + 1$"

Z = $e \times \sin\gamma$

V = $e \times \cos\gamma$

Width of the Required Plate = $R - V + 1$"

Length of the Required Plate if the Frustum made from:

2 Plates : $2X + Y + Z$

3 Plates : $2X + 2Y + 2Z$

4 Plates : $2X + 3Y + 3Z$

6 Plates : $2X + 5Y + 5Z$

Frustum of ECCENTRIC CONE

Determination of the Required Plate by Layout and by Calculation

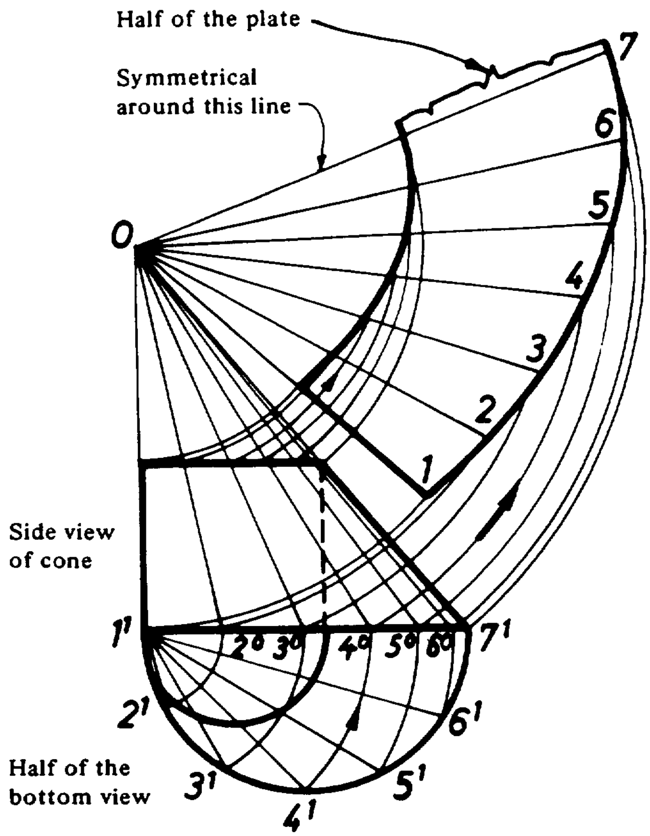


Fig. A

LAYOUT

1. Draw the side view and half of the bottom view of the cone.
2. Divide into equal parts the base and the top circle.
3. Draw arcs from points 2^1, 3^1, 4^1, etc. with the center 1^1.
4. From the points 1^o, 2^o, 3^o, etc. strike arcs with center 0.
5. Starting from a point on arc 1^1 (marked 1) measure the spacing of the bottom circle of the cone and intersect arc 2^o. From this point marked 2 measure again one space intersecting arc 3^o etc. The points or intersections are points on the curvature of the plate at the bottom of the cone.
6. To determine the curvature of the plate at the top of the cone, repeat steps 4 and 5, but measure on the arcs drawn with center 0 the spaces of the top circle.

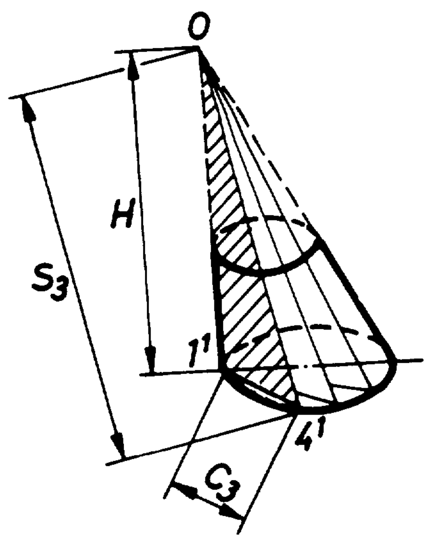


Fig. B

CALCULATION

To find the curvature of the plate by calculation, the dimensions $1^1 - 2^1$, $1^1 - 3^1$ etc. and $0 - 1^1$, $0 - 2^1$ etc. shall be determined.

Fig. B shows as an example the calculation of $0 - 4^1$ only (marked S_3)

If the bottom circle divided into 12 equal spaces,

$$C_3 = 2\,R \times \sin 45^o$$

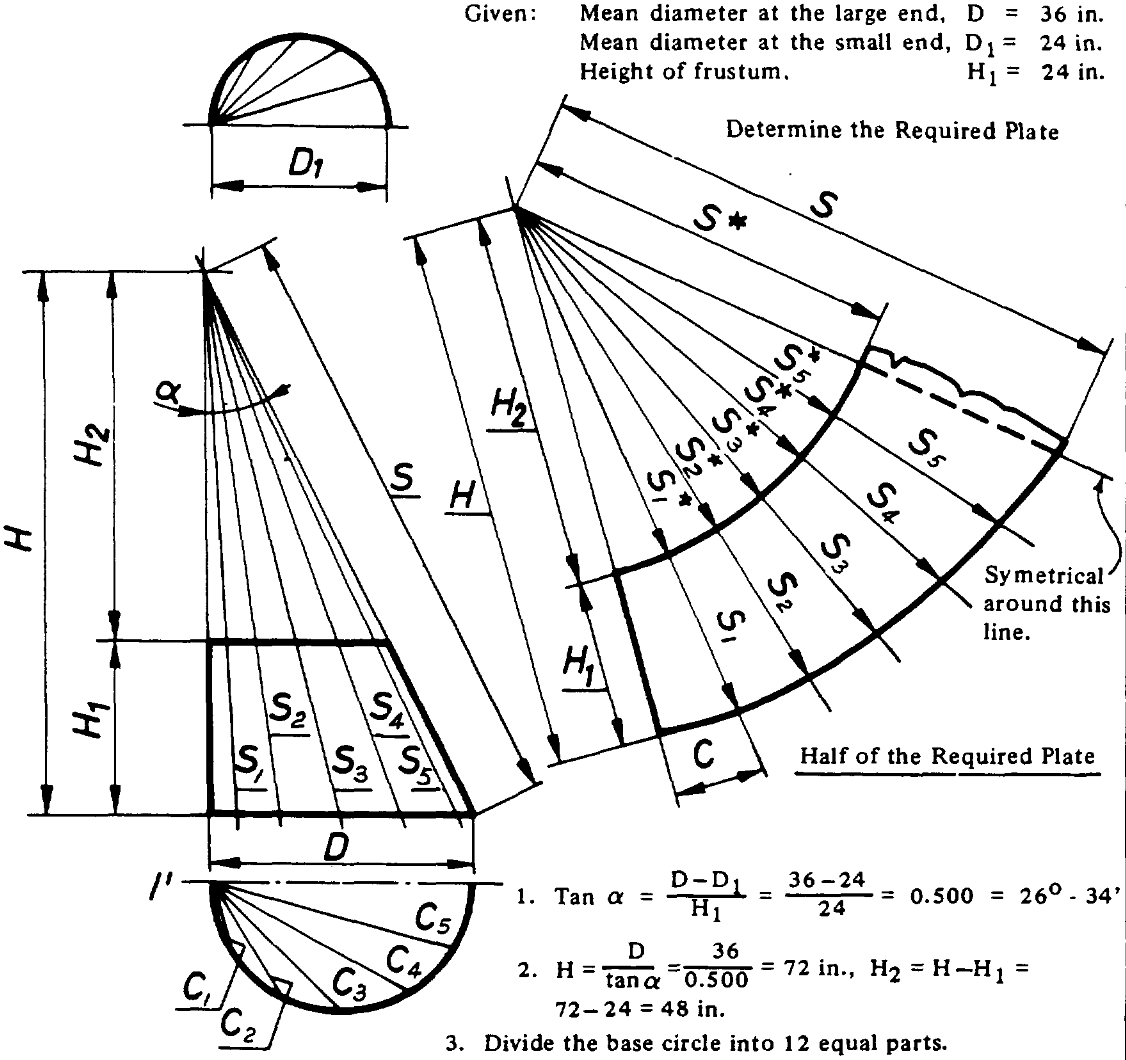
$$S_3 = \sqrt{H^2 + C_3^2}$$

Where R denoted the mean radius of the base circle.

See example.

Frustum of ECCENTRIC CONE
EXAMPLE

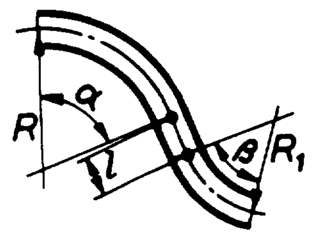
Given: Mean diameter at the large end, $D = 36$ in.
Mean diameter at the small end, $D_1 = 24$ in.
Height of frustum, $H_1 = 24$ in.



1. $\tan \alpha = \frac{D - D_1}{H_1} = \frac{36 - 24}{24} = 0.500 = 26^\circ - 34'$
2. $H = \frac{D}{\tan \alpha} = \frac{36}{0.500} = 72$ in., $H_2 = H - H_1 = 72 - 24 = 48$ in.
3. Divide the base circle into 12 equal parts.
4. Draw chords C_1, C_2, C_3, etc. to the dividing points.
5. Calculate the length of the chords C_1, C_2, C_3, etc. using Factor, C from table "Segments of Circles for Radius = 1 on page 250.
6. Calculate the lengths of S_1, S_2, etc. and S_1^*, S_2^*, etc.

	At The Bottom		At The Top	
	Factor c times mean radius = Chords, C_1 C_2... in.	$\sqrt{H^2 + C_{1,2}^2} =$ $S_{1,2}$... ft.-in.	Factor c times mean radius = Chords, C_1 C_2 etc. in.	$\sqrt{H_2^2 + C_{1,2}^2} =$... $S_{1,2}^*$... ft.-in.
30°	$C_1 =$ 9.317"	$S_1 =$ 6'-0 5/8	$C_1 =$ 6.212"	$S_1^* =$ 4'-0 3/8
60°	$C_2 =$ 18.000"	$S_2 =$ 6'-2 3/16	$C_2 =$ 12.000"	$S_2^* =$ 4'-1 1/2
90°	$C_3 =$ 25.452"	$S_3 =$ 6'-4 3/8	$C_3 =$ 16.968"	$S_3^* =$ 4'-2 15/16
120°	$C_4 =$ 31.176"	$S_4 =$ 6'-6 7/16	$C_4 =$ 20.784"	$S_4^* =$ 4'-4 5/16
150°	$C_5 =$ 34.776"	$S_5 =$ 6'-7 15/16	$C_5 =$ 23.184"	$S_5^* =$ 4'-5 5/16
	$S_6 = \sqrt{H^2 + D^2} =$ 6'-8½		$S_6^* = \sqrt{H_2^2 + D_1^2} =$ 4'-5 11/16	

BENT AND MITERED PIPE



The length of a pipe bent to any shape is equal to the length measured on the centerline of pipe. Example: (The pipe bent as shown)

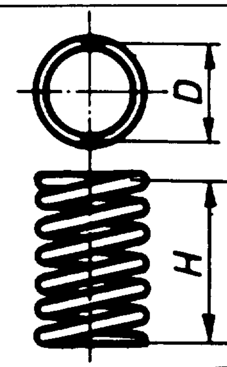
Given: R = 8 in., R_1 = 6 in., $\alpha = 72^\circ$ $\beta = 36^\circ$ l = 2 in.
Find the length of pipe, L.

$$L = R\pi \times \frac{\alpha}{180} + R_1 \pi \frac{\beta}{180} + l$$

$$= 8 \times 3.14 \times \frac{72}{180} + 6 \times 3.14 \times \frac{36}{180} + 2$$

$$= 25.13 \times 0.40 + 18.85 \times 0.20 + 2 = \quad 15.82 \text{ in.}$$

The Required Length of Pipe for Coil

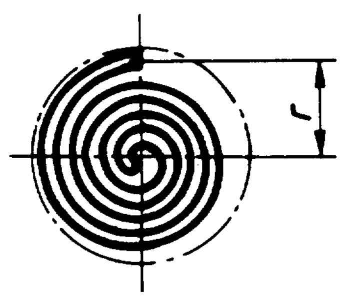


$L = \sqrt{(n \times D \times \pi)^2 + H^2}$ Where
n = Number of turns
L = Length of required pipe

EXAMPLE
Given: D = 10 in., H = 24 in., n = 12

$L = \sqrt{(12 \times 10 \times 3.14)^2 + 24^2} = 378$ in.

The Required Length of Pipe for Coil



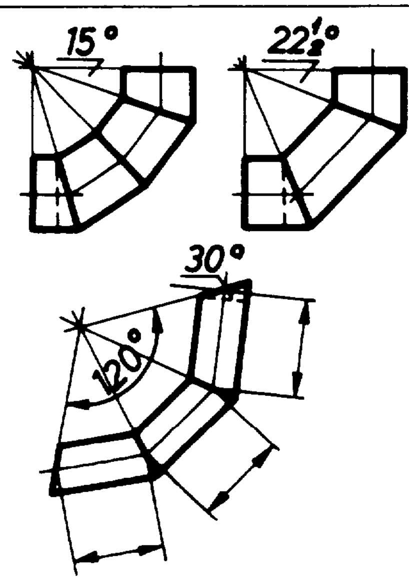
$L = \dfrac{r^2 \pi}{d + c}$ (Approximation)

Where
c = Clearance between turns of pipe.
d = Outside diameter of pipe.
L = Required length of pipe.

EXAMPLE
Given: r = 10 in. d = 2.375 in., c = 1 in.

$L = \dfrac{10^2 \times 3.14}{2.375 + 1} = 93.08$ in.

Mitered Elbow



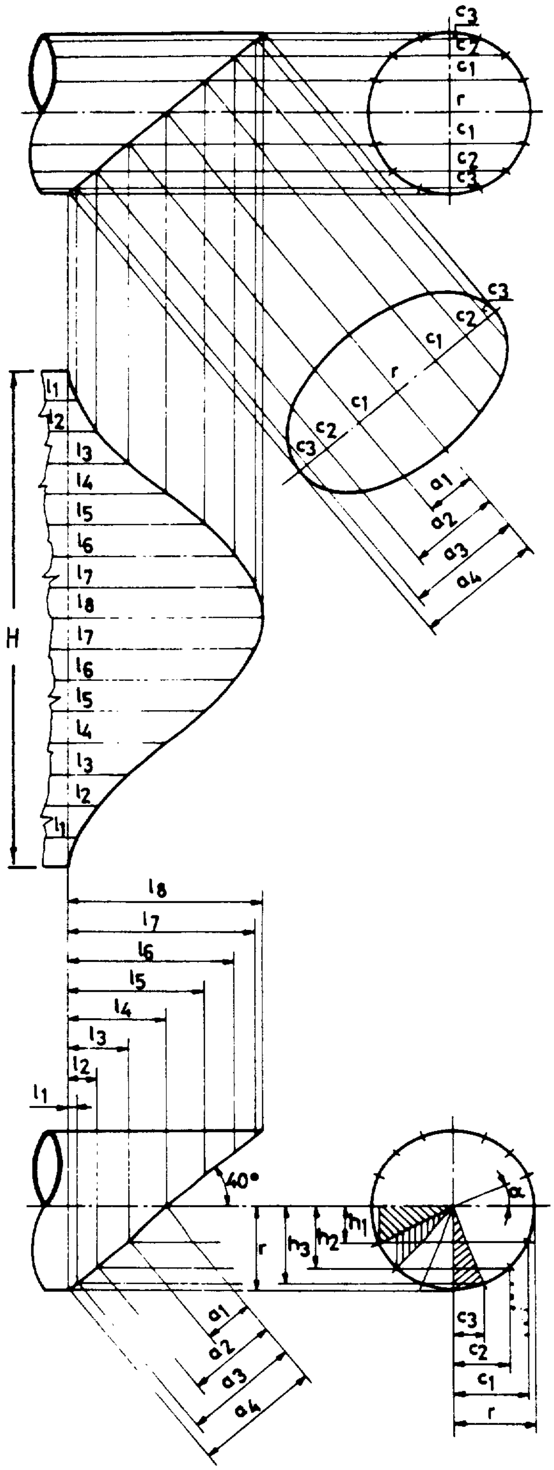
To find the angle of cut for any elbow, divide the total number of degrees of the elbow by twice the number of cuts.

EXAMPLES

3 cuts x 2 = 6	$90^\circ : 6 = 15^\circ$
2 cuts x 2 = 4	$90^\circ : 4 = 22½^\circ$
2 cuts x 2 = 4	$120^\circ : 4 = 30^\circ$

The length of pipe required to form any shapes by mitering is the sum of the centerline lengths of the pipe sections.

INTERSECTION OF CYLINDER & PLANE



$$h_1 = \sqrt{r^2 - c_1^2} \quad h_2 = \sqrt{r^2 - c_2^2} \quad \text{etc.}$$

$$l_1 = (a_4 - a_3)\cos 40^\circ$$

$$l_2 = (a_4 - a_2)\cos 40^\circ \quad \text{etc.}$$

When the intersecting plane is not perpendicular to the axis of the cylinder, the intersection is an ellipse.

CONSTRUCTION OF THE INTERSECTING ELLIPSE

Divide the circumference of the cylinder into equal parts and draw an element at each division point. The major axis of the ellipse is the longest distance between the intersecting points and the minor axis is the diameter of the cylinder. The points of the ellipse can be determined by using the chords of the cylinder spaced by projection as shown or by calculations as exemplified below. With this method may be laid out sloping trays, baffles, down-comers etc. The thickness of the plate and the required clearance shall also be taken into consideration.

DEVELOPMENT

The length, H is equal to the circumference of the cylinder. Divide this line into the same number of equal parts as the circumference of the cylinder. Draw an element through each division perpendicular to this line. Determine the length of each element as shown or by calculation. By connecting the end points of the elements can be obtained the stretched-out line of the intersection and may be used for cutting out pattern for pipe mitering, etc.

EXAMPLE

for calculation of length of elements.

The circumference of the cylinder is divided into 16 equal parts.

The angle of a section = 22-1/2 degrees.

The angle of the intersecting plane to the axis of the cylinder = 40 degrees.

$c_1 = r \times \cos 22\text{-}1/2^\circ$

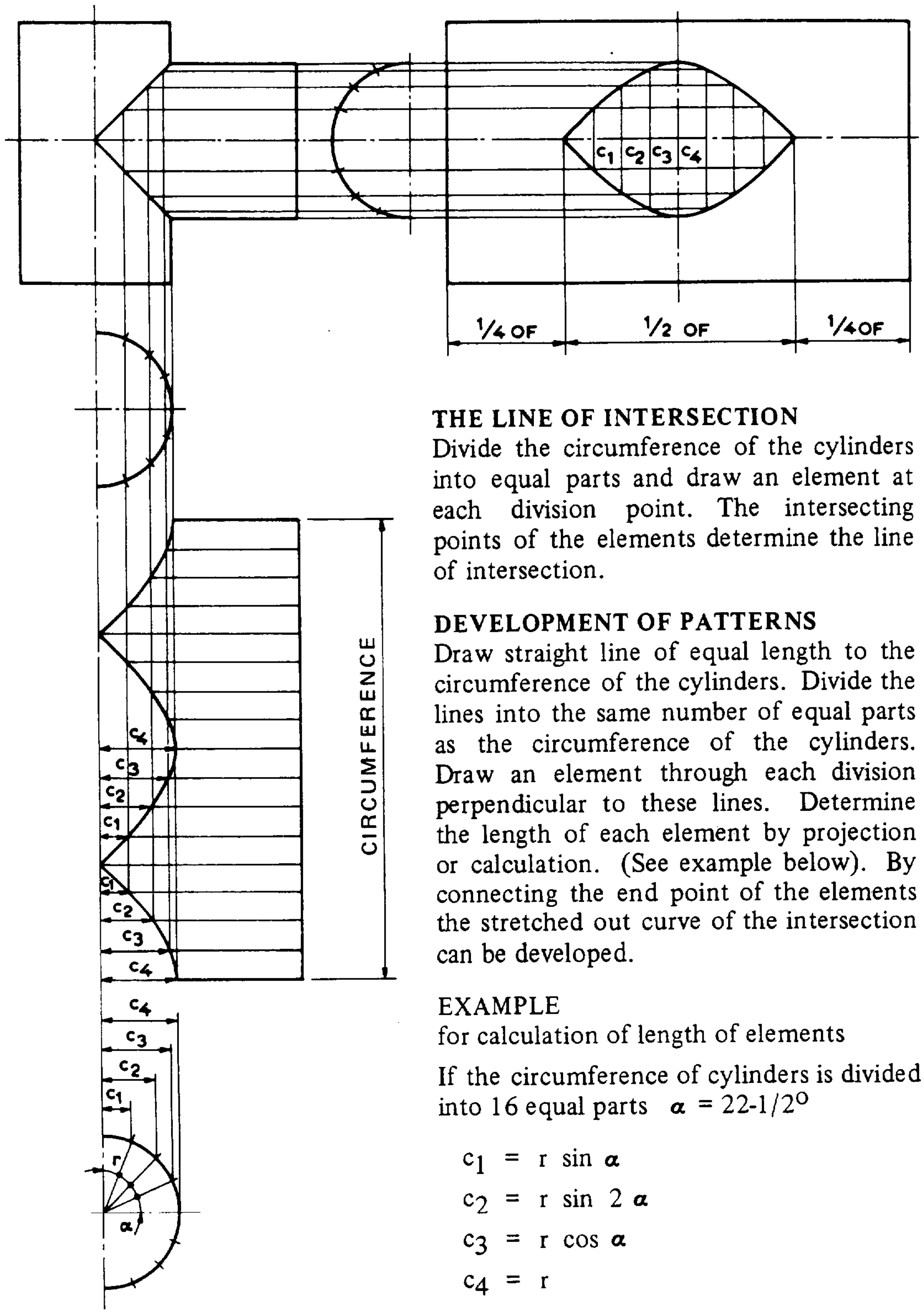
$c_2 = r \times \cos 45^\circ$

$c_3 = r \times \sin 22\text{-}1/2^\circ$

$$a_1 = \frac{h_1}{\sin 40^\circ} \quad a_2 = \frac{h_2}{\sin 40^\circ} \quad \text{etc.}$$

INTERSECTION OF CYLINDERS

of equal diameters with angle of intersection 90°



THE LINE OF INTERSECTION

Divide the circumference of the cylinders into equal parts and draw an element at each division point. The intersecting points of the elements determine the line of intersection.

DEVELOPMENT OF PATTERNS

Draw straight line of equal length to the circumference of the cylinders. Divide the lines into the same number of equal parts as the circumference of the cylinders. Draw an element through each division perpendicular to these lines. Determine the length of each element by projection or calculation. (See example below). By connecting the end point of the elements the stretched out curve of the intersection can be developed.

EXAMPLE

for calculation of length of elements

If the circumference of cylinders is divided into 16 equal parts $\alpha = 22\text{-}1/2^{\circ}$

$c_1 = r \sin \alpha$

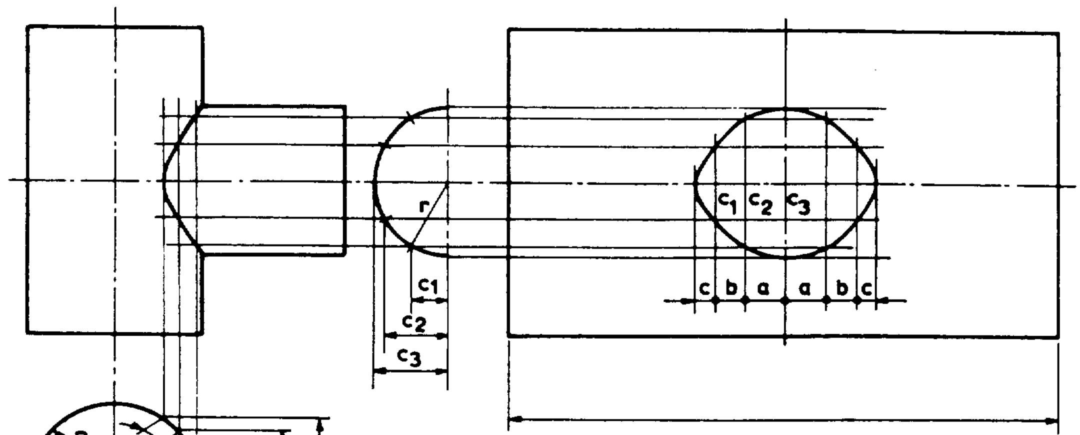
$c_2 = r \sin 2\alpha$

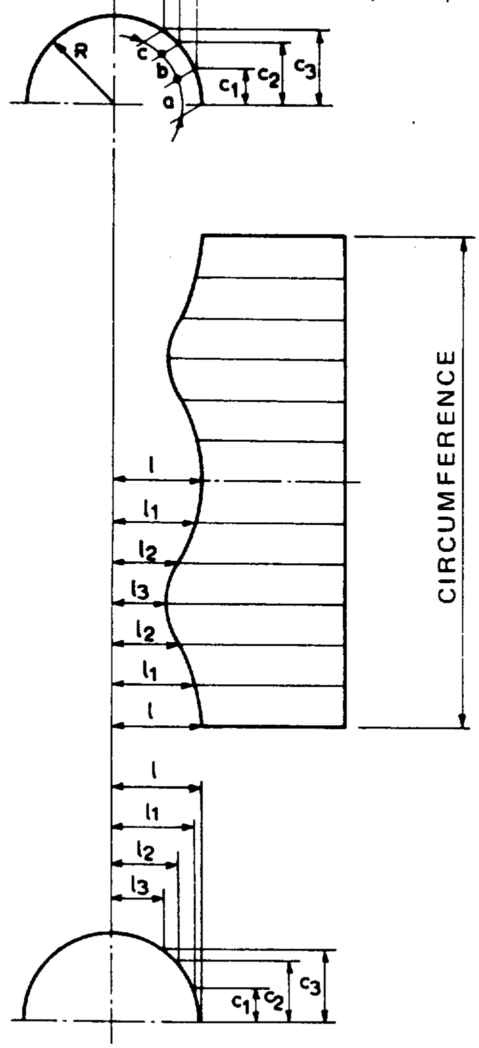
$c_3 = r \cos \alpha$

$c_4 = r$

INTERSECTION OF CYLINDERS

of unequal diameters with angle of intersection 90°





THE LINE OF INTERSECTION

Divide the circumference of the small cylinder into as many equal parts as necessary for the desired accuracy. Draw an element at each division point. Project distances c_1, c_2 etc. to the circumference of the larger cylinder and draw elements at each points. The intersecting points of the elements of the large and small cylinder determine the curve of intersection.

DEVELOPMENT OF PATTERNS

Draw a straight line of equal length to the circumference of the cylinders. Divide the line for the small cylinder into the same number of equal parts as the circumference of the small cylinder. Draw an element through each division perpendicular to the line. Determine the length of the elements by projection or calculation. (See example below). By connecting the end point of the elements the stretched out curve of the intersection can be developed.

The curvature of the hole in the large cylinder is determined by the length of elements c_1, c_2 etc. spacing them at distances a, b, c etc., which are the length of arcs on the partial view of the large cylinder.

EXAMPLE

for calculation of length of elements.
Dividing the circumference of the cylinder into 12 equal parts, $\alpha = 30^\circ$

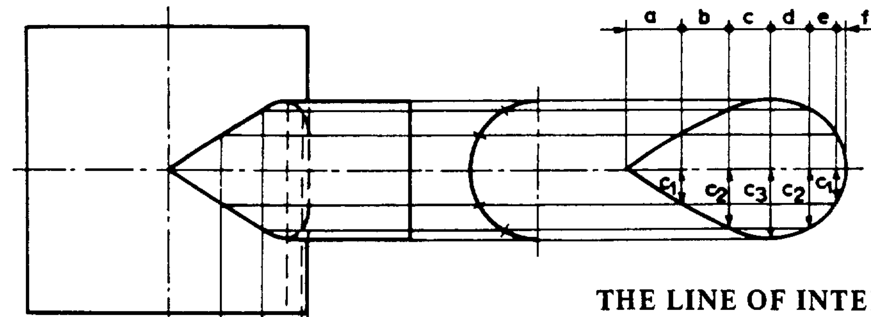
$c_1 = r \sin 30^\circ \quad c_2 = r \cos 30^\circ \quad c_3 = r$

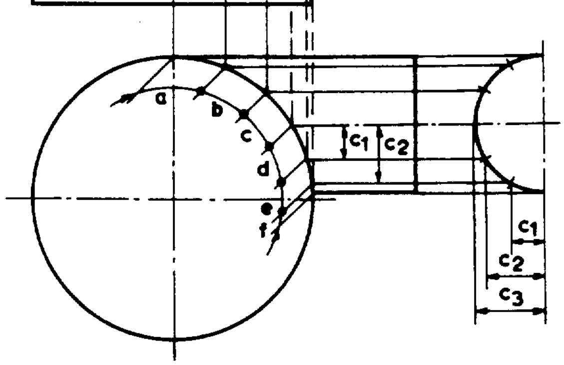
$l_1 = \sqrt{R^2 - c_1^2} \qquad l_3 = \sqrt{R^2 - c_3^2}$

$l_2 = \sqrt{R^2 - c_2^2} \qquad l_4 = R$

INTERSECTION OF CYLINDERS

with non intersecting axes



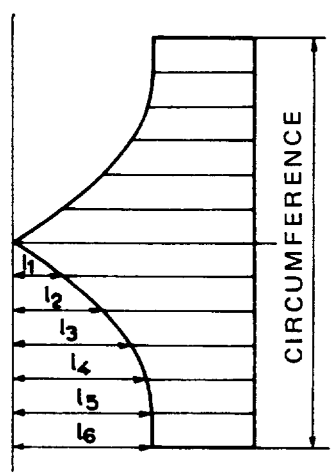


THE LINE OF INTERSECTION

Divide the circumference of the branch cylinder on both views into as many equal parts as necessary for the intended accuracy. Draw an element at each division point. The points of intersection of the corresponding elements determine the line of intersection.

DEVELOPMENT OF PATTERN

Draw a straight line of equal length to the circumference of the branch cylinder and divide it into the same number of equal parts as the circumference. Draw an element through each division perpendicular to the line. Determine the length of the elements by projection or calculation. (See example below). By connecting the end point of the elements the stretched out curve of the intersection can be developed.

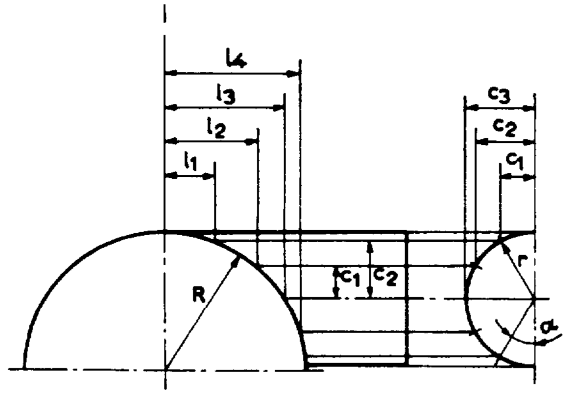


The curvature of the hole in the main cylinder is determined by the length of elements c_1, c_2 etc. spacing them at distances a, b, c, etc., which are the length of arcs on the main cylinder (see elevation).

EXAMPLE

for calculation of length of elements

Dividing the circumference of the cylinder into 12 equal parts, $\alpha = 30°$



$c_1 = r \sin 30°$ $\quad l_1 = \sqrt{R^2 - (r + c_2)^2}$

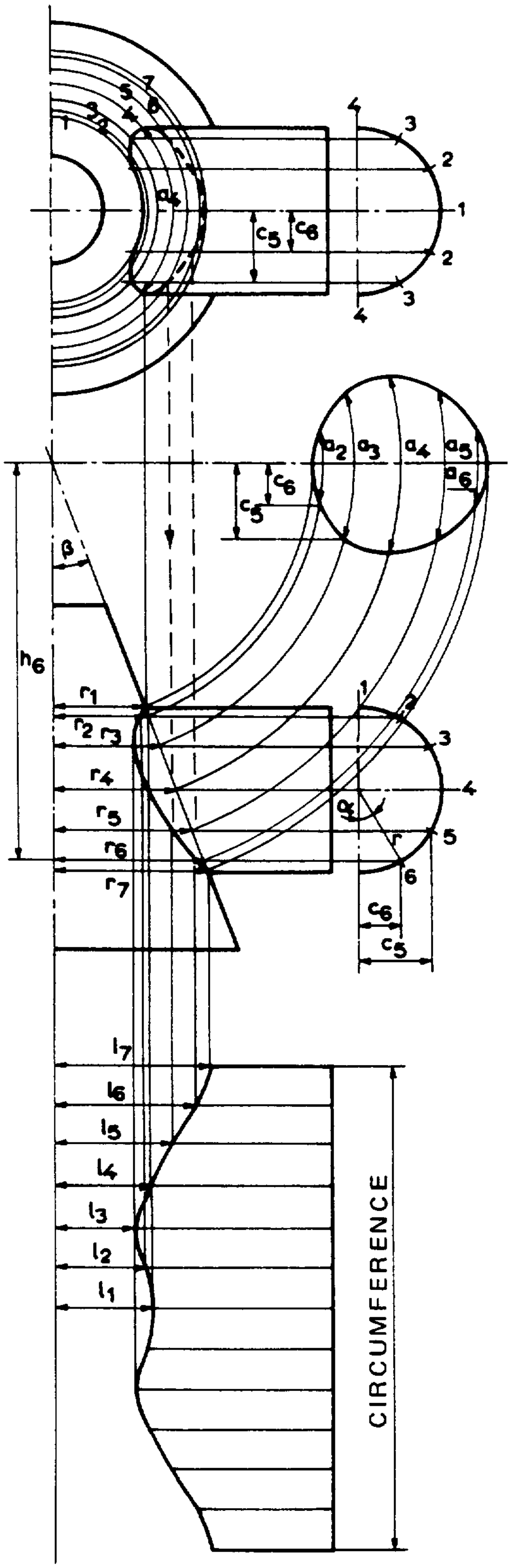
$c_2 = r \cos 30°$ $\quad l_2 = \sqrt{R^2 - (r + c_1)^2}$

$c_3 = r$ $\quad l_3 = \sqrt{R^2 - r^2}$

$l_4 = \sqrt{R^2 - (r - c_1)^2}$

$l_6 = R$ $\quad l_5 = \sqrt{R^2 - (r - c_2)^2}$

INTERSECTION OF CONE AND CYLINDER



THE LINE OF INTERSECTION
Divide the circumference of the cylinder on both views into as many equal parts as necessary for the desired accuracy. Draw an element at each division point. Draw circles on plan view with radius r_1, r_2, etc. The line of intersection on the plan is determined by the points of intersections of elements and the corresponding circles. Project these points to the elevation. The intersecting points of the projectors and elements will determine the line of intersection on the elevation. The stretched out curvature of the hole in the cone is to be determined by the length of arcs a_2, a_3, etc. transferred from the plan view or calculated as exemplified below. The spacing of arcs a_2, a_3, etc. may be obtained as shown or may be calculated. (See example below).

DEVELOPMENT OF PATTERN
Draw a straight line of length equal to the circumference of the cylinder and divide it into the same number of equal parts as the circumference. Draw an element through each division point perpendicular to the line. Determine the length of the elements by projection or by calculating the length of l_1, l_2, etc.(See example below).

EXAMPLE
for calculation of length of elements

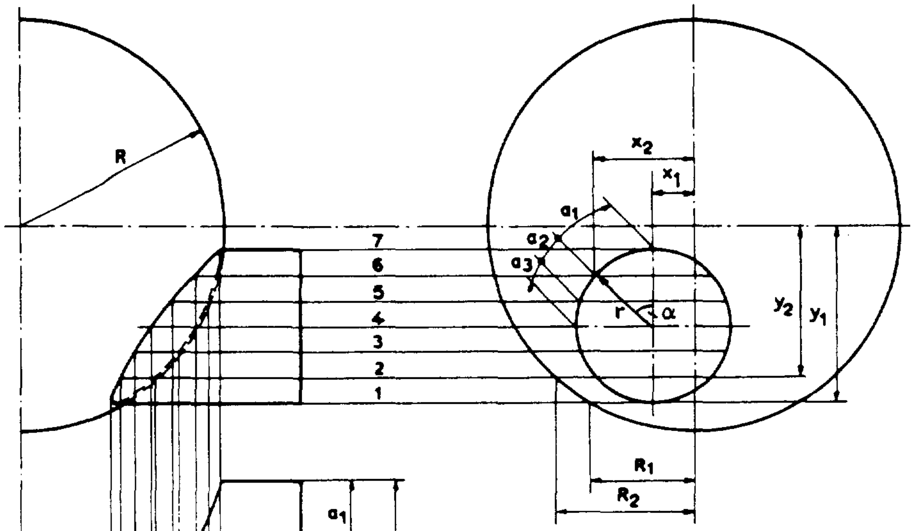
$$c_6 = r \sin\alpha$$

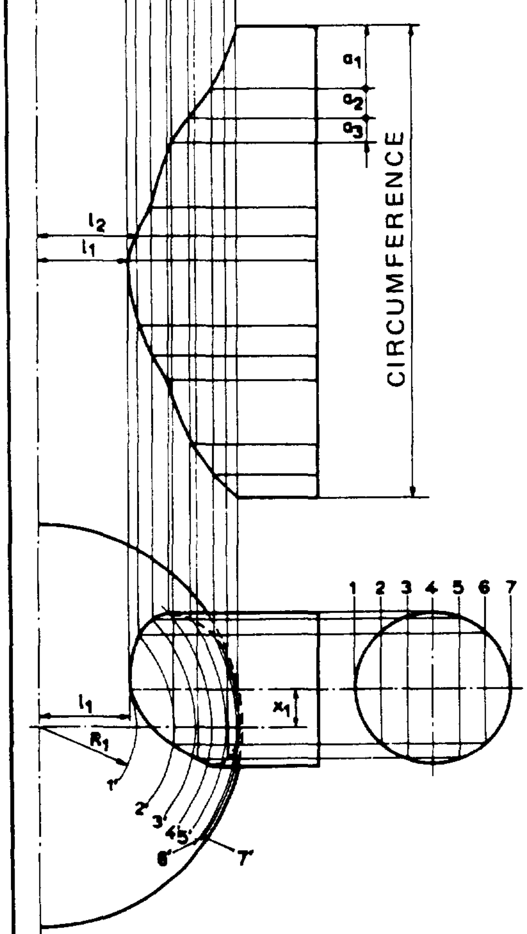
$$\text{radius, } R_6 = h_6 \tan\beta$$

$$\text{arc } a_6 = 2R_6\,\pi \times \frac{2\alpha}{360}$$

$$l_6 = \sqrt{R_6^2 - c_6^2} \quad \text{etc.}$$

INTERSECTION OF CYLINDER AND SPHERE





THE LINE OF INTERSECTION

Divide the diameter of the cylinder into equal spaces. The horizontal planes through the division points cut elements from the cylinder and circles from the sphere. The intersections of the elements with the corresponding circles are points on the curvature of intersection.

DEVELOPMENT OF THE CYLINDER

Draw a straight line of equal length to the circumference of the cylinder and divide it into the same number of parts as the cylinder. The spacing of the division points are determined by the length of arcs of the cylinder. Draw an element through each division point perpendicular to the line. Determine the length of the elements by projection or by calculation of the lengths of l_1, l_2, etc.

EXAMPLE
for calculation of length of elements.

Calculate the distances, x_1, x_2, etc.
x_1 is given; $x_2 = x_1 + r \times \sin\alpha$, etc..

$$l_1 = \sqrt{R_1^2 - x_1^2}, \quad \text{etc.}$$

$$R_1 = \sqrt{R^2 - y_1^2}, \quad \text{etc.}$$

Pipe in 2:1 Ellipsoidal Head

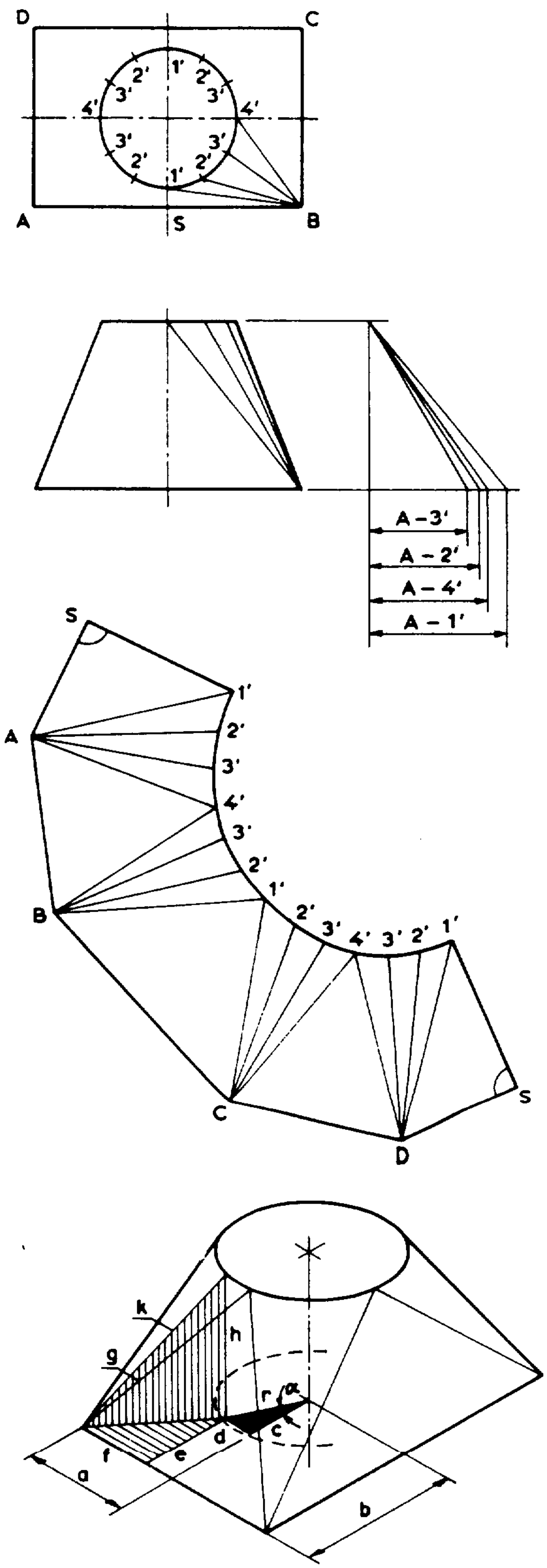
The center portion of the head is approximately a spherical segment the radius of which is equal 0.9 times the diameter of the head. When the pipe is within a limit of 0.8 times the diameter of the head the line of intersection and development of the cylinder can be found in the above described manner.

Pipe in Flanged and Dished Head

Similar way the center portion of the head within the knuckles is a spherical segment the radius of which is equal to the radius of the dish.

TRANSITION PIECES

connecting cylindrical and rectangular shapes



DEVELOPMENT

Divide the circle into equal parts and draw an element at each division point.

Find the length of each element by triangulation or by calculation. The elements are the hypotenuse of the triangles one side of which is A-1', A-2', A-3' etc. and the other side is the height of the transition piece.

Begin the development on the line 1-S and draw the right triangle 1-S-A, whose base SA is equal to half the side AD and whose hypotenuse A-1 found by triangulation or calculation. Find the points 1, 2, 3 etc. The length of 1-2, 2-3, 3-4 etc. may be taken equal to the cord of the divisions of the top circle if they are small enough for the desired accuracy. Strike an arc with 1 as center and the chord of divisions as radius. With A as center and A-2 as radius draw arc at 2. The intersection of these arcs give the point 2. The points 3, 4 etc. in the curve can be found in a similar manner.

EXAMPLE

for calculation of length of elements

$c = r \times \cos \alpha$ $\quad d = r \times \sin \alpha$

$e = b - c$ $\quad f = a - d$

$g = \sqrt{f^2 + e^2}$ $\quad k = \sqrt{g^2 + h^2}$

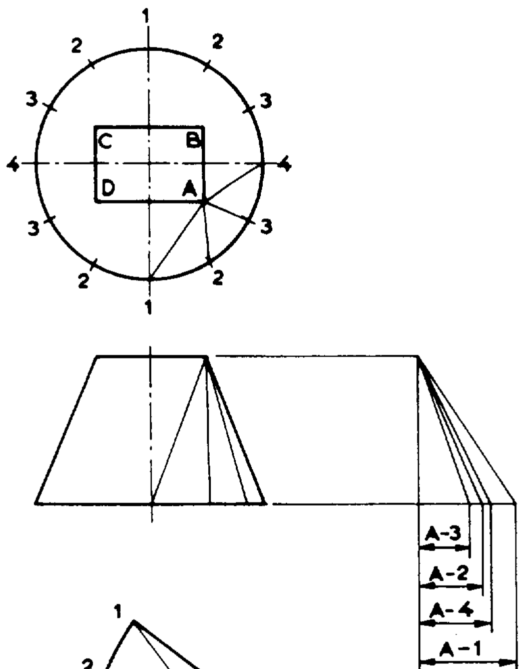
LENGTH OF ELEMENTS

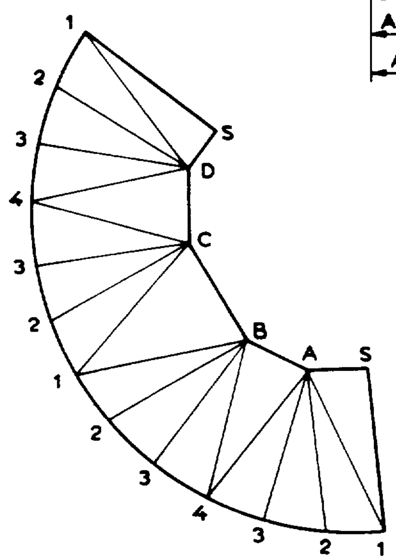
In the above described manner can be found the development for transition pieces when:

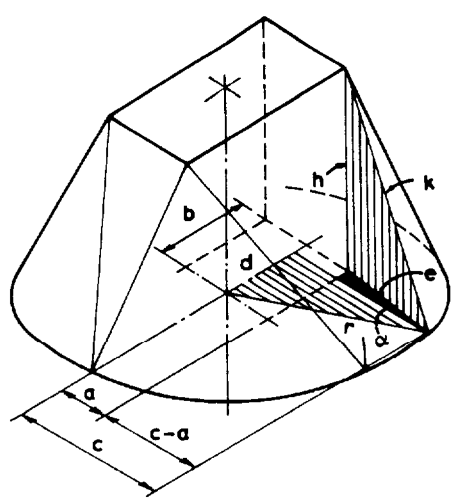
1. one end is square
2. one or both sides of the rectangle are equal to the diameter of the circle
3. the circular and rectangular planes are eccentric
4. the circular and rectangular planes are not parallel

TRANSITION PIECES

connecting cylindrical and rectangular shapes







DEVELOPMENT

Divide the circle into equal parts and draw an element at each division point.

Find the length of each element by triangulation or by calculation. The elements are the hypotenuse of the triangles one side of which is A-1′, A-2′, A-3′ etc. and the other side is the height of the transition piece.

Begin the development on the line 1-S and draw the right triangle 1-S-A, whose base SA is equal to half the side AD and whose hypotenuse A-1 found by triangulation or calculation. Find the points 1, 2, 3 etc. The length of 1-2, 2-3, 3-4 etc. may be taken equal to the cord of the divisions of the top circle if they are small enough for the desired accuracy. Strike an arc with 1 as center and the chord of divisions as radius. With A as center and A-2 as radius draw arc at 2. The intersection of these arcs give the point 2. The points 3, 4 etc. in the curve can be found in a similar manner.

EXAMPLE

for calculation of length of elements

$$c = r \times \cos \alpha \qquad d = r \times \sin \alpha$$

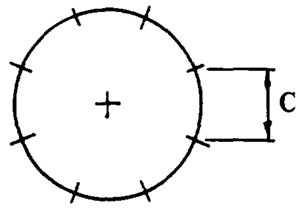
$$e = \sqrt{(b - d)^2 + (c - a)^2}$$

$$k = \sqrt{e^2 + h^2}$$

In the above described manner can be found the development for transition pieces when:

1. one end is square
2. one or both sides of the rectangle are equal to the diameter of the circle
3. the circular and rectangular planes are eccentric
4. the circular and rectangular planes are not parallel

DIVISION OF CIRCLES INTO EQUAL PARTS



The best method for division of a circle into equal parts is to find the length of the chord of a part and measure this length with the divider on the circumference. The length of the chord, C = diameter of circle × c, where c is a factor tabulated below.

EXAMPLE:

It is required to divide a 20 inch diameter circle into 8 equal spaces.

c for 8 spaces from the table: 0.38268

C = Diameter × 0.38268 = 20 × 0.38268 = 7.6536 inches

To find the length of chords for any desired number of spaces not shown in the table:

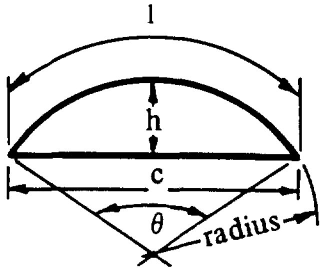
$$C = \text{Diameter} \times \sin \frac{180}{\text{number of spaces}}$$

EXAMPLE:

It is required to divide a 100 inch diameter circle into 120 equal parts

$$C = 100 \times \sin \frac{180}{120} = 100 \times \sin 1^\circ 30' = 100 \times 0.0262 = 2.62 \text{ inches}$$

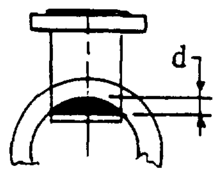
No. of Spaces	C	No. of Spaces	C	No. of Spaces	C	No. of Spaces	C
1	0.00000	26	0.12054	51	0.06153	76	0.04132
2	1.00000	27	0.11609	52	0.06038	77	0.04079
3	0.86603	28	0.11196	53	0.05924	78	0.04027
4	0.70711	29	0.10812	54	0.05814	79	0.03976
5	0.58779	30	0.10453	55	0.05709	80	0.03926
6	0.50000	31	0.10117	56	0.05607	81	0.03878
7	0.43388	32	0.09802	57	0.05509	82	0.03830
8	0.38268	33	0.09506	58	0.05414	83	0.03784
9	0.34202	34	0.09227	59	0.05322	84	0.03739
10	0.30902	35	0.08964	60	0.05234	85	0.03695
11	0.28173	36	0 08716	61	0.05148	86	0.03652
12	0.25882	37	0 08481	62	0.05065	87	0.03610
13	0.23932	38	0.08258	63	0.04985	88	0.03569
14	0.22252	39	0.08047	64	0.04907	89	0.03529
15	0.20791	40	0.07846	65	0.04831	90	0.03490
16	0.19509	41	0.07655	66	0.04758	91	0.03452
17	0.18375	42	0.07473	67	0.04687	92	0.03414
18	0.17365	43	0.07300	68	0.04618	93	0.03377
19	0.16460	44	0.07134	69	0.04551	94	0.03341
20	0.15643	45	0.06976	70	0.04487	95	0.03306
21	0.14904	46	0.06824	71	0.04423	96	0.03272
22	0.14232	47	0.06679	72	0.04362	97	0.03238
23	0.13617	48	0.06540	73	0.04302	98	0.03205
24	0.13053	49	0.06407	74	0.04244	99	0.03173
25	0.12533	50	0.06279	75	0.04188	100	0.03141



SEGMENTS OF CIRCLES FOR RADIUS = 1

Length of arc, height of segment, length of chord, and area of segment for angles from 1 to 180 degrees and radius = 1. For other radii, multiply the values of l, h and c in the table by the given radius r, and the values for areas, by r^2, the square of the radius.

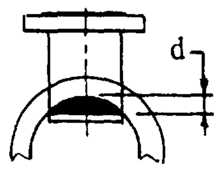
θ Deg	l	h	c	Area of Segment A	θ Deg	l	h	c	Area of Segment A	θ Deg	l	h	c	Area of Segment A
1	0.017	0.0000	0.017	0.0000	61	1.065	0.1384	1.015	0.0950	121	2.112	0.5076	1.741	0.6273
2	0.034	0.0001	0.034	0.0000	62	1.082	0.1428	1.030	0.0995	122	2.129	0.5152	1.749	0.6406
3	0.052	0.0003	0.052	0.0000	63	1.100	0.1474	1.045	0.1042	123	2.147	0.5228	1.758	0.6540
4	0.069	0.0006	0.069	0.0000	64	1.117	0.1520	1.060	0.1091	124	2.164	0.5305	1.766	0.6676
5	0.087	0.0009	0.087	0.0000	65	1.134	0.1566	1.075	0.1140	125	2.182	0.5383	1.774	0.6812
6	0.104	0.0013	0.104	0.0001	66	1.152	0.1613	1.089	0.1191	126	2.199	0.5460	1.782	0.6950
7	0.122	0.0018	0.122	0.0001	67	1.169	0.1661	1.104	0.1244	127	2.217	0.5538	1.790	0.7090
8	0.139	0.0024	0.139	0.0002	68	1.187	0.1710	1.118	0.1298	128	2.234	0.5616	1.798	0.7230
9	0.157	0.0030	0.156	0.0003	69	1.204	0.1759	1.133	0.1353	129	2.251	0.5695	1.805	0.7372
10	0.174	0.0038	0.174	0.0004	70	1.222	0.1808	1.147	0.1410	130	2.269	0.5774	1.813	0.7514
11	0.191	0.0046	0.191	0.0005	71	1.239	0.1859	1.161	0.1468	131	2.286	0.5853	1.820	0.7658
12	0.209	0.0054	0.209	0.0007	72	1.257	0.1910	1.176	0.1527	132	2.304	0.5933	1.827	0.7803
13	0.226	0.0064	0.226	0.0009	73	1.274	0.1961	1.190	0.1588	133	2.321	0.6013	1.834	0.7950
14	0.244	0.0074	0.243	0.0012	74	1.291	0.2014	1.204	0.1651	134	2.339	0.6093	1.841	0.8097
15	0.261	0.0085	0.261	0.0014	75	1.309	0.2066	1.217	0.1715	135	2.356	0.6173	1.848	0.8245
16	0.279	0.0097	0.278	0.0018	76	1.326	0.2120	1.231	0.1780	136	2.374	0.6254	1.854	0.8395
17	0.296	0.0110	0.295	0.0021	77	1.344	0.2174	1.245	0.1847	137	2.391	0.6335	1.861	0.8545
18	0.314	0.0123	0.312	0.0025	78	1.361	0.2229	1.259	0.1916	138	2.409	0.6416	1.867	0.8697
19	0.331	0.0137	0.330	0.0030	79	1.379	0.2284	1.272	0.1985	139	2.426	0.6498	1.873	0.8850
20	0.349	0.0151	0.347	0.0035	80	1.396	0.2340	1.286	0.2057	140	2.443	0.6580	1.879	0.9003
21	0.366	0.0167	0.364	0.0040	81	1.414	0.2396	1.299	0.2130	141	2.461	0.6662	1.885	0.9158
22	0.383	0.0183	0.381	0.0046	82	1.431	0.2453	1.312	0.2204	142	2.478	0.6744	1.891	0.9313
23	0.401	0.0200	0.398	0.0053	83	1.449	0.2510	1.325	0.2280	143	2.496	0.6827	1.897	0.9470
24	0.418	0.0218	0.415	0.0060	84	1.466	0.2569	1.338	0.2357	144	2.513	0.6910	1.902	0.9627
25	0.436	0.0237	0.432	0.0068	85	1.483	0.2627	1.351	0.2436	145	2.531	0.6993	1.907	0.9786
26	0.453	0.0256	0.449	0.0077	86	1.501	0.2686	1.364	0.2517	146	2.548	0.7076	1.913	0.9945
27	0.471	0.0276	0.466	0.0086	87	1.518	0.2746	1.377	0.2599	147	2.566	0.7160	1.918	1.0105
28	0.488	0.0297	0.483	0.0096	88	1.536	0.2807	1.389	0.2682	148	2.583	0.7244	1.922	1.0266
29	0.506	0.0318	0.500	0.0106	89	1.553	0.2867	1.402	0.2767	149	2.600	0.7328	1.927	1.0427
30	0.523	0.0340	0.517	0.0118	90	1.571	0.2929	1.414	0.2854	150	2.618	0.7412	1.932	1.0590
31	0.541	0.0363	0.534	0.0130	91	1.588	0.2991	1.426	0.2942	151	2.635	0.7496	1.936	1.0753
32	0.558	0.0387	0.551	0.0142	92	1.606	0.3053	1.439	0.3032	152	2.653	0.7581	1.941	1.0917
33	0.575	0.0411	0.568	0.0156	93	1.623	0.3116	1.451	0.3123	153	2.670	0.7666	1.945	1.1082
34	0.593	0.0436	0.584	0.0171	94	1.641	0.3180	1.463	0.3215	154	2.688	0.7750	1.949	1.1247
35	0.610	0.0462	0.601	0.0186	95	1.658	0.3244	1.475	0.3309	155	2.705	0.7836	1.953	1.1413
36	0.628	0.0489	0.618	0.0202	96	1.675	0.3309	1.486	0.3405	156	2.723	0.7921	1.956	1.1580
37	0.645	0.0516	0.634	0.0219	97	1.693	0.3374	1.498	0.3502	157	2.740	0.8006	1.960	1.1747
38	0.663	0.0544	0.651	0.0237	98	1.710	0.3439	1.509	0.3601	158	2.758	0.8092	1.963	1.1915
39	0.680	0.0573	0.667	0.0256	99	1.728	0.3506	1.521	0.3701	159	2.775	0.8178	1.966	1.2083
40	0.698	0.0603	0.684	0.0276	100	1.745	0.3572	1.532	0.3803	160	2.792	0.8264	1.970	1.2252
41	0.715	0.0633	0.700	0.0297	101	1.763	0.3639	1.543	0.3906	161	2.810	0.8350	1.973	1.2422
42	0.733	0.0664	0.716	0.0319	102	1.780	0.3707	1.554	0.4010	162	2.827	0.8436	1.975	1.2592
43	0.750	0.0695	0.733	0.0342	103	1.798	0.3775	1.565	0.4117	163	2.845	0.8522	1.978	1.2763
44	0.767	0.0728	0.749	0.0366	104	1.815	0.3843	1.576	0.4224	164	2.862	0.8608	1.980	1.2933
45	0.785	0.0761	0.765	0.0391	105	1.833	0.3912	1.587	0.4333	165	2.880	0.8695	1.983	1.3105
46	0.803	0.0795	0.781	0.0417	106	1.850	0.3982	1.597	0.4444	166	2.897	0.8781	1.985	1.3277
47	0.820	0.0829	0.797	0.0444	107	1.867	0.4052	1.608	0.4556	167	2.915	0.8868	1.987	1.3449
48	0.838	0.0865	0.813	0.0473	108	1.885	0.4122	1.618	0.4669	168	2.932	0.8955	1.989	1.3621
49	0.855	0.0900	0.829	0.0502	109	1.902	0.4193	1.628	0.4784	169	2.950	0.9042	1.991	1.3794
50	0.873	0.0937	0.845	0.0533	110	1.920	0.4264	1.638	0.4901	170	2.967	0.9128	1.992	1.3967
51	0.890	0.0974	0.861	0.0564	111	1.937	0.4336	1.648	0.5019	171	2.984	0.9215	1.994	1.4140
52	0.908	0.1012	0.877	0.0597	112	1.955	0.4408	1.658	0.5138	172	3.002	0.9302	1.995	1.4314
53	0.925	0.1051	0.892	0.0631	113	1.972	0.4481	1.668	0.5259	173	3.019	0.9390	1.996	1.4488
54	0.942	0.1090	0.908	0.0667	114	1.990	0.4554	1.677	0.5381	174	3.037	0.9477	1.997	1.4662
55	0.960	0.1130	0.923	0.0703	115	2.007	0.4627	1.687	0.5504	175	3.054	0.9564	1.998	1.4836
56	0.977	0.1171	0.939	0.0741	116	2.025	0.4701	1.696	0.5629	176	3.072	0.9651	1.999	1.5010
57	0.995	0.1212	0.954	0.0780	117	2.042	0.4775	1.705	0.5755	177	3.089	0.9738	1.999	1.5185
58	1.012	0.1254	0.970	0.0821	118	2.059	0.4850	1.714	0.5883	178	3.107	0.9825	2.000	1.5359
59	1.030	0.1296	0.985	0.0862	119	2.077	0.4925	1.723	0.6012	179	3.124	0.9913	2.000	1.5533
60	1.047	0.1340	1.000	0.0905	120	2.094	0.5000	1.732	0.6142	180	3.142	1.000	2.000	1.5708



DROP AT THE INTERSECTION OF SHELL AND NOZZLE

(Dimension,d Inches)

Shell I. S. Diam.	NOMINAL PIPE SIZE									
	1¼	1½	2	2½	3	3½	4	5	6	8
12	0.0625	0.0625	0.1250	0.1875	0.2500	0.3750	0.4375	0.6875	1.0000	1.8125
14	0.0625	0.0625	0.1250	0.1250	0.2500	0.3125	0.3750	0.5625	0.8125	1.5000
16	0.0625	0.0625	0.0625	0.1250	0.1875	0.2500	0.3125	0.5000	0.6875	1.2500
18	0.0625	0.0625	0.0625	0.1250	0.1875	0.2500	0.3125	0.4375	0.6250	1.1250
20	0.0625	0.0625	0.0625	0.1250	0.1250	0.1875	0.2500	0.3750	0.5625	1.0000
22		0.0625	0.0625	0.1250	0.1250	0.1875	0.2500	0.3750	0.5000	0.8750
24		0.0625	0.0625	0.0625	0.1250	0.1875	0.1875	0.3125	0.4375	0.8125
26		0.0625	0.0625	0.0625	0.1250	0.1250	0.1875	0.3125	0.4375	0.7500
28		0.0625	0.0625	0.0625	0.1250	0.1250	0.1875	0.3125	0.3750	0.6875
30			0.0625	0.0625	0.1250	0.1250	0.1875	0.2500	0.3750	0.6250
32			0.0625	0.0625	0.1250	0.1250	0.1250	0.2500	0.3750	0.5625
34			0.0625	0.0625	0.0625	0.1250	0.1250	0.2500	0.3125	0.5625
36			0.0625	0.0625	0.0625	0.1250	0.1250	0.2500	0.3125	0.5000
38			0.0625	0.0625	0.0625	0.1250	0.1250	0.1875	0.3125	0.5000
40			0.0625	0.0625	0.0625	0.1250	0.1250	0.1875	0.2500	0.5000
42			0.0625	0.0625	0.0625	0.1250	0.1250	0.1875	0.2500	0.4375
48				0.0625	0.0625	0.0625	0.1250	0.1875	0.2500	0.3750
54				0.0625	0.0625	0.0625	0.1250	0.1250	0.1875	0.3750
60				0.0625	0.0625	0.0625	0.0625	0.1250	0.1875	0.3125
66				0.0625	0.0625	0.0625	0.0625	0.1250	0.1875	0.3125
72					0.0625	0.0625	0.0625	0.1250	0.1250	0.2500
78					0.0625	0.0625	0.0625	0.1250	0.1250	0.2500
84					0.0625	0.0625	0.0625	0.1250	0.1250	0.2500
90					0.0625	0.0625	0.0625	0.0625	0.1250	0.1875
96					0.0625	0.0625	0.0625	0.0625	0.1250	0.1875
102						0.0625	0.0625	0.0625	0.1250	0.1875
108						0.0625	0.0625	0.0625	0.1250	0.1875
114						0.0625	0.0625	0.0625	0.1250	0.1875
120							0.0625	0.0625	0.0625	0.1250
126							0.0625	0.0625	0.0625	0.1250
132							0.0625	0.0625	0.0625	0.1250
138							0.0625	0.0625	0.0625	0.1250
144							0.0625	0.0625	0.0625	0.1250

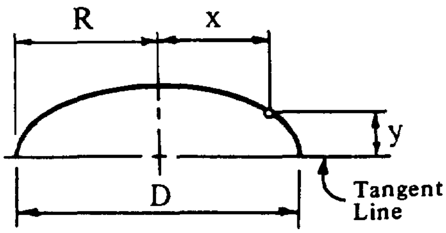


DROP AT THE INTERSECTION OF SHELL AND NOZZLE

(Dimension d, Inches)

Shell I. S. Diam.	NOMINAL PIPE SIZE									
	10	12	14	16	18	20	22	24	26	30
12	3.0625									
14	2.5000	4.1250	7.000							
16	2.0625	3.1875	4.1250	8.000						
18	1.7500	2.6250	3.3750	4.8750	9.0000					
20	1.5625	2.3125	2.8750	4.0000	5.6250	10.0000				
22	1.3750	2.0625	2 5000	3.4375	4.6875	6.4375	11.0000			
24	1.2500	1.8125	2.2500	3.0625	4.0625	5.3750	7.1875	12.0000		
26	1.1875	1.6875	2.0625	2.7500	3.6250	4.6875	6.0625	8.0000	13.0000	
28	1.0625	1.5000	1.8750	2.5000	3.2500	4.1875	5.3125	6.8125	8.9125	
30	1.0000	1.4375	1.7500	2.3125	3.0000	3.8125	4.8125	6.0000	7.5000	15.0000
32	0.9375	1.3125	1.6250	2.1250	2.7500	3.5000	4.3750	5.4375	6.6875	10.4375
34	0.8750	1.2500	1.5000	2.0000	2.5625	3.2500	4.0625	4.8125	6.0625	9.0000
36	0.8125	0.8125	1.4375	1.8750	2.4375	3.0625	3.7500	4.5625	5.5625	8.1250
38	0.7500	1.1250	1.3125	1.7500	2.2500	2.8750	3.5000	4.2500	5.1250	7.3125
40	0.7500	1.0625	1.2500	1.6875	2.1250	2.6875	3.3125	4.0000	4.8125	6.7500
42	0.6875	1.0000	1.1250	1.5675	2.0000	2.5625	3.1250	3.7500	4.5000	6.3125
48	0.3125	0.875	1.0625	1.1875	1.7500	2.1875	2.6875	3.1875	3.8125	5.2500
54	0.5625	0.7500	0.9375	1.1875	1.5625	1.9375	2.3125	2.8125	3.3125	4.5625
60	0.4375	0.6875	0.8125	1.0625	1.3750	1.6875	2.1250	2.5000	2.9375	4.0000
66	0.4375	0.6250	0.7500	1.0000	1.2500	1.5625	1.8750	2.2500	2.6875	3.6250
72	0.3750	0.5625	0.6875	0.8750	1.1250	1.4375	1.7500	2.0625	2.4375	3.2500
78	0.3750	0.5000	0.6250	0.8125	1.0625	1.3125	1.5625	1.8750	2.2500	3.0000
84	0.3750	0.5000	0.5625	0.7500	1.0000	1.1875	1.4375	1.7500	2.0625	2.7500
90	0.3125	0.4375	0.5625	0.6875	0.4375	1.1250	1.3750	1.8750	1.9375	2.5625
96	0.3125	0.4375	0.5000	0.6875	0.8750	1.0625	1.2500	1.5000	1.8125	2.3750
102	0.3125	0.3750	0.5000	0.6250	0.8125	1.0000	1.1875	1.4375	1.6875	2.2500
108	0.2500	0.3750	0.4375	0.6250	0.7500	0.9375	1.1250	1.3750	1.5625	2.1250
114	0.2500	0.1875	0.4375	0.5625	0.6875	0.8750	1.0625	1.2500	1.5000	2.0000
120	0.2500	0.1875	0.4375	0.5625	0.6875	0.8125	1.0000	1.1875	1.4375	1.8750
126	0.2500	0.3125	0.3750	0.5000	0.6250	0.8125	0.9375	1.1250	1.3750	1.8125
132	0.2500	0.3125	0.3750	0.5000	0.6250	0.7500	0.9375	1.1250	1.3125	1.7500
138	0.1825	0.3125	0.3750	0.4375	0.5625	0.7500	0.8750	1.0625	1.2500	1.6250
144	0.1825	0.3125	0.3125	0.4375	0.5625	0.6875	0.8750	1.0000	1.1875	1.5625

TABLE FOR LOCATING POINTS ON 2:1 ELLIPSOIDAL HEADS



From these tables the dimension y can be found if the diameter, D and dimension x are known, or x can be determined if D and y are given. The tables based on the formula: $y = \frac{1}{2}\sqrt{R^2 - x^2}$, where R = the radius of head.

D = 12

x	y
1	2.9580
2	2.8284
3	2.5980
4	2.2360
5	1.6583
6	0

D = 14

x	y
1	3.4641
2	3.3541
3	3.1622
4	2.8722
5	2.4494
6	1.8027
7	0

D = 16

x	y
1	3.9686
2	3.8729
3	3.7081
4	3.4641
5	3.1225
6	2.6457
7	1.9364
8	0

D = 18

x	y
1	4.4721
2	4.3878
3	4.2426
4	4.0311
5	3.7416
6	3.3541
7	2.8284
8	2.0615
9	0

D = 20

x	y
1	4.9749
2	4.8989
3	4.7697
4	4.5825
5	4.3301
6	4
7	3.5707
8	3
9	2.1794
10	0

D = 22

x	y
1	5.4772
2	5.4083
3	5.2915
4	5.1234
5	4.8989
6	4.6097
7	4.2426
8	3.7749
9	3.1622
10	2.2912
11	0

D = 24

x	y
1	5.9791
2	5.9160
3	5.8094
4	5.6568
5	5.4543
6	5.1961
7	4.8734
8	4.4721
9	3.9686
10	3.3166
11	2.3979
12	0

D = 26

x	y
1	6.4807
2	6.4226
3	6.3245
4	6.1846
5	6
6	5.7662
7	5.4772
8	5.1234
9	4.6904
10	4.1533
11	3.4641
12	2.5
13	0

D = 28

x	y
1	6.9821
2	6.9282
3	6.8374
4	6.7082
5	6.5383
6	6.3245
7	6.0621
8	5.7445
9	5.3619
10	4.8989
11	4.3301
12	3.6055
13	2.5980
14	0

D = 30

x	y
1	7.4833
2	7.4330
3	7.3484
4	7.2284
5	7.0710
6	6.8738
7	6.6332
8	6.3442
9	6
10	5.5901
11	5.0990
12	4.5
13	3.7416
14	2.6925
15	0

D = 32

x	y
1	7.9843
2	7.9372
3	7.8581
4	7.7459
5	7.5993
6	7.4162
7	7.1937
8	6.9282
9	6.6143
10	6.245
11	5.8094
12	5.2915
13	4.6636
14	3.8729
15	2.7838
16	0

D = 34

x	y
1	8.4852
2	8.4409
3	8.3666
4	8.2613
5	8.1240
6	7.9529
7	7.7459
8	7.5
9	7.2111
10	6.8738
11	6.4807
12	6.0208
13	5.4772
14	4.8218
15	4
16	2.8722
17	0

D = 36

x	y
1	8.9861
2	8.9442
3	8.8741
4	8.7749
5	8.6458
6	8.4852
7	8.2915
8	8.0622
9	7.7942
10	7.4833
11	7.1239
12	6.7082
13	6.2249
14	5.6568
15	4.9749
16	4.1231
17	2.9580
18	0

D = 38

x	y
1	9.4868
2	9.4472
3	9.3808
4	9.2870
5	9.1651

TABLE FOR LOCATING POINTS ON 2:1 ELLIPSOIDAL HEADS (Cont.)

D = 38

x	y
6	9.0138
7	8.8317
8	8.6168
9	8.3666
10	8.0777
11	7.7459
12	7.3654
13	6.9282
14	6.4226
15	5.8309
16	5.1234
17	4.2426
18	3.0413
19	0

D = 40

x	y
1	9.9874
2	9.9498
3	9.8868
4	9.7979
5	9.6824
6	9.5393
7	9.3675
8	9.1651
9	8.9302
10	8.6602
11	8.3516
12	8
13	7.5993
14	7.1414
15	6.6143
16	6
17	5.2678
18	4.3589
19	3.1225
20	0

D = 42

x	y
1	10.4881
2	10.4523
3	10.3923
4	10.3078
5	10.198
6	10.0623
7	9.8994
8	9.7082
9	9.4868
10	9.2330
11	8.9442
12	8.6168
13	8.2462
14	7.8262
15	7.3484
16	6.8007
17	6.1644
18	5.4083
19	4.4721
20	3.2015
21	0

D = 48

x	y
1	11.9896
2	11.9583
3	11.9059
4	11.8322
5	11.7367
6	11.619
7	11.4782
8	11.3137
9	11.1243
10	10.9087
11	10.6654
12	10.3923
13	10.0871
14	9.7467
15	9.3675
16	8.9442
17	8.4705
18	7.9372
19	7.3314
20	6.6332
21	5.8094
22	4.7958
23	3.4278
24	0

D = 54

x	y
1	13.4907
2	13.4629
3	13.4164
4	13.351
5	13.2665
6	13.1624
7	13.0384
8	12.8939
9	12.7279
10	12.5399
11	12.3288
12	12.0934
13	11.8322
14	11.5434
15	11.225
16	10.8743
17	10.4881
18	10.0623
19	9.5916
20	9.0691
21	8.4852
22	7.8264
23	7.0710
24	6.1846
25	5.0990
26	3.6400
27	0

D = 60

x	y
1	14.9917
2	14.9666
3	14.9248
4	14.8661
5	14.7902
6	14.6969
7	14.586
8	14.4568
9	14.3091
10	14.1421
11	13.9553
12	13.7477
13	13.5185
14	13.2665
15	12.9904
16	12.6886
17	12.3592
18	12
19	11.6082
20	11.1803
21	10.7121
22	10.198
23	9.6306
24	9
25	8.2915
26	7.4833
27	6.5383
28	5.3851
29	3.8405
30	0

D = 66

x	y
1	16.4924
2	16.4697
3	16.4317
4	16.3783
5	16.3095
6	16.225
7	16.1245
8	16.0078
9	15.8745
10	15.7242
11	15.5563
12	15.3704
13	15.1658
14	14.9416
15	14.6969
16	14.4309
17	14.1421
18	13.8293
19	13.4907
20	13.1244
21	12.7279
22	12.2984
23	11.8322
24	11.3248
25	10.7703
26	10.1612
27	9.4868
28	8.7321
29	7.8740
30	6.8738
31	5.6558
32	4.0311
33	0

D = 72

x	y
1	17.9931
2	17.9722
3	17.9374
4	17.8885
5	17.8255
6	17.7482
7	17.6564
8	17.5499
9	17.4284
10	17.2916
11	17.1391
12	16.9706
13	16.7854
14	16.5831
15	16.3631
16	16.1245
17	15.8666
18	15.5885
19	15.2889
20	14.9666
21	14.6202
22	14.2478
23	13.8474
24	13.4164
25	12.9518
26	12.4499
27	11.9059
28	11.3137
29	10.6654
30	9.9498
31	9.1515
32	8.2462
33	7.1937
34	5.9160
35	4.2130
36	0

D = 78

x	y
1	19.4936
2	19.4743
3	19.4422
4	19.3972
5	19.3391
6	19.2678
7	19.1833
8	19.0853
9	18.9737
10	18.8481
11	18.7083

TABLE FOR LOCATING POINTS ON 2:1 ELLIPSOIDAL HEADS (Cont.)

D=78

12	18.554
13	18.3848
14	18.2003
15	18
16	17.7834
17	17.5499
18	17.2988
19	17.0294
20	16.7407
21	16.4317
22	16.1012
23	15.748
24	15.3704
25	14.9666
26	14.5344
27	14.0712
28	13.5739
29	13.0384
30	12.4599
31	11.8322
32	11.1467
33	10.3923
34	9.5524
35	8.6023
36	7.5
37	6.1644
38	4.3874
39	0

D = 84

x	y
1	20.994
2	20.9762
3	20.9464
4	20.9045
5	20.8507
6	20.7846
7	20.7063
8	20.6155
9	20.5122
10	20.3961
11	20.267
12	20.1246
13	19.9687
14	19.799
15	19.615
16	19.4165
17	19.2029
18	18.9737
19	18.7283
20	18.4662
21	18.1865
22	17.8885
23	17.5713
24	17.2337
25	16.8745
26	16.4924
27	16.0857
28	15.6525
29	15.1905
30	14.6969
31	14.1686
32	13.6015
33	12.9904
34	12.3288
35	11.6082
36	10.8167
37	9.9373
38	8.9442
39	7.7942
40	6.4031
41	4.5552
42	0

D = 90

x	y
1	22.4944
2	22.4778
3	22.4499
4	22.4109
5	22.3607
6	22.2991
7	22.2261
8	22.1416
9	22.0454
10	21.9374
11	21.8174
12	21.6852
13	21.5407
14	21.3834
15	21.2132
16	21.0297
17	20.8327
18	20.6216
19	20.3961
20	20.1556
21	19.8997
22	19.6278
23	19.3391
24	19.0329
25	18.7083
26	18.3644
27	18
28	17.6139
29	17.2047
30	16.7705
31	16.3095
32	15.8193
33	15.2971
34	14.7394
35	14.1421
36	13.5
37	12.8062
38	12.052
39	11.225
40	10.3078
41	9.2736
42	8.0777
43	6.6332
44	4.7169
45	0

D = 96

x	y
1	23.9948
2	23.9792
3	23.9531
4	23.9165
5	23.8694
6	23.8118
7	23.7434
8	23.6643
9	23.5744
10	23.4734
11	23.3613
12	23.2379
13	23.103
14	22.9565
15	22.798
16	22.6274
17	22.4444
18	22.2486
19	22.0397
20	21.8174
21	21.5812
22	21.3307
23	21.0654
24	20.7846
25	20.4878
26	20.1742
27	19.8431
28	19.4936
29	19.1246
30	18.735
31	18.3235
32	17.8885
33	17.4284
34	16.9411
35	16.4241
36	15.8745
37	15.2889
38	14.6629
39	13.9911
40	13.2665
41	12.48
42	11.619
43	10.6654
44	9.5916
45	8.3516
46	6.8556
47	4.8734
48	0

D = 108

x	y
1	26.9954
2	26.9815
3	26.9583
4	26.9258
5	26.884
6	26.8328
7	26.7722
8	26.7021
9	26.6224
10	26.533
11	26.4339
12	26.3249
13	26.2059
14	26.0768
15	25.9374
16	25.7876
17	25.6271
18	25.4558
19	25.2735
20	25.0799
21	24.8747
22	24.6577
23	24.4285
24	24.1868
25	23.9322
26	23.6643
27	23.3827
28	23.0868
29	22.7761
30	22.4499
31	22.1077
32	21.7486
33	21.3717
34	20.9762
35	20.5609
36	20.1246
37	19.666
38	19.1833
39	18.6748
40	18.1384
41	17.5713
42	16.9706
43	16.3325
44	15.6525
45	14.9248
46	14.1421
47	13.2947
48	12.3693
49	11.3468
50	10.198
51	8.8741
52	7.2801
53	5.1720
54	0

D = 120

x	y
1	29.9958
2	29.9833
3	29.9625
4	29.9333
5	29.8957
6	29.8496
7	29.7951

TABLE FOR LOCATING POINTS ON 2:1 ELLIPOIDAL HEADS (Cont.)

D=120	
8	29.7321
9	29.6606
10	29.5804
11	29.4915
12	29.3939
13	29.2874
14	29.1719
15	29.0474
16	28.9137
17	28.7706
18	28.6182
19	28.4561
20	28.2843
21	28.1025
22	27.9106
23	27.7083
24	27.4955
25	27.2718
26	27.037
27	26.7909
28	26.533
29	26.2631
30	25.9808
31	25.6856
32	25.3772
33	25.0549
34	24.7184
35	24.367
36	24
37	23.6167
38	23.2164
39	22.798
40	22.3607
41	21.9032
42	21.4243
43	20.9225
44	20.3961
45	19.8431
46	19.2614
47	18.6481
48	18
49	17.3133
50	16.5831
51	15.8035
52	14.9666
53	14.0624
54	13.0767
55	10.9896
56	10.7703
57	9.3675
58	7.6811
59	5.4543
60	0

D = 132	
x	y
1	32.9962
2	32.9848
3	32.9659
4	32.9393
5	32.9052
6	32.8634
7	32.8139
8	32.7567
9	32.6917
10	32.619
11	32.5384
12	32.45
13	32.3535
14	32.249
15	32.1364
16	32.0156
17	31.8865
18	31.749
19	31.603
20	31.4484
21	31.285
22	31.1127
23	30.9314
24	30.7409
25	30.541
26	30.3315
27	30.1123
28	29.8831
29	29.6437
30	29.3939
31	29.1333
32	28.8617
33	28.5788
34	28.2843
35	27.9777
36	27.6586
37	27.3267
38	26.9815
39	26.6224
40	26.2488
41	25.8602
42	25.4558
43	25.035
44	24.5967
45	24.1402
46	23.6643
47	23.1679
48	22.6495
49	22.1077
50	21.5407
51	20.9464
52	20.3224
53	19.666
54	18.9737
55	18.2414
56	17.4642
57	16.6358
58	15.748
59	14.7902
60	13.7477
61	12.5996
62	11.3137
63	9.8361
64	8.0622
65	5.7227
66	0

D = 144	
x	y
1	35.9965
2	35.9861
3	35.9687
4	35.9444
5	35.9131
6	35.8748
7	35.8295
8	35.7771
9	35.7176
10	35.6511
11	35.5774
12	35.4965
13	35.4083
14	35.3129
15	35.2101
16	35.0999
17	34.9821
18	34.8569
19	34.7239
20	34.5832
21	34.4347
22	34.2783
23	34.1138
24	33.9411
25	33.7602
26	33.5708
27	33.3729
28	33.1662
29	32.9507
30	32.7261
31	32.4923
32	32.249
33	31.9961
34	31.7333
35	31.4603
36	31.1769
37	30.8828
38	30.5778
39	30.2614
40	29.9333
41	29.5931
42	29.2404
43	28.8747
44	28.4956
45	28.1025
46	27.6948
47	27.2718
48	26.8328
49	26.3771
50	25.9037
51	25.4116
52	24.8998
53	24.367
54	23.8118
55	23.2325
56	22.6274
57	21.9943
58	21.3307
59	20.6337
60	19.8997
61	19.1246
62	18.303
63	17.4284
64	16.4924
65	15.4839
66	14.3875
67	13.1814
68	11.8322
69	10.2835
70	8.4261
71	5.9791
72	0

NOTE:

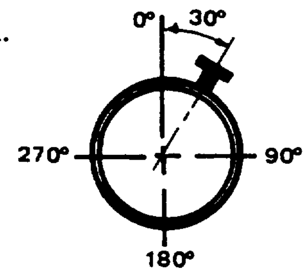
The curvature of an ellipsoidal head either inside or outside is a true ellipse. The parallel curve of the opposite side is not ellipse and the data of this table are not applicable to locate points on that geometrically undetermined curve. (especially in the case of heavy walled heads)

LENGTH OF ARCS

1. These tables are for locating points on pipes and shells by measuring the length of arcs.
2. The length of arcs are computed for the most commonly used pipe-sizes and vessel diameters.
3. The length of arcs for any diameters and any degrees, not shown in the table, can be obtained easily using the values given for diam. 1 or degree 1.
4. All dimensions are in inches.

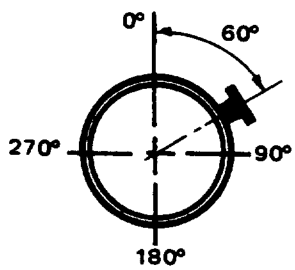
EXAMPLES

A.



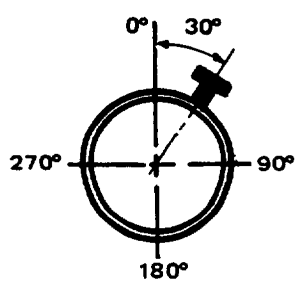
O.D. = 30"
Nozzle located @ 30°
From table the length of
arc = 7.8438 in.

B.



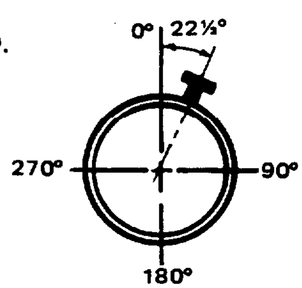
O.D. = 30"
Nozzle located @ 60°
The arc to be measured from the closest centerline
The nozzle is @ 30° from the 90° ℄. The length of this arc: 7.8438 in.

C.



I.D. = 30" Wall thickness = 3/8", than
O.D. = 30 ¾"
Nozzle located @ 30°
From table length of 30° arc for
dia. 1 = 0.26180
0.26180 x 30.75 = 8.0503 in.

D.



O.D. = 30"
Nozzle located @ 22½°
From table length of 1° arc on
30" O.D. Pipe = 0.26180
0.26180 x 22.5 = 5.890 in.

LENGTH OF ARCS

	Diam.	1	5	10	15	20	25	30
		DEGREES						
	1	0.00873	0.04363	0.08727	0.13090	0.17453	0.21817	0.26180
NOMINAL PIPE SIZE	1	0.01148	0.0625	0.1250	0.1875	0.2188	0.2813	0.3438
	1½	0.01658	0.0938	0.1563	0.2500	0.3438	0.4063	0.5000
	2	0.02073	0.0938	0.2188	0.3125	0.4063	0.5313	0.6250
	2½	0.02509	0.1250	0.2500	0.3750	0.5000	0.6250	0.7500
	3	0.03054	0.1563	0.3125	0.4688	0.6250	0.7500	0.9063
	3½	0.03491	0.1875	0.3438	0.5313	0.6875	0.8750	1.0625
	4	0.03927	0.1875	0.4063	0.5938	0.7813	0.9688	1.1875
	5	0.04855	0.2500	0.5000	0.7188	0.9688	1.2188	1.4688
	6	0.05781	0.2813	0.5938	0.8750	1.1563	1.4375	1.7500
	8	0.07527	0.3750	0.7500	1.1250	1.5000	1.8750	2.2500
	10	0.09381	0.4688	0.9375	1.4063	1.8750	2.3488	2.8125
	12	0.11126	0.5625	1.1250	1.6563	2.2188	2.7813	3.3438
DIAMETER OF SHELL INCHES	12	0.10472	0.5313	1.0625	1.5625	2.0938	2.6250	3.1563
	14	0.12217	0.6250	1.2188	1.8438	2.4375	3.0625	3.6563
	16	0.13963	0.6875	1.4063	2.0938	2.7813	3.5000	4.1875
	18	0.15708	0.7813	1.5625	2.3438	3.1563	3.9375	4.7188
	20	0.17453	0.8750	1.7500	2.6250	3.5000	4.3750	5.2500
	22	0.19199	0.9688	1.9063	2.8750	3.8438	4.8125	5.7500
	24	0.20944	1.0625	2.0938	3.1563	4.1875	5.2500	6.2813
	26	0.22689	1.1250	2.2813	3.4063	4.5313	5.6875	6.8125
	28	0.24435	1.2188	2.4375	3.6563	4.8750	6.0938	7.3488
	30	0.26180	1.3125	2.6250	3.9375	5.2500	6.5313	7.8438
	32	0.27925	1.6172	2.7813	4.1875	5.5938	6.9688	8.3750
	34	0.29671	1.6224	2.9688	4.4375	5.9375	7.4063	8.9063
	36	0.31416	1.5625	3.1563	4.7188	6.2813	7.8438	9.4375
	38	0.33161	1.6563	3.3125	4.9688	6.6250	8.2813	9.9375
	40	0.34907	1.7500	3.5000	5.2500	6.9688	8.7188	10.4688
	42	0.36652	1.8438	3.6563	5.5000	7.3438	9.1563	11.0000
	48	0.41888	2.0938	4.1875	6.2813	8.3750	10.4688	12.5625
	54	0.47124	2.3438	4.7188	7.0625	9.4375	11.7813	14.1250
	60	0.57360	2.6250	5.2500	7.8438	10.4688	13.0938	15.7188
	66	0.57596	2.8750	5.7500	8.6250	11.5313	14.4063	17.2813
	72	0.62832	3.1250	6.2813	9.4375	12.5625	15.7188	18.8438
	78	0.68068	3.4063	6.8125	10.2188	13.6250	17.0313	20.4063
	84	0.73304	3.6563	7.3438	11.0000	14.6563	18.3125	22.0000
	90	0.78540	3.9375	7.8438	11.7813	15.7188	19.6250	23.5625
	96	0.83776	4.1875	8.3750	12.5625	16.7500	20.9375	25.1250
	102	0.89012	4.4375	8.9063	13.3438	17.8125	22.2500	26.7188
	108	0.94248	4.7188	9.4375	14.1250	18.8438	23.5625	28.9063
	114	0.99484	4.9688	9.9375	14.9375	19.9063	24.8750	29.8438
	120	1.04720	5.2500	10.4688	15.7188	20.9375	26.1875	31.5313
	126	1.09956	5.5000	11.0000	16.5000	22.0000	27.5000	33.0000
	132	1.15192	5.7500	11.5313	17.2813	23.0313	28.8125	34.5625
	138	1.20428	6.0313	12.0313	18.0625	24.0938	30.0938	36.1250
	144	1.25664	6.2813	12.5625	18.8438	25.1250	31.4063	37.6875

LENGTH OF ARCS

	Diam.	DEGREES						
		35	40	45	90	180	270	360
	1	0.30543	0.34907	0.39270	0.78540	1.57080	2.35619	3.14159
NOMINAL PIPE SIZE	1	0.4063	0.4688	0.5313	1.0313	2.0625	3.0938	4.1250
	1½	0.5938	0.6563	0.7500	1.5000	3.0000	4.4688	5.9688
	2	0.7188	0.8438	0.9375	1.8750	3.7188	5.5938	7.4688
	2½	0.8750	1.0000	1.1250	2.2500	4.5313	6.7813	9.0313
	3	1.0625	1.2188	1.3750	2.7500	5.5000	8.2500	11.0000
	3½	1.2188	1.4003	1.5625	3.1563	6.2813	9.4375	12.5625
	4	1.3750	1.5625	1.7813	3.5313	7.0625	10.5938	14.1250
	5	1.6875	1.9375	2.1875	4.3750	8.7500	13.0938	17.4688
	6	2.0313	2.3125	2.5938	5.2188	10.4063	15.6250	20.8125
	8	2.6250	3.0938	3.3750	6.7813	13.5625	20.3125	27.0938
	10	3.2813	3.7500	4.2188	8.4375	16.8750	25.3438	33.7813
	12	3.9063	4.4375	5.0000	10.0000	20.0313	30.0313	40.0625
DIAMETER OF SHELL INCHES	12	3.6563	4.1875	4.7188	9.4375	18.8438	29.2813	37.0625
	14	4.2813	4.8750	5.5000	11.0000	22.0000	33.0000	43.9688
	16	4.8750	5.5938	6.2813	12.5625	25.1250	37.6875	50.2500
	18	5.5000	6.2813	7.0313	14.1250	28.2813	42.4063	56.5625
	20	6.0938	6.9688	7.8438	15.7188	31.4063	47.1250	62.8438
	22	6.7188	7.6875	8.6563	17.2813	34.5625	51.8438	69.1250
	24	7.3438	8.3750	9.4375	18.8438	37.6875	56.5625	75.4063
	26	7.9375	9.0625	10.2188	20.4063	40.8438	61.2500	81.6875
	28	8.5625	9.7813	11.0000	22.0000	43.9688	65.9688	87.9688
	30	9.1563	10.4688	11.7813	23.5625	47.1250	70.6875	94.2500
	32	9.7813	11.1563	12.5625	25.1250	50.2500	75.4063	100.5313
	34	10.3750	11.8750	13.3438	26.7188	53.4060	80.1250	106.8125
	36	11.0000	12.5625	14.1250	28.2813	56.5625	84.8125	113.0938
	38	11.5938	13.2500	14.9375	29.8438	59.6875	89.5313	119.3750
	40	12.2188	13.9688	15.7188	31.4063	62.8438	94.2500	125.6563
	42	12.8438	14.6563	16.5000	33.0000	65.9688	98.9688	131.9375
	48	14.6563	16.7500	18.8438	37.6875	75.4063	113.0938	150.7813
	54	16.5000	18.8438	21.2188	42.4063	84.8125	127.2500	169.6563
	60	18.3125	20.9375	23.5625	47.1250	94.2500	141.3750	188.5000
	66	20.1563	23.0313	25.9065	51.8438	103.6875	155.5000	207.3458
	72	22.0000	25.1250	28.2813	56.5625	113.0938	169.6563	226.1875
	78	23.8125	27.2188	30.6250	61.2500	122.5313	183.7813	245.0313
	84	25.6563	29.3125	33.0000	65.9688	131.9375	197.9063	263.9063
	90	27.5000	31.4063	35.2438	70.6875	141.3750	212.0625	282.7500
	96	29.3125	33.5000	37.6875	75.4063	150.7813	226.1875	301.5938
	102	31.1563	35.5938	40.1250	80.1250	160.2188	240.3438	320.4375
	108	33.0000	37.6875	42.4063	84.8125	169.6563	354.4688	339.2813
	114	34.8125	39.7813	49.7813	89.5313	179.0625	268.5938	358.1250
	120	36.6563	41.8750	47.1250	94.2500	188.5000	282.7500	377.0000
	126	38.5000	43.9688	49.4688	98.9688	197.9063	296.8750	395.8438
	132	40.3125	46.0625	51.8438	103.6563	207.3438	311.0313	414.6875
	138	42.1563	48.1563	54.1875	108.3750	216.7813	325.1563	433.5313
	144	43.9688	50.2500	56.5625	113.0938	226.1875	339.2813	452.3750

CIRCUMFERENCES AND AREAS OF CIRCLES

Dia.	Circum.	Area
1/64	.04909	.00019
1/32	.09818	.00077
3/64	.14726	.00173
1/16	.19635	.00307
3/32	.29452	.00690
1/8	.39270	.01227
5/32	.49087	.01917
3/16	.58905	.02761
7/32	.68722	.03758
1/4	.78540	.04909
9/32	.88357	.06213
5/16	.98175	.07670
11/32	1.0799	.09281
3/8	1.1781	.11045
13/32	1.2763	.12962
7/16	1.3744	.15033
15/32	1.4726	.17257
1/2	1.5708	.19635
17/32	1.6690	.22166
9/16	1.7671	.24850
19/32	1.8653	.27688
5/8	1.9635	.30680
21/32	2.0617	.33824
11/16	2.1598	.37122
23/32	2.2580	.40574
3/4	2.3562	.44179
25/32	2.4544	.47937
13/16	2.5525	.51849
27/32	2.6507	.55914
7/8	2.7489	.60132
29/32	2.8471	.64504
15/16	2.9452	.69029
31/32	3.0434	.73708
1.	3.1416	.7854
1/16	3.3379	.8866
1/8	3.5343	.9940
3/16	3.7306	1.1075
1/4	3.9270	1.2272
5/16	4.1233	1.3530
3/8	4.3197	1.4849
7/16	4.5160	1.6230
1/2	4.7124	1.7671
9/16	4.9087	1.9175
5/8	5.1051	2.0739
11/16	5.3014	2.2365
3/4	5.4978	2.4053
13/16	5.6941	2.5802
7/8	5.8905	2.7612
15/16	6.0868	2.9483

Dia.	Circum.	Area
2.	6.2832	3.1416
1/16	6.4795	3.3410
1/8	6.6759	3.5466
3/16	6.8722	3.7583
1/4	7.0686	3.9761
5/16	7.2649	4.2000
3/8	7.4613	4.4301
7/16	7.6576	4.6664
1/2	7.8540	4.9087
9/16	8.0503	5.1572
5/8	8.2467	5.4119
11/16	8.4430	5.6727
3/4	8.6394	5.9396
13/16	8.8357	6.2126
7/8	9.0321	6.4918
15/16	9.2284	6.7771
3.	9.4248	7.0686
1/16	9.6211	7.3662
1/8	9.8175	7.6699
3/16	10.014	7.9798
1/4	10.210	8.2958
5/16	10.407	8.6179
3/8	10.603	8.9462
7/16	10.799	9.2806
1/2	10.996	9.6211
9/16	11.192	9.9678
5/8	11.388	10.321
11/16	11.585	10.680
3/4	11.781	11.045
13/16	11.977	11.416
7/8	12.174	11.793
15/16	12.370	12.177
4.	12.566	12.566
1/16	12.763	12.962
1/8	12.959	13.364
3/16	13.155	13.772
1/4	13.352	14.186
5/16	13.548	14.607
3/8	13.744	15.033
7/16	13.941	15.466
1/2	14.137	15.904
9/16	14.334	16.349
5/8	14.530	16.800
11/16	14.726	17.257
3/4	14.923	17.728
13/16	15.119	18.190
7/8	15.315	18.665
15/16	15.512	19.147
5.	15.708	19.635
1/16	15.904	20.129
1/8	16.101	20.629

Dia.	Circum.	Area
3/16	16.297	21.135
1/4	16.493	21.648
5/16	16.690	22.166
3/8	16.886	22.691
7/16	17.082	23.221
1/2	17.279	23.758
9/16	17.475	24.301
5/8	17.671	24.850
11/16	17.868	25.406
3/4	18.064	25.967
13/16	18.261	26.535
7/8	18.457	27.109
15/16	18.653	27.688
6.	18.850	28.274
1/8	19.242	29.465
1/4	19.635	30.680
3/8	20.028	31.919
1/2	20.420	33.183
5/8	20.813	34.472
3/4	21.206	35.785
7/8	21.598	37.122
7.	21.991	38.485
1/8	22.384	39.871
1/4	22.776	41.282
3/8	23.169	42.718
1/2	23.562	44.179
5/8	23.955	45.664
3/4	24.347	47.173
7/8	24.740	48.707
8.	25.133	50.265
1/8	25.525	51.849
1/4	25.918	53.456
3/8	26.311	55.088
1/2	26.704	56.745
5/8	27.096	58.426
3/4	27.489	60.132
7/8	27.882	61.862
9.	28.274	63.617
1/8	28.667	65.397
1/4	29.060	67.201
3/8	29.452	69.029
1/2	29.845	70.882
5/8	30.238	72.760
3/4	30.631	74.662
7/8	31.023	76.589
10.	31.416	78.540
1/8	31.809	80.516
1/4	32.201	82.516

CIRCUMFERENCES AND AREAS OF CIRCLES *(continued)*

Dia.	Circum.	Area
10. 3/8	32.594	84.541
1/2	32.987	86.590
5/8	33.379	88.664
3/4	33.772	90.763
7/8	34.165	92.886
11.	34.558	95.033
1/8	34.950	97.205
1/4	35.343	99.402
3/8	35.736	101.62
1/2	36.128	103.87
5/8	36.521	106.14
3/4	36.914	108.43
7/8	37.306	110.75
12.	37.699	113.10
1/8	38.092	115.47
1/4	38.485	117.86
3/8	38.877	120.28
1/2	39.270	122.72
5/8	39.663	125.19
3/4	40.055	127.68
7/8	40.448	130.19
13.	40.841	132.73
1/8	41.233	135.30
1/4	41.626	137.89
3/8	42.019	140.50
1/2	42.412	143.14
5/8	42.804	145.80
3/4	43.197	148.49
7/8	43.590	151.20
14.	43.982	153.94
1/8	44.375	156.70
1/4	44.768	159.48
3/8	45.160	162.30
1/2	45.553	165.13
5/8	45.946	167.99
3/4	46.338	170.87
7/8	46.731	173.78
15.	47.124	176.71
1/8	47.517	179.67
1/4	47.909	182.65
3/8	48.302	185.66
1/2	48.695	188.69
5/8	49.087	191.75
3/4	49.480	194.83
7/8	49.873	197.93
16.	50.265	201.06
1/8	50.658	204.22

Dia.	Circum.	Area
1/4	51.051	207.39
3/8	51.444	210.60
1/2	51.836	213.82
5/8	52.229	217.08
3/4	52.622	220.35
7/8	53.014	223.65
17.	53.407	226.98
1/8	53.800	230.33
1/4	54.192	233.71
3/8	54.585	237.10
1/2	54.978	240.53
5/8	55.371	243.98
3/4	55.763	247.45
7/8	56.156	250.95
18.	56.549	254.47
1/8	56.941	258.02
1/4	57.334	261.59
3/8	57.727	265.18
1/2	58.119	268.80
5/8	58.512	272.45
3/4	58.905	276.12
7/8	59.298	279.81
19.	59.690	283.53
1/8	60.083	287.27
1/4	60.476	291.04
3/8	60.868	294.83
1/2	61.261	298.65
5/8	61.654	302.49
3/4	62.046	306.35
7/8	62.439	310.24
20.	62.832	314.16
1/8	63.225	318.10
1/4	63.617	322.06
3/8	64.010	326.05
1/2	64.403	330.06
5/8	64.795	334.10
3/4	65.188	338.16
7/8	65.581	342.25
21.	65.973	346.36
1/8	66.366	350.50
1/4	66.759	354.66
3/8	67.152	358.84
1/2	67.544	363.05
5/8	67.937	367.28
3/4	68.330	371.54
7/8	68.722	375.83
22.	69.115	380.13

Dia.	Circum.	Area
1/8	69.508	384.46
1/4	69.900	388.82
3/8	70.293	393.20
1/2	70.686	397.61
5/8	71.079	402.04
3/4	71.471	406.49
7/8	71.864	410.97
23.	72.257	415.48
1/8	72.649	420.00
1/4	73.042	424.56
3/8	73.435	429.13
1/2	73.827	433.74
5/8	74.220	438.36
3/4	74.613	443.01
7/8	75.006	447.69
24.	75.398	452.39
1/8	75.791	457.11
1/4	76.184	461.86
3/8	76.576	466.64
1/2	76.969	471.44
5/8	77.362	476.26
3/4	77.754	481.11
7/8	78.147	485.98
25.	78.540	490.87
1/8	78.933	495.79
1/4	79.325	500.74
3/8	79.718	505.71
1/2	80.111	510.71
5/8	80.503	515.72
3/4	80.896	520.77
7/8	81.289	525.84
26.	81.681	530.93
1/8	82.074	536.05
1/4	82.467	541.19
3/8	82.860	546.35
1/2	83.252	551.55
5/8	83.645	556.76
3/4	84.038	562.00
7/8	84.430	567.27
27.	84.823	572.56
1/8	85.216	577.87
1/4	85.608	583.21
3/8	86.001	588.57
1/2	86.394	593.96
5/8	86.786	599.37
3/4	87.179	604.81
7/8	87.572	610.27

CIRCUMFERENCES AND AREAS OF CIRCLES *(continued)*

Dia.	Circum.	Area	Dia.	Circum.	Area	Dia.	Circum.	Area
28.	87.965	615.75	34.	106.814	907.92	40.	125.664	1256.6
⅛	88.357	621.26	⅛	107.207	914.61	⅛	126.056	1264.5
¼	88.750	626.80	¼	107.600	921.32	¼	126.449	1272.4
⅜	89.143	632.36	⅜	107.992	928.06	⅜	126.842	1280.3
½	89.535	637.94	½	108.385	934.82	½	127.235	1288.2
⅝	89.928	643.55	⅝	108.778	941.61	⅝	127.627	1296.2
¾	90.321	649.18	¾	109.170	948.42	¾	128.020	1304.2
⅞	90.713	654.84	⅞	109.563	955.25	⅞	128.413	1312.2
29.	91.106	660.52	35.	109.956	962.11	41.	128.805	1320.3
⅛	91.499	666.23	⅛	110.348	969.00	⅛	129.198	1328.3
¼	91.892	671.96	¼	110.741	975.91	¼	129.591	1336.4
⅜	92.284	677.71	⅜	111.134	982.84	⅜	129.983	1344.5
½	92.677	683.49	½	111.527	989.80	½	130.376	1352.7
⅝	93.070	689.30	⅝	111.919	996.78	⅝	130.769	1360.8
¾	93.462	695.13	¾	112.312	1003.8	¾	131.161	1369.0
⅞	93.855	700.98	⅞	112.705	1010.8	⅞	131.554	1377.2
30.	94.248	706.86	36.	113.097	1017.9	42.	131.947	1385.4
⅛	94.640	712.76	⅛	113.490	1025.0	⅛	132.340	1393.7
¼	95.033	718.69	¼	113.883	1032.1	¼	132.732	1402.0
⅜	95.426	724.64	⅜	114.275	1039.2	⅜	133.125	1410.3
½	95.819	730.62	½	114.668	1046.3	½	133.518	1418.6
⅝	96.211	736.62	⅝	115.061	1053.5	⅝	133.910	1427.0
¾	96.604	742.64	¾	115.454	1060.7	¾	134.303	1435.4
⅞	96.997	748.69	⅞	115.846	1068.0	⅞	134.696	1443.8
31.	97.389	754.77	37.	116.239	1075.2	43.	135.088	1452.2
⅛	97.782	760.87	⅛	116.632	1082.5	⅛	135.481	1460.7
¼	98.175	766.99	¼	117.024	1089.8	¼	135.874	1469.1
⅜	98.567	773.14	⅜	117.417	1097.1	⅜	136.267	1477.6
½	98.960	779.31	½	117.810	1104.5	½	136.659	1486.2
⅝	99.353	785.51	⅝	118.202	1111.8	⅝	137.052	1494.7
¾	99.746	791.73	¾	118.596	1119.2	¾	137.445	1503.3
⅞	100.138	797.98	⅞	118.988	1126.7	⅞	137.837	1511.9
32.	100.531	804.25	38.	119.381	1134.1	44.	138.230	1520.5
⅛	100.924	810.54	⅛	119.773	1141.6	⅛	138.623	1529.2
¼	101.316	816.86	¼	120.166	1149.1	¼	139.015	1537.9
⅜	101.709	823.21	⅜	120.559	1156.6	⅜	139.408	1546.6
½	102.102	829.58	½	120.951	1164.2	½	139.801	1555.3
⅝	102.494	835.97	⅝	121.344	1171.7	⅝	140.194	1564.0
¾	102.887	842.39	¾	121.737	1179.3	¾	140.586	1572.8
⅞	103.280	848.83	⅞	122.129	1186.9	⅞	140.979	1581.6
33.	103.673	855.30	39.	122.522	1194.6	45.	141.372	1590.4
⅛	104.065	861.79	⅛	122.915	1202.3	⅛	141.764	1599.3
¼	104.458	868.31	¼	123.308	1210.6	¼	142.157	1608.2
⅜	104.851	874.85	⅜	123.700	1217.7	⅜	142.550	1617.0
½	105.243	881.41	½	124.093	1225.4	½	142.942	1626.0
⅝	105.636	888.00	⅝	124.486	1233.2	⅝	143.335	1634.9
¾	106.029	894.62	¾	124.878	1241.0	¾	143.728	1643.9
⅞	106.421	901.26	⅞	125.271	1248.8	⅞	144.121	1652.9

CIRCUMFERENCES AND AREAS OF CIRCLES *(continued)*

Dia.	Circum.	Area	Dia.	Circum.	Area	Dia.	Circum.	Area
46.	144.513	1661.9	52.	163.363	2123.7	58.	182.212	2642.1
⅛	144.906	1670.9	⅛	163.756	2133.9	⅛	182.605	2653.5
¼	145.299	1680.0	¼	164.148	2144.2	¼	182.998	2664.9
⅜	145.691	1689.1	⅜	164.541	2154.5	⅜	183.390	2676.4
½	146.084	1698.2	½	164.934	2164.8	½	183.783	2687.8
⅝	146.477	1707.4	⅝	165.326	2175.1	⅝	184.176	2699.3
¾	146.869	1716.5	¾	165.719	2185.4	¾	184.569	2710.9
⅞	147.262	1725.7	⅞	166.112	2195.8	⅞	184.961	2722.4
47.	147.655	1734.9	53.	166.504	2206.2	59.	185.354	2734.0
⅛	148.048	1744.2	⅛	166.897	2216.6	⅛	185.747	2745.6
¼	148.440	1753.5	¼	167.290	2227.0	¼	186.139	2757.2
⅜	148.833	1762.7	⅜	167.683	2237.5	⅜	186.532	2768.8
½	149.226	1772.1	½	168.075	2248.0	½	186.925	2780.5
⅝	149.618	1781.4	⅝	168.468	2258.5	⅝	187.317	2792.2
¾	150.011	1790.8	¾	168.861	2269.1	¾	187.710	2803.9
⅞	150.404	1800.1	⅞	169.253	2279.6	⅞	188.103	2815.7
48.	150.796	1809.6	54.	169.646	2290.2	60.	188.496	2827.4
⅛	151.189	1819.0	⅛	170.039	2300.8	⅛	188.888	2839.2
¼	151.582	1828.5	¼	170.431	2311.5	¼	189.281	2851.0
⅜	151.975	1837.9	⅜	170.824	2322.1	⅜	189.674	2862.9
½	152.367	1847.5	½	171.217	2332.8	½	190.066	2874.8
⅝	152.760	1857.0	⅝	171.609	2343.5	⅝	190.459	2886.6
¾	153.153	1866.5	¾	172.002	2354.3	¾	190.852	2898.6
⅞	153.545	1876.1	⅞	172.395	2365.0	⅞	191.244	2910.5
49.	153.938	1885.7	55.	172.788	2375.8	61.	191.637	2922.5
⅛	154.331	1895.4	⅛	173.180	2386.6	⅛	192.030	2934.5
¼	154.723	1905.0	¼	173.573	2397.5	¼	192.423	2946.5
⅜	155.116	1914.7	⅜	173.966	2408.3	⅜	192.815	2958.5
½	155.509	1924.4	½	174.358	2419.2	½	193.208	2970.6
⅝	155.902	1934.2	⅝	174.751	2430.1	⅝	193.601	2982.7
¾	156.294	1943.9	¾	175.144	2441.1	¾	193.993	2994.8
⅞	156.687	1953.7	⅞	175.536	2452.0	⅞	194.386	3006.9
50.	157.080	1963.5	56.	175.929	2463.0	62.	194.779	3019.1
⅛	157.472	1973.3	⅛	176.322	2474.0	⅛	195.171	3031.3
¼	157.865	1983.2	¼	176.715	2485.0	¼	195.564	3043.5
⅜	158.258	1993.1	⅜	177.107	2496.1	⅜	195.957	3055.7
½	158.650	2003.0	½	177.500	2507.2	½	196.350	3068.0
⅝	159.043	2012.9	⅝	177.893	2518.3	⅝	196.742	3080.3
¾	159.436	2022.8	¾	178.285	2529.4	¾	197.135	3092.6
⅞	159.829	2032.8	⅞	178.678	2540.6	⅞	197.528	3104.9
51.	160.221	2042.8	57.	179.071	2551.8	63.	197.920	3117.2
⅛	160.614	2052.8	⅛	179.463	2563.0	⅛	198.313	3129.6
¼	161.007	2062.9	¼	179.856	2574.2	¼	198.706	3142.0
⅜	161.399	2073.0	⅜	180.249	2585.4	⅜	199.098	3154.5
½	161.792	2083.1	½	180.642	2596.7	½	199.491	3166.9
⅝	162.185	2093.2	⅝	181.034	2608.0	⅝	199.884	3179.4
¾	162.577	2103.3	¾	181.427	2619.4	¾	200.277	3191.9
⅞	162.970	2113.5	⅞	181.820	2630.7	⅞	200.669	3204.4

CIRCUMFERENCES AND AREAS OF CIRCLES *(continued)*

Dia.	Circum.	Area	Dia.	Circum.	Area	Dia.	Circum.	Area
64.	201.062	3217.0	70.	219.911	3848.5	76.	238.761	4536.5
1/8	201.455	3229.6	1/8	220.304	3862.2	1/8	239.154	4551.4
1/4	201.847	3242.2	1/4	220.697	3876.0	1/4	239.546	4566.4
3/8	202.240	3254.8	3/8	221.090	3889.8	3/8	239.939	4581.3
1/2	202.633	3267.5	1/2	221.482	3903.6	1/2	240.332	4596.3
5/8	203.025	3280.1	5/8	221.875	3917.5	5/8	240.725	4611.4
3/4	203.418	3292.8	3/4	222.268	3931.4	3/4	241.117	4626.4
7/8	203.811	3305.6	7/8	222.660	3945.3	7/8	241.510	4641.5
65.	204.204	3318.3	71.	223.053	3959.2	77.	241.903	4656.6
1/8	204.596	3331.1	1/8	223.446	3973.1	1/8	242.295	4671.8
1/4	204.989	3343.9	1/4	223.838	3987.1	1/4	242.688	4686.9
3/8	205.382	3356.7	3/8	224.231	4001.1	3/8	243.081	4702.1
1/2	205.774	3369.6	1/2	224.624	4015.2	1/2	243.473	4717.3
5/8	206.167	3382.4	5/8	225.017	4029.2	5/8	243.866	4732.5
3/4	206.560	3395.3	3/4	225.409	4043.3	3/4	244.259	4747.8
7/8	206.952	3408.2	7/8	225.802	4057.4	7/8	244.652	4763.1
66.	207.345	3421.2	72.	226.195	4071.5	78.	245.044	4778.4
1/8	207.738	3434.2	1/8	226.587	4085.7	1/8	245.437	4793.7
1/4	208.131	3447.2	1/4	226.980	4099.8	1/4	245.830	4809.0
3/8	208.523	3460.2	3/8	227.373	4114.0	3/8	246.222	4824.4
1/2	208.916	3473.2	1/2	227.765	4128.2	1/2	246.615	4839.8
5/8	209.309	3486.3	5/8	228.158	4142.5	5/8	247.008	4855.2
3/4	209.701	3499.4	3/4	228.551	4156.8	3/4	247.400	4870.7
7/8	210.094	3512.5	7/8	228.944	4171.1	7/8	247.793	4886.2
67.	210.487	3525.7	73.	229.336	4185.4	79.	248.186	4901.7
1/8	210.879	3538.8	1/8	229.729	4199.7	1/8	248.579	4917.2
1/4	211.272	3552.0	1/4	230.122	4214.1	1/4	248.971	4932.7
3/8	211.665	3565.2	3/8	230.514	4228.5	3/8	249.364	4948.3
1/2	212.058	3578.5	1/2	230.907	4242.9	1/2	249.757	4963.9
5/8	212.450	3591.7	5/8	231.300	4257.4	5/8	250.149	4979.5
3/4	212.843	3605.0	3/4	231.692	4271.8	3/4	250.542	4995.2
7/8	213.236	3618.3	7/8	232.085	4286.3	7/8	250.935	5010.9
68.	213.628	3631.7	74.	232.478	4300.8	80.	251.327	5026.5
1/8	214.021	3645.0	1/8	232.871	4315.4	1/8	251.720	5042.3
1/4	214.414	3658.4	1/4	233.263	4329.9	1/4	252.113	5058.0
3/8	214.806	3671.8	3/8	233.656	4344.5	3/8	252.506	5073.8
1/2	215.199	3685.3	1/2	234.049	4359.2	1/2	252.898	5089.6
5/8	215.592	3698.7	5/8	234.441	4373.8	5/8	253.291	5105.4
3/4	215.984	3712.2	3/4	234.834	4388.5	3/4	253.684	5121.2
7/8	216.377	3725.7	7/8	235.227	4403.1	7/8	254.076	5137.1
69.	216.770	3739.3	75.	235.619	4417.9	81.	254.469	5153.0
1/8	217.163	3752.8	1/8	236.012	4432.6	1/8	254.862	5168.9
1/4	217.555	3766.4	1/4	236.405	4447.4	1/4	255.254	5184.9
3/8	217.948	3780.0	3/8	236.798	4462.2	3/8	255.647	5200.8
1/2	218.341	3793.7	1/2	237.190	4477.0	1/2	256.040	5216.8
5/8	218.733	3807.3	5/8	237.583	4491.8	5/8	256.433	5232.8
3/4	219.126	3821.0	3/4	237.976	4506.7	3/4	256.825	5248.9
7/8	219.519	3834.7	7/8	238.368	4521.5	7/8	257.218	5264.9

CIRCUMFERENCES AND AREAS OF CIRCLES *(continued)*

Dia.	Circum.	Area	Dia.	Circum.	Area	Dia.	Circum.	Are
82.	257.611	5281.0	88.	276.460	6082.1	94.	295.310	6939.8
⅛	258.003	5297.1	⅛	276.853	6099.4	⅛	295.702	6958.2
¼	258.396	5313.3	¼	277.246	6116.7	¼	296.095	6976.7
⅜	258.789	5329.4	⅜	277.638	6134.1	⅜	296.488	6995.3
½	259.181	5345.6	½	278.031	6151.4	½	296.881	7013.8
⅝	259.574	5361.8	⅝	278.424	6168.8	⅝	297.273	7032.4
¾	259.967	5378.1	¾	278.816	6186.2	¾	297.666	7051.0
⅞	260.359	5394.3	⅞	279.209	6203.7	⅞	298.059	7069.6
83.	260.752	5410.6	89.	279.602	6221.1	95.	298.451	7088.2
⅛	261.145	5426.9	⅛	279.994	6238.6	⅛	298.844	7106.9
¼	261.538	5443.3	¼	280.387	6256.1	¼	299.237	7125.6
⅜	261.930	5459.6	⅜	280.780	6273.7	⅜	299.629	7144.3
½	262.323	5476.0	½	281.173	6291.2	½	300.022	7163.0
⅝	262.716	5492.4	⅝	281.565	6308.8	⅝	300.415	7181.8
¾	263.108	5508.8	¾	281.958	6326.4	¾	300.807	7200.6
⅞	263.501	5525.3	⅞	282.351	6344.1	⅞	301.200	7219.4
84.	263.894	5541.8	90.	282.743	6361.7	96.	301.593	7238.2
⅛	264.286	5558.3	⅛	283.136	6379.4	⅛	301.986	7257.1
¼	264.679	5574.8	¼	283.529	6397.1	¼	302.378	7276.0
⅜	265.072	5591.4	⅜	283.921	6414.9	⅜	302.771	7294.9
½	265.465	5607.9	½	284.314	6432.6	½	303.164	7313.8
⅝	265.857	5624.5	⅝	284.707	6450.4	⅝	303.556	7332.8
¾	266.250	5641.2	¾	285.100	6468.2	¾	303.949	7351.8
⅞	266.643	5657.8	⅞	285.492	6486.0	⅞	304.342	7370.8
85.	267.035	5674.5	91.	285.885	6503.9	97.	304.734	7389.8
⅛	267.428	5691.2	⅛	286.278	6521.8	⅛	305.127	7408.9
¼	267.821	5707.9	¼	286.670	6539.7	¼	305.520	7428.0
⅜	268.213	5724.7	⅜	287.063	6557.6	⅜	305.913	7447.1
½	268.606	5741.5	½	287.456	6575.5	½	306.305	7466.2
⅝	268.999	5758.3	⅝	287.848	6593.5	⅝	306.698	7485.3
¾	269.392	5775.1	¾	288.241	6611.5	¾	307.091	7504.5
⅞	269.784	5791.9	⅞	288.634	6629.6	⅞	307.483	7523.7
86.	270.177	5808.8	92.	289.027	6647.6	98.	307.876	7543.0
⅛	270.570	5825.7	⅛	289.419	6665.7	⅛	308.269	7562.2
¼	270.962	5842.6	¼	289.812	6683.8	¼	308.661	7581.5
⅜	271.355	5859.6	⅜	290.205	6701.9	⅜	309.054	7600.8
½	271.748	5876.5	½	290.597	6720.1	½	309.447	7620.1
⅝	272.140	5893.5	⅝	290.990	6738.2	⅝	309.840	7639.5
¾	272.533	5910.6	¾	291.383	6756.4	¾	310.232	7658.9
⅞	272.926	5927.6	⅞	291.775	6774.7	⅞	310.625	7678.3
87.	273.319	5944.7	93.	292.168	6792.9	99.	311.018	7697.7
⅛	273.711	5961.8	⅛	292.561	6811.2	⅛	311.410	7717.1
¼	274.104	5978.9	¼	292.954	6829.5	¼	311.803	7736.6
⅜	274.497	5996.0	⅜	293.346	6847.8	⅜	312.196	7756.1
½	274.889	6013.2	½	293.739	6866.1	½	312.588	7775.6
⅝	275.282	6030.4	⅝	294.132	6884.5	⅝	312.981	7795.2
¾	275.675	6047.6	¾	294.524	6902.9	¾	313.374	7814.8
⅞	276.067	6064.9	⅞	294.917	6921.3	⅞	313.767	7834.4

CIRCUMFERENCES AND AREAS OF CIRCLES *(continued)*

Dia.	Circum.	Area	Dia.	Circum.	Area	Dia.	Circum.	Area
100.	314.16	7854	106.	333.01	8825	112.	351.86	9852
1/8	314.55	7873	1/8	333.40	8845	1/8	352.25	9874
1/4	314.95	7893	1/4	333.80	8866	1/4	352.65	9897
3/8	315.34	7913	3/8	334.19	8887	3/8	353.04	9919
1/2	315.73	7933	1/2	334.58	8908	1/2	353.43	9941
5/8	316.12	7952	5/8	334.97	8929	5/8	353.82	9963
3/4	316.52	7972	3/4	335.37	8950	3/4	354.22	9985
7/8	316.91	7992	7/8	335.76	8971	7/8	354.61	10007
101.	317.30	8012	107.	336.15	8992	113.	355.00	10029
1/8	317.69	8032	1/8	336.54	9014	1/8	355.39	10052
1/4	318.09	8052	1/4	336.94	9035	1/4	355.79	10074
3/8	318.48	8071	3/8	337.33	9056	3/8	356.18	10097
1/2	318.87	8091	1/2	337.72	9077	1/2	356.57	10119
5/8	319.27	8111	5/8	338.12	9098	5/8	356.96	10141
3/4	319.66	8131	3/4	338.51	9119	3/4	357.36	10163
7/8	320.05	8151	7/8	338.90	9140	7/8	357.75	10185
102.	320.44	8171	108.	339.29	9161	114.	358.14	10207
1/8	320.84	8191	1/8	339.69	9183	1/8	358.54	10230
1/4	321.23	8211	1/4	340.08	9204	1/4	358.93	10252
3/8	321.62	8231	3/8	340.47	9225	3/8	359.32	10275
1/2	322.01	8252	1/2	340.86	9246	1/2	359.71	10297
5/8	322.41	8272	5/8	341.26	9268	5/8	360.11	10320
3/4	322.80	8292	3/4	341.65	9289	3/4	360.50	10342
7/8	323.19	8312	7/8	342.04	9310	7/8	360.89	10365
103.	323.59	8332	109.	342.43	9331	115.	361.28	10387
1/8	323.98	8352	1/8	342.83	9353	1/8	361.68	10410
1/4	324.37	8372	1/4	343.22	9374	1/4	362.07	10432
3/8	324.76	8393	3/8	343.61	9396	3/8	362.46	10455
1/2	325.16	8413	1/2	344.01	9417	1/2	362.86	10477
5/8	325.55	8434	5/8	344.40	9439	5/8	363.25	10500
3/4	325.94	8454	3/4	344.79	9460	3/4	363.64	10522
7/8	326.33	8474	7/8	345.18	9481	7/8	364.03	10545
104.	326.73	8495	110.	345.58	9503	116.	364.43	10568
1/8	327.12	8515	1/8	345.97	9525	1/8	364.82	10590
1/4	327.51	8536	1/4	346.36	9546	1/4	365.21	10613
3/8	327.91	8556	3/8	346.75	9568	3/8	365.60	10636
1/2	328.30	8577	1/2	347.15	9589	1/2	366.00	10659
5/8	328.69	8597	5/8	347.54	9611	5/8	366.39	10682
3/4	329.08	8618	3/4	347.93	9633	3/4	366.78	10705
7/8	329.48	8638	7/8	348.33	9655	7/8	367.18	10728
105.	329.87	8659	111.	348.72	9677	117.	367.57	10751
1/8	330.26	8679	1/8	349.11	9698	1/8	367.96	10774
1/4	330.65	8700	1/4	349.50	9720	1/4	368.35	10798
3/8	331.05	8721	3/8	349.90	9742	3/8	368.75	10821
1/2	331.44	8741	1/2	350.29	9764	1/2	369.14	10844
5/8	331.83	8762	5/8	350.68	9786	5/8	369.53	10867
3/4	332.22	8783	3/4	351.07	9808	3/4	369.92	10890
7/8	332.62	8804	7/8	351.47	9830	7/8	370.32	10913

CIRCUMFERENCES AND AREAS OF CIRCLES *(continued)*

Dia.	Circum.	Area
118.	370.71	10936
1/8	371.11	10960
1/4	371.49	10983
3/8	371.89	11007
1/2	372.28	11030
5/8	372.67	11053
3/4	373.07	11076
7/8	373.46	11099
119.	373.85	11122
1/8	374.24	11146
1/4	374.64	11169
3/8	375.03	11193
1/2	375.42	11216
5/8	375.81	11240
3/4	376.21	11263
7/8	376.60	11287
120.	376.99	11310
1/8	377.39	11334
1/4	377.78	11357
3/8	378.17	11381
1/2	378.56	11404
5/8	378.96	11428
3/4	379.35	11451
7/8	379.74	11475
121.	380.13	11499
1/8	380.53	11522
1/4	380.92	11546
3/8	381.31	11570
1/2	381.70	11594
5/8	382.10	11618
3/4	382.49	11642
7/8	382.88	11666
122.	383.28	11690
1/8	383.67	11714
1/4	384.06	11738
3/8	384.45	11762
1/2	384.85	11786
5/8	385.24	11810
3/4	385.63	11834
7/8	386.02	11858
123.	386.42	11882
1/8	386.81	11907
1/4	387.20	11931
3/8	387.60	11956
1/2	387.99	11980
5/8	388.38	12004
3/4	388.77	12028
7/8	389.17	12052

Dia.	Circum.	Area
124.	389.56	12076
1/8	389.95	12101
1/4	390.34	12125
3/8	390.74	12150
1/2	391.13	12174
5/8	391.52	12199
3/4	391.92	12223
7/8	392.31	12248
125.	392.70	12272
1/8	393.09	12297
1/4	393.49	12321
3/8	393.88	12346
1/2	394.27	12370
5/8	394.66	12395
3/4	395.06	12419
7/8	395.45	12444
126.	395.84	12469
1/8	396.23	12494
1/4	396.63	12518
3/8	397.02	12543
1/2	397.41	12568
5/8	397.81	12593
3/4	398.20	12618
7/8	398.59	12643
127.	398.98	12668
1/8	399.38	12693
1/4	399.77	12718
3/8	400.16	12743
1/2	400.55	12768
5/8	400.95	12793
3/4	401.34	12818
7/8	401.73	12843
128.	402.13	12868
1/8	402.52	12893
1/4	402.91	12919
3/8	403.30	12944
1/2	403.70	12970
5/8	404.09	12995
3/4	404.48	13020
7/8	404.87	13045
129.	405.27	13070
1/8	405.66	13096
1/4	406.05	13121
3/8	406.44	13147
1/2	406.84	13172
5/8	407.23	13198
3/4	407.62	13223
7/8	408.02	13248

Dia.	Circum.	Area
130.	408.41	13273
1/8	408.80	13299
1/4	409.19	13324
3/8	409.59	13350
1/2	409.98	13375
5/8	410.37	13401
3/4	410.76	13426
7/8	411.16	13452
131.	411.55	13478
1/8	411.94	13504
1/4	412.34	13529
3/8	412.73	13555
1/2	413.12	13581
5/8	413.51	13607
3/4	413.91	13633
7/8	414.30	13659
132.	414.69	13685
1/8	415.08	13711
1/4	415.48	13737
3/8	415.87	13763
1/2	416.26	13789
5/8	416.66	13815
3/4	417.05	13841
7/8	417.44	13867
133.	417.83	13893
1/8	418.23	13919
1/4	418.62	13946
3/8	419.01	13972
1/2	419.40	13999
5/8	419.80	14025
3/4	420.19	14051
7/8	420.58	14077
134.	420.97	14103
1/8	421.37	14130
1/4	421.76	14156
3/8	422.15	14183
1/2	422.55	14209
5/8	422.94	14236
3/4	423.33	14262
7/8	423.72	14288
135.	424.12	14314
1/8	424.51	14341
1/4	424.90	14367
3/8	425.29	14394
1/2	425.69	14420
5/8	426.08	14447
3/4	426.47	14473
7/8	426.87	14500

CIRCUMFERENCES AND AREAS OF CIRCLES *(continued)*

Dia.	Circum.	Area
136.	427.26	14527
⅛	427.65	14553
¼	428.04	14580
⅜	428.44	14607
½	428.83	14633
⅝	429.22	14660
¾	429.61	14687
⅞	430.01	14714
137.	430.40	14741
⅛	430.79	14768
¼	431.19	14795
⅜	431.58	14822
½	431.97	14849
⅝	432.36	14876
¾	432.76	14903
⅞	433.15	14930
138.	433.54	14957
⅛	433.93	14984
¼	434.33	15012
⅜	434.72	15039
½	435.11	15067
⅝	435.50	15094
¾	435.90	15121
⅞	436.29	15148
139.	436.68	15175
⅛	437.08	15203
¼	437.47	15230
⅜	437.86	15258
½	438.25	15285
⅝	438.65	15313
¾	439.04	15340
⅞	439.43	15367
140.	439.82	15394
⅛	440.22	15422
¼	440.61	15449
⅜	441.00	15477
½	441.40	15504
⅝	441.79	15532
¾	442.18	15559
⅞	442.57	15587
141.	442.97	15615
⅛	443.36	15642
¼	443.75	15670
⅜	444.14	15697
½	444.54	15725
⅝	444.93	15753
¾	445.32	15781
⅞	445.72	15809

Dia.	Circum.	Area
142.	446.11	15837
⅛	446.50	15865
¼	446.89	15893
⅜	447.29	15921
½	447.68	15949
⅝	448.07	15977
¾	448.46	16005
⅞	448.86	16033
143.	449.25	16061
⅛	449.64	16089
¼	450.03	16117
⅜	450.43	16145
½	450.82	16173
⅝	451.21	16201
¾	451.61	16229
⅞	452.00	16258
144.	452.39	16286
⅛	452.78	16314
¼	453.18	16342
⅜	453.57	16371
½	453.96	16399
⅝	454.35	16428
¾	454.75	16456
⅞	455.14	16485
145.	455.53	16513
⅛	455.93	16542
¼	456.32	16570
⅜	456.71	16599
½	457.10	16627
⅝	457.50	16656
¾	457.89	16684
⅞	458.28	16713
146.	458.67	16742
⅛	459.07	16770
¼	459.46	16799
⅜	459.85	16827
½	460.24	16856
⅝	460.64	16885
¾	461.03	16914
⅞	461.42	16943
147.	461.82	16972
⅛	462.21	17000
¼	462.60	17029
⅜	462.99	17058
½	463.39	17087
⅝	463.78	17116
¾	464.17	17145
⅞	464.56	17174

Dia.	Circum.	Area
148.	464.96	17203
⅛	465.35	17232
¼	465.74	17262
⅜	466.14	17291
½	466.53	17321
⅝	466.92	17350
¾	467.31	17379
⅞	467.71	17408
149.	468.10	17437
⅛	468.49	17466
¼	468.88	17496
⅜	469.28	17525
½	469.67	17555
⅝	470.06	17584
¾	470.46	17614
⅞	470.85	17643
150.	471.24	17672
⅛	471.63	17702
¼	472.03	17731
⅜	472.42	17761
½	472.81	17790
⅝	473.20	17820
¾	473.60	17849
⅞	473.99	17879
151.	474.38	17908
⅛	474.77	17938
¼	475.17	17967
⅜	475.56	17997
½	475.95	18026
⅝	476.35	18056
¾	476.74	18086
⅞	477.13	18116
152.	477.52	18146
⅛	477.92	18175
¼	478.31	18205
⅜	478.70	18235
½	479.09	18265
⅝	479.49	18295
¾	479.88	18325
⅞	480.27	18355
153.	480.67	18385
⅛	481.06	18415
¼	481.45	18446
⅜	481.84	18476
½	482.24	18507
⅝	482.63	18537
¾	483.02	18567
⅞	483.41	18597

CIRCUMFERENCES AND AREAS OF CIRCLES *(continued)*

Dia.	Circum.	Area	Dia.	Circum.	Area	Dia.	Circum.	Area
154.	483.81	18627	160.	502.66	20106	166.	521.51	21642
1/8	484.20	18658	1/8	503.05	20138	1/8	521.90	21675
1/4	484.59	18688	1/4	503.44	20169	1/4	522.29	21707
3/8	484.99	18719	3/8	503.83	20201	3/8	522.68	21740
1/2	485.38	18749	1/2	504.23	20232	1/2	523.08	21772
5/8	485.77	18779	5/8	504.62	20264	5/8	523.47	21805
3/4	486.16	18809	3/4	505.01	20295	3/4	523.86	21838
7/8	486.56	18839	7/8	505.41	20327	7/8	524.26	21871
155.	486.95	18869	161.	505.80	20358	167.	524.65	21904
1/8	487.34	18900	1/8	506.19	20390	1/8	525.04	21937
1/4	487.73	18930	1/4	506.58	20421	1/4	525.43	21969
3/8	488.13	18961	3/8	506.98	20453	3/8	525.83	22002
1/2	488.52	18991	1/2	507.37	20484	1/2	526.22	22035
5/8	488.91	19022	5/8	507.76	20516	5/8	526.61	22068
3/4	489.30	19052	3/4	508.15	20548	3/4	527.00	22101
7/8	489.70	19083	7/8	508.55	20580	7/8	527.40	22134
156.	490.09	19113	162.	508.94	20612	168.	527.79	22167
1/8	490.48	19144	1/8	509.33	20644	1/8	528.18	22200
1/4	490.88	19174	1/4	509.73	20675	1/4	528.57	22233
3/8	491.27	19205	3/8	510.12	20707	3/8	528.97	22266
1/2	491.66	19235	1/2	510.51	20739	1/2	529.36	22299
5/8	492.05	19266	5/8	510.90	20771	5/8	529.75	22332
3/4	492.45	19297	3/4	511.30	20803	3/4	530.15	22366
7/8	492.84	19328	7/8	511.69	20835	7/8	530.54	22399
157.	493.23	19359	163.	512.08	20867	169.	530.93	22432
1/8	493.62	19390	1/8	512.47	20899	1/8	531.32	22465
1/4	494.02	19421	1/4	512.87	20931	1/4	531.72	22499
3/8	494.41	19452	3/8	513.26	20964	3/8	532.11	22532
1/2	494.80	19483	1/2	513.65	20996	1/2	532.50	22566
5/8	495.20	19514	5/8	514.04	21028	5/8	532.89	22599
3/4	495.59	19545	3/4	514.44	21060	3/4	533.29	22632
7/8	495.98	19576	7/8	514.83	21092	7/8	533.68	22665
158.	496.37	19607	164.	515.22	21124	170.	534.07	22698
1/8	496.77	19638	1/8	515.62	21157	1/8	534.47	22731
1/4	497.16	19669	1/4	516.01	21189	1/4	534.86	22765
3/8	497.55	19701	3/8	516.40	21222	3/8	535.25	22798
1/2	497.94	19732	1/2	516.79	21254	1/2	535.64	22832
5/8	498.34	19763	5/8	517.19	21287	5/8	536.04	22865
3/4	498.73	19794	3/4	517.58	21319	3/4	536.43	22899
7/8	499.12	19825	7/8	517.97	21351	7/8	536.82	22932
159.	499.51	19856	165.	518.36	21383	171.	537.21	22966
1/8	499.91	19887	1/8	518.76	21416	1/8	537.61	22999
1/4	500.30	19919	1/4	519.15	21448	1/4	538.00	23033
3/8	500.69	19950	3/8	519.54	21481	3/8	538.39	23066
1/2	501.09	19982	1/2	519.94	21513	1/2	538.78	23100
5/8	501.48	20013	5/8	520.33	21546	5/8	539.18	23133
3/4	501.87	20044	3/4	520.72	21578	3/4	539.57	23167
7/8	502.26	20075	7/8	521.11	21610	7/8	539.96	23201

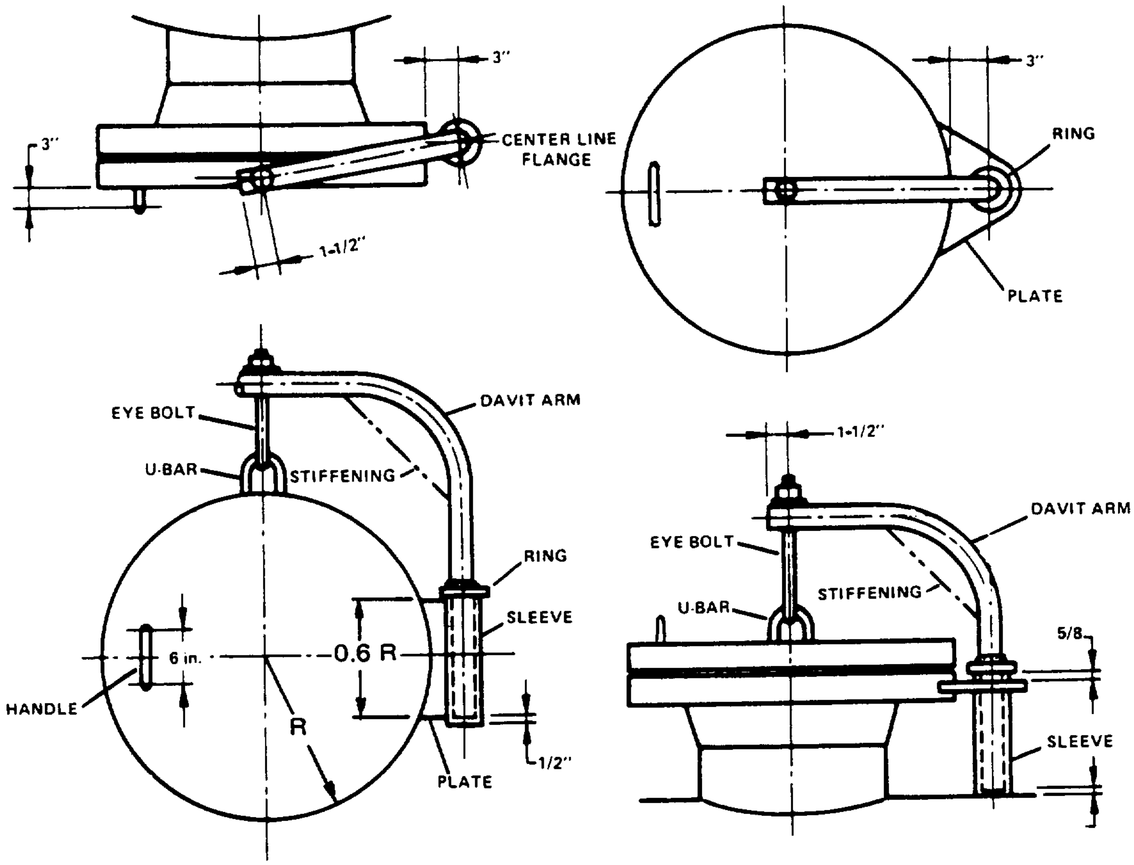
CIRCUMFERENCES AND AREAS OF CIRCLES *(continued)*

Dia.	Circum.	Area	Dia.	Circum.	Area	Dia.	Circum.	Area
172.	540.36	23235	178.	559.21	24885	184.	578.05	26590
1/8	540.75	23268	1/8	559.60	24920	1/8	578.45	26626
1/4	541.14	23302	1/4	559.99	24955	1/4	578.84	26663
3/8	541.53	23336	3/8	560.38	24990	3/8	579.23	26699
1/2	541.93	23370	1/2	560.78	25025	1/2	579.63	26736
5/8	542.32	23404	5/8	561.17	25060	5/8	580.02	26772
3/4	542.71	23438	3/4	561.56	25095	3/4	580.41	26808
7/8	543.10	23472	7/8	561.95	25130	7/8	580.80	26844
173.	543.50	23506	179.	562.35	25165	185.	581.20	26880
1/8	543.89	23540	1/8	562.74	25200	1/8	581.59	26916
1/4	544.28	23575	1/4	563.13	25236	1/4	581.98	26953
3/8	544.68	23609	3/8	563.53	25271	3/8	582.37	26989
1/2	545.07	23643	1/2	563.92	25307	1/2	582.77	27026
5/8	545.46	23677	5/8	564.31	25342	5/8	583.16	27062
3/4	545.85	23711	3/4	564.70	25377	3/4	583.55	27099
7/8	546.25	23745	7/8	565.10	25412	7/8	583.95	27135
174.	546.64	23779	180.	565.49	25447	186.	584.34	27172
1/8	547.03	23813	1/8	565.88	25482	1/8	584.73	27208
1/4	547.42	23848	1/4	566.27	25518	1/4	585.12	27245
3/8	547.82	23882	3/8	566.67	25553	3/8	585.52	27281
1/2	548.21	23917	1/2	567.06	25589	1/2	585.91	27318
5/8	548.60	23951	5/8	567.45	25624	5/8	586.30	27354
3/4	549.00	23985	3/4	567.84	25660	3/4	586.59	27391
7/8	549.39	24019	7/8	568.24	25695	7/8	587.09	27428
175.	549.78	24053	181.	568.63	25730	187.	587.48	27465
1/8	550.17	24087	1/8	569.02	25765	1/8	587.87	27501
1/4	550.57	24122	1/4	569.42	25801	1/4	588.27	27538
3/8	550.96	24156	3/8	569.81	25836	3/8	588.66	27574
1/2	551.35	24191	1/2	570.20	25872	1/2	589.05	27611
5/8	551.74	24225	5/8	570.59	25908	5/8	589.44	27648
3/4	552.14	24260	3/4	570.99	25944	3/4	589.84	27685
7/8	552.53	24294	7/8	571.38	25980	7/8	590.23	27722
176.	552.92	24329	182.	571.77	26016	188.	590.62	27759
1/8	553.31	24363	1/8	572.16	26051	1/8	591.01	27796
1/4	553.71	24398	1/4	572.56	26087	1/4	591.41	27833
3/8	554.10	24432	3/8	572.95	26122	3/8	591.80	27870
1/2	554.49	24467	1/2	573.34	26158	1/2	592.19	27907
5/8	554.89	24501	5/8	573.74	26194	5/8	592.58	27944
3/4	555.28	24536	3/4	574.13	26230	3/4	592.98	27981
7/8	555.67	24571	7/8	574.52	26266	7/8	593.37	28018
177.	556.06	24606	183.	574.91	26302	189.	593.76	28055
1/8	556.46	24640	1/8	575.31	26338	1/8	594.16	28092
1/4	556.85	24675	1/4	575.70	26374	1/4	594.55	28130
3/8	557.24	24710	3/8	576.09	26410	3/8	594.94	28167
1/2	557.63	24745	1/2	576.48	26446	1/2	595.33	28205
5/8	558.03	24780	5/8	576.88	26482	5/8	595.73	28242
3/4	558.42	24815	3/4	577.27	26518	3/4	596.12	28279
7/8	558.81	24850	7/8	577.66	26554	7/8	596.51	28316

CIRCUMFERENCES AND AREAS OF CIRCLES *(continued)*

Dia.	Circum.	Area	Dia.	Circum.	Area	Dia.	Circum.	Area
190.	596.90	28353	196.	615.75	30172	202.	634.60	32047
1/8	597.29	28390	1/8	616.15	30210	1/8	635.00	32086
1/4	597.68	28428	1/4	616.54	30249	1/4	635.40	32126
3/8	598.08	28465	3/8	616.93	30287	3/8	635.79	32166
1/2	598.47	28503	1/2	617.32	30326	1/2	636.18	32206
5/8	598.86	28540	5/8	617.72	30364	5/8	636.57	32246
3/4	599.25	28578	3/4	618.11	30403	3/4	636.97	32286
7/8	599.64	28615	7/8	618.50	30442	7/8	637.36	32326
191.	600.04	28652	197.	618.89	30481	203.	637.74	32366
1/8	600.44	28689	1/8	619.29	30519	1/8	638.15	32405
1/4	600.83	28727	1/4	619.68	30558	1/4	638.54	32445
3/8	601.22	28764	3/8	620.08	30596	3/8	638.93	32485
1/2	601.62	28802	1/2	620.47	30635	1/2	639.32	32525
5/8	602.01	28839	5/8	620.86	30674	5/8	639.72	32565
3/4	602.40	28877	3/4	621.25	30713	3/4	640.11	32605
7/8	602.79	28915	7/8	621.64	30752	7/8	640.50	32645
192.	603.19	28953	198.	622.04	30791	204.	640.88	32685
1/8	603.58	28990	1/8	622.44	30830	1/8	641.28	32725
1/4	603.97	29028	1/4	622.83	30869	1/4	641.67	32766
3/8	604.36	29065	3/8	623.22	30908	3/8	642.07	32806
1/2	604.76	29103	1/2	623.62	30947	1/2	642.46	32846
5/8	605.15	29141	5/8	624.01	30986	5/8	642.85	32886
3/4	605.54	29179	3/4	624.40	31025	3/4	643.24	32926
7/8	605.94	29217	7/8	624.79	31064	7/8	643.63	32966
193.	606.33	29255	199.	625.18	31103	205.	644.03	33006
1/8	606.72	29293	1/8	625.58	31142	1/8	644.43	33046
1/4	607.11	29331	1/4	625.97	31181	1/4	644.82	33087
3/8	607.51	29369	3/8	626.36	31220	3/8	645.21	33127
1/2	607.90	29407	1/2	626.76	31260	1/2	645.61	33168
5/8	608.29	29445	5/8	627.15	31299	5/8	646.00	33208
3/4	608.58	29483	3/4	627.54	31338	3/4	646.39	33249
7/8	609.08	29521	7/8	627.94	31377	7/8	646.78	33289
194.	609.47	29559	200.	628.32	31416	206.	647.17	33329
1/8	609.86	29597	1/8	628.72	31455	1/8	647.57	33369
1/4	610 26	29636	1/4	629.11	31495	1/4	647.96	33410
3/8	610.65	29674	3/8	629.51	31534	3/8	648.35	33450
1/2	611.05	29713	1/2	629.90	31574	1/2	648.75	33491
5/8	611.43	29751	5/8	630.29	31613	5/8	649.14	33531
3/4	611.83	29789	3/4	630.58	31653	3/4	649.53	33572
7/8	612.29	29827	7/8	631.08	31692	7/8	649.93	33613
195.	612.61	29865	201.	631.46	31731	207.	650.31	33654
1/8	613.00	29903	1/8	631.86	31770	1/8	650.71	33694
1/4	613.40	29942	1/4	632.26	31810	1/4	651.10	33735
3/8	613.79	29980	3/8	632.65	31849	3/8	651.50	33775
1/2	614.18	30019	1/2	633.05	31889	1/2	651.89	33816
5/8	614.57	30057	5/8	633.43	31928	5/8	652.28	33857
3/4	614.97	30096	3/4	633.83	31968	3/4	652.57	33898
7/8	615.36	30134	7/8	634.29	32007	7/8	653.07	33939

DAVIT



FOR HORIZONTAL OPENING **FOR VERTICAL OPENING**

NOTES:
1. All material carbon steel
2. All welds 3/8" continuous filet weld
3. The davit has been tested against excessive deflection
4. Using davit less room is required than with the use of hinge
5. For frequently used opening, davit is preferred to hinge

FLANGE RATING	150#						300#						600#						900 #					
SIZE	12	14	16	18	20	24	12	14	16	18	20	24	12	14	16	18	20	24	12	14	16	18	20	24
NO. OF LIST	1	1	1	1	1	1	1	1	1	1	2	2	1	1	2	2	2	2	1	1	2	2	2	3

	LIST #1	LIST #2	LIST #3
DAVIT ARM	1-1/2"-XH PIPE	2"-XXH PIPE	2"-XXH PIPE
SLEEVE	2"-XH PIPE	2-1/2"-STD PIPE	2-1/2"-STD PIPE
EYE-BOLT	5/8 ϕ	3/4 ϕ	1" ϕ
U-BAR	5/8 ϕ	3/4 ϕ	1" ϕ
RING	5/8	3/4	1"
PLATE	5/8	3/4	1"
HANDLE	5/8 ϕ	3/4 ϕ	1" ϕ
STIFFENER	——	——	3/8"

FIXED STAIR

Conforms to the requirements of

OCCUPATIONAL SAFETY AND HEALTH (OSHA) STANDARDS

Fixed stairs will be provided where operations necessitate regular travel between levels.

Fixed stairways shall be designed to carry a load of five times the normal live load anticipated but never less than to carry a moving concentrated load of 1,000 pounds.

Minimum width: 22 inches

Angle of stairway rise to the horizontal: 30 to 50 degrees.

Railings shall be provided on the open sides of all exposed stairways. Handrails shall be provided on at least once side of closed stairways, preferably on the right side descending.

Each tread and nosing shall be reasonably slip-resistant.

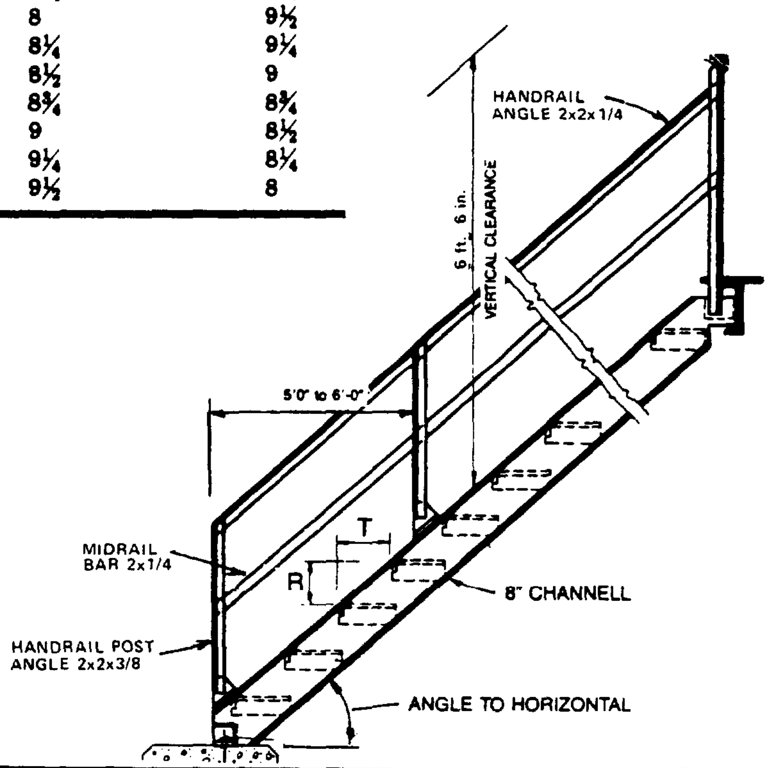
Stairs having treads of less than nine-inch width should have open risers. Open grating type treads are desirable for outside stairs.

See figure for minimum dimensions. Bolts ½ ø Bolt holes 9/16 ø

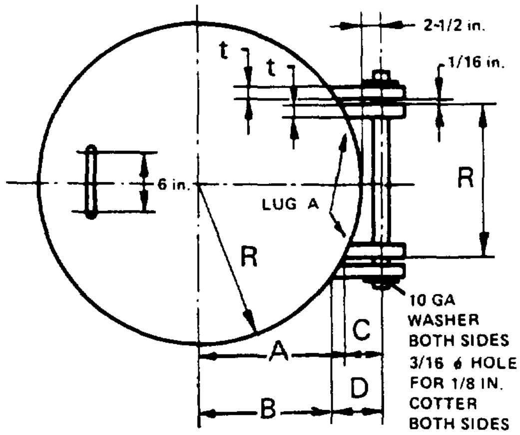
All burrs and sharp edges shall be removed.

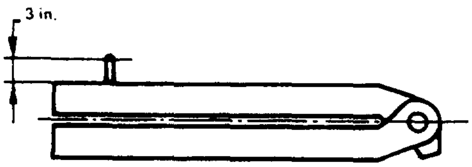
Dimensions of rises (R) and tread runs (T) tabulated below:

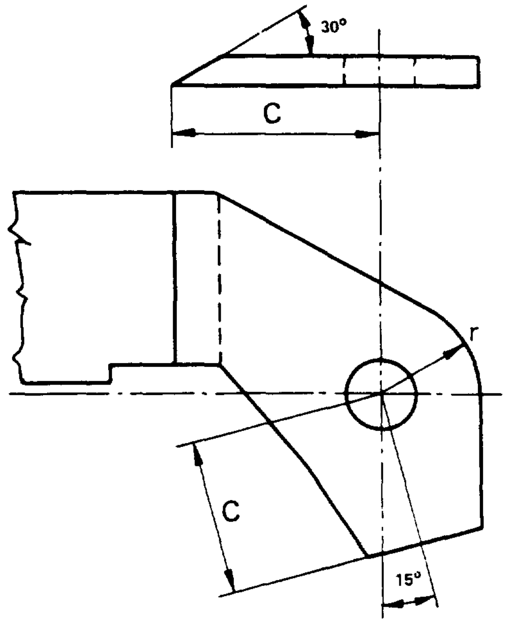
Angle to Horizontal	Rise (in inches)	Tread Run (in inches)
30° 35′	6½	11
32° 08′	6¾	10¾
33° 41′	7	10½
35° 16′	7¼	10¼
36° 52′	7½	10
38° 29′	7¾	9¾
40° 08′	8	9½
41° 44′	8¼	9¼
43° 22′	8½	9
45° 00′	8¾	8¾
46° 38′	9	8½
48° 16′	9¼	8¼
49° 54′	9½	8



HINGE







LUG-A WELDED TO BLIND FLANGE

NOTE

Fit lugs and pin so that pin is loose when cover is bolted up. Weld lugs to flanges with full penetration weld.

The use of davit preferred to hinge, especially for frequently used openings.

$$A = \sqrt{R^2 - (R/2)^2}$$

$$B = \sqrt{R^2 - (R/2 + 1/16 + t)^2}$$

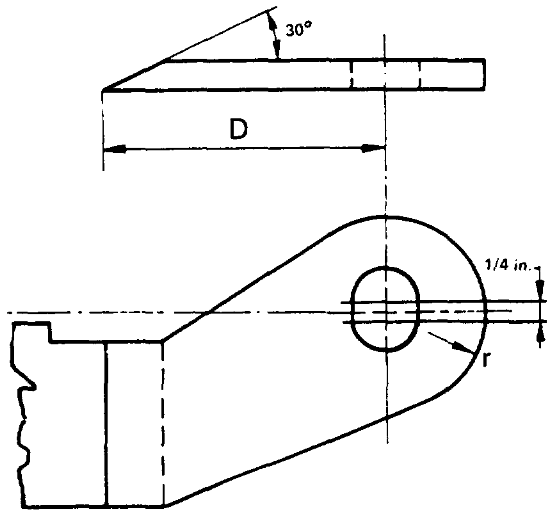
$$C = R + 2\tfrac{1}{2} - A$$

$$D = R + 2\tfrac{1}{2} - B$$

R = Radius of flange

r = 1.5 times diameter of hole

Diameter of hole = Pin diameter + 1/16 in.



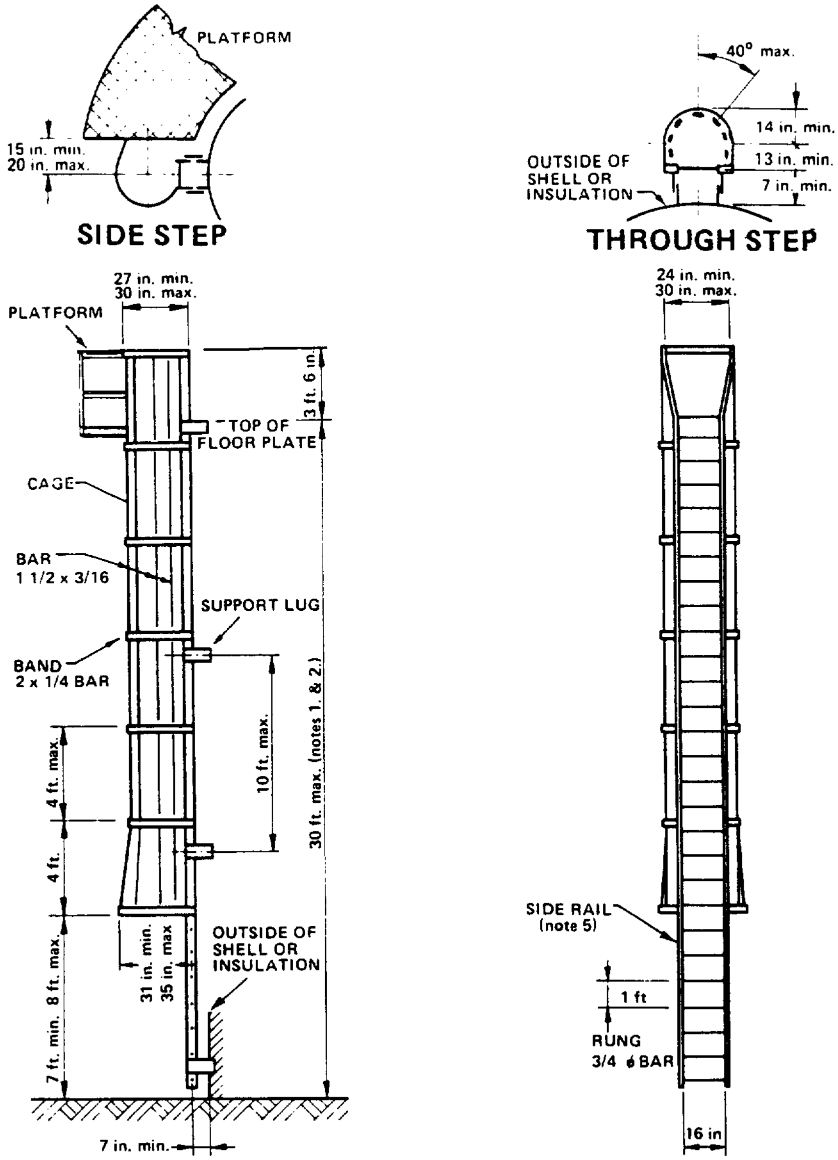
LUG-B WELDED TO FLANGE

THICKNESS, t OF LUGS AND DIAMETER OF PINS

RATING	150#						300#					
	3/4	3/4	3/4	3/4	3/4	3/4	3/4	3/4	3/4	3/4	3/4	1
FLG. DIAM.	12	14	16	18	20	24	12	14	16	18	20	24
	3/4	3/4	1	1	1	1	3/4	3/4	1	1	1	1 1/2
RATING	600#						900#					

LADDER

Conforms to the requirements of
STANDARD ANSI A14.3-1974 SAFETY REQUIREMENTS FOR FIXED LADDERS.

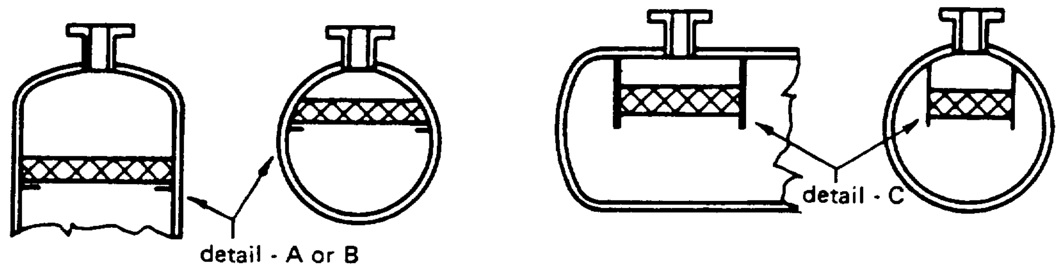


NOTES

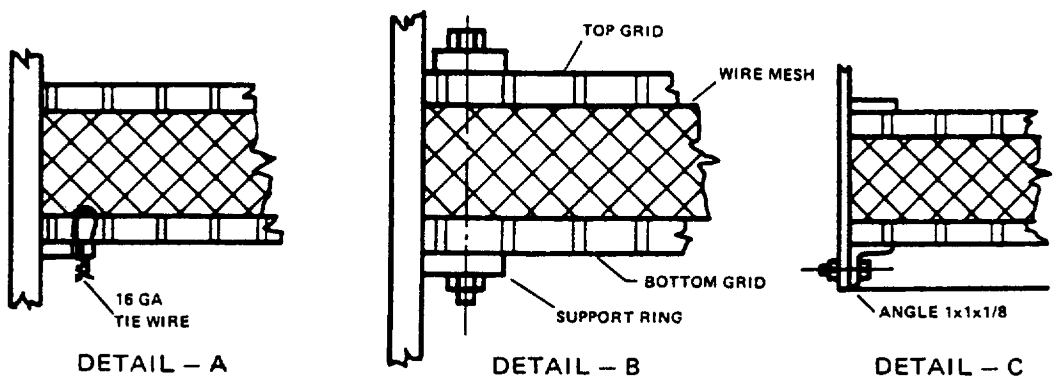
1. Cage is not required where the length of climb is 20 feet or less above ground level.
2. Horizontally offset landing platform shall be provided at least every 30 ft. of climbing length. Where safety devices are used, rest platforms shall be provided at maximum interwalls of 250 feet.
3. All material: steel conforming to ASTM A 36
4. Instead of the above specified structural shapes any other structural steel of equivalent strength may be used. To avoid damages during shipping or galvanizing, structural angles are widely used for side rail and vertical members of the cage.
5. The recommended minimum size of side rails under normal atmospheric condition 2 1/2 x 3/8 in. flat bar, although 2 x 1/4 bars are frequently used in practice.
6. All burrs and sharp edges shall be removed.
7. Protective Coating: one shop coat primer and one field coat of paint or hot dip galvanizing.

MIST EXTRACTOR

Mist extractors by separating mist, undesirable liquids from vapor, steam, liquids, etc. improve the performance of various process equipments. They are manufactured from metal or plastic mesh and available in any required size and shape.



TYPES OF MIST EXTRACTORS



SUPPORT OF MIST EXTRACTORS

Use 6 I 12.5 beam support in center of mist extractor, when the diameter is greater than 6 ft.

SPECIFICATION

WIRE MESH	THICKNESS OF PAD	4"	6"
	THICKNESS OF WIRE	.011"	.011"
	MATERIAL OF WIRE	TYPE 304 S.S.	TYPE 304 S.S.
	DENSITY lb./Cu. ft.	9.0	5.0
	PRESSURE DROP	0.5" TO 1" WATER GAGE	
GRID	MATERIAL CARBON STEEL		
	BEARING BAR	1"x3/16"	1x3/16"
	CROSS BAR	¼ ϕ	¼ ϕ
	BEARING BAR SPACING	3-9/16	3-9/16
	CROSS BAR SPACING	4"	4"
WEIGHT lb./sq.ft.		5.7	7.4
WIDTH OF ONE SECTION		12"	12"

NAME PLATE

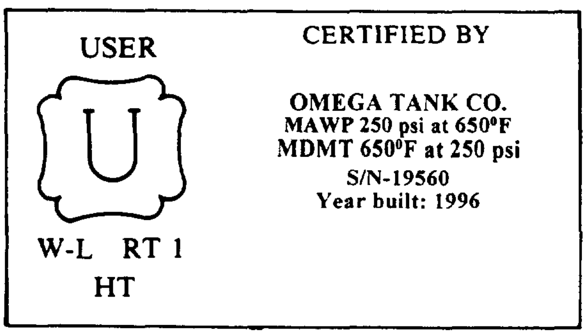
Pressure vessels built in accordance with the requirements of the Code may be stamped with the official symbol "U" to denote The American Society of Mechanical Engineers' standard.

Pressure vessels stamped with the Code-symbol shall be marked with the following:

1. manufacturer's name; preceded with the words: "certified by";
   maximum allowable working pressure, (MAWP) psi at temperature, °F;
   minimum design metal temperature at pressure, psi; (MDMT)
   manufacturer's serial number; (S/N)
   year built
   Abbreviations may be used as shown in parenthesis.
2. the appropriate abbreviations indicating the type of construction, service, etc. as tabulated:

When inspected by a user's inspector	USER
Arc or gas welded	W
Lethal service	L
Unfired steam boiler	UB
Direct firing	DF
Fully radiographed and UW-11(a) (5) not applied	RT 1
Joints A & D fully radiographed; UW-11(a) (5) (b) applied	RT 2
Spot radiographed	RT 3
When RT1, RT2 or RT3 are not applicable	RT 4
Post weld heat treated	HT
Part of the vessel post weld heat treated	PHT
Nonstationary Pressure Vessels	NPV

1. Symbol "UM" shall be used when the vessel is exempted from inspection [Code U-1(k)]
2. For vessels made of 5%, 8% and 9% nickel steels, the use of nameplates is mandatory for shell thicknesses below ½ in.; name plates are preferred on all thicknesses. Code ULT-115(c)



NAME PLATE EXAMPLE

(The vessel was inspected by user's inspector, arc welded, used in lethal service, fully radiographed and post weld heat treated.)

Additional data shall be below the Code required marking.

The name plate shall be affixed directly to the shell. If additional name plate is used on skirts, supports, etc., it shall be marked: "Duplicate".

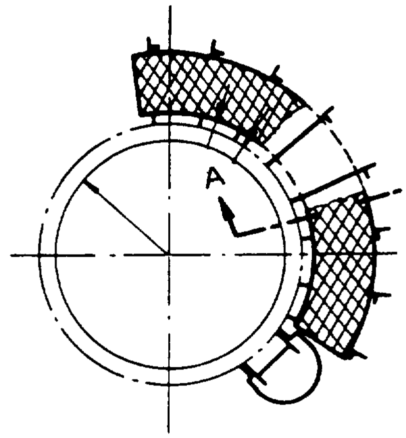
Lettering size shall be not less than 5/32 in. high. The Code-symbol and serial number shall be stamped, the other data may be stamped, etched, cast or impressed.

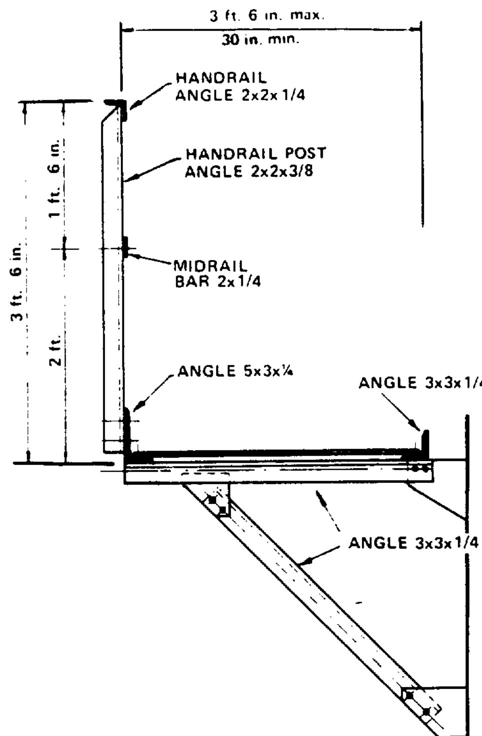
Commonly used material for name plate 0.32 in. stainless steel or 1/8 in. carbon steel. The name plate shall be seal welded to uninsulated vessel or mounted on bracket if the vessel is insulated, and located in some conspicuous place; near manways, liquid level control, level gage, about 5 ft above ground etc.

PLATFORM

Conforms to the requirements of

OCCUPATIONAL SAFETY AND HEALTH (OSHA) STANDARDS





SECTION A – A

Platforms shall be fabricated in sections if necessary suitable for shipping and field erection.

Platforms fabricated in sections shall be shop fitted, marked and knocked down for shipping.

All field connections are to be bolted.

Manufacturer shall furnish 10% extra bolts of each sizes for spare.

All burrs and sharp edges shall be removed.

Paint: one shop coat primer, except walking surfaces.

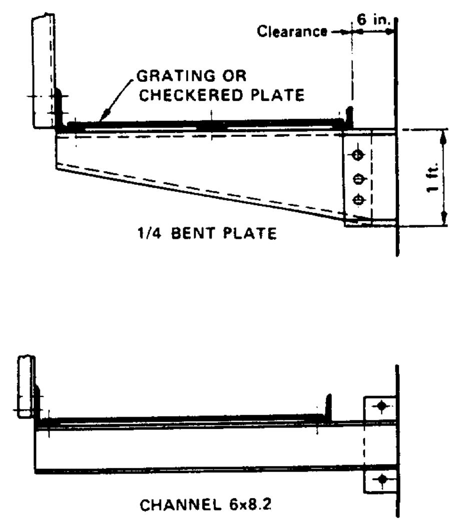
Max. spacing of supports 6 ft.

Max. spacing of handrail posts 6 ft.

Drill one 9/16 ϕ drain hole in checkered plate for each 10 sq. ft. area of floor.

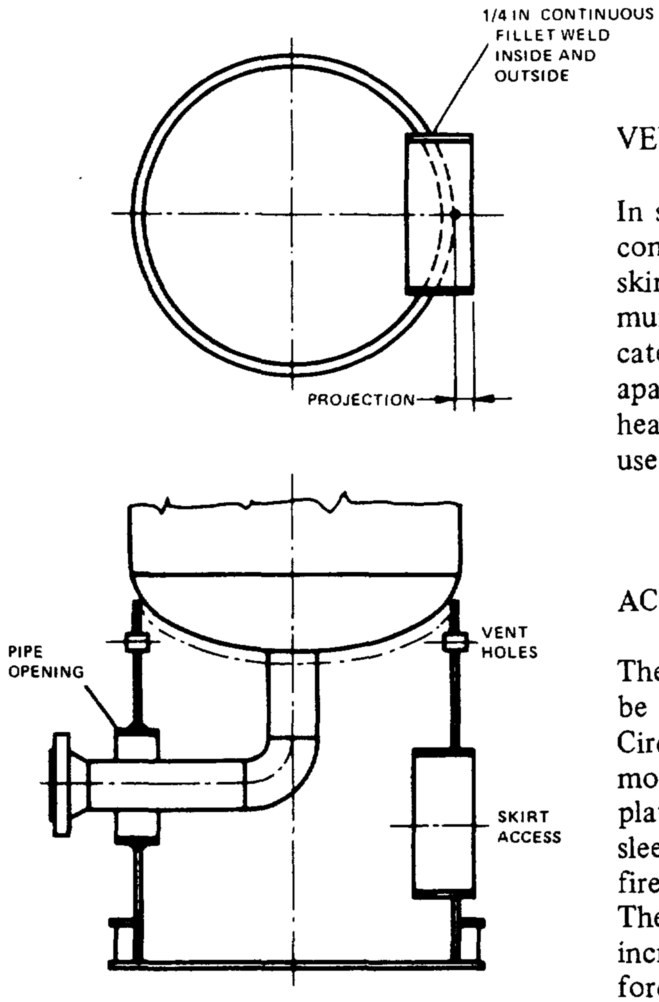
Bolts 1/2 ϕ

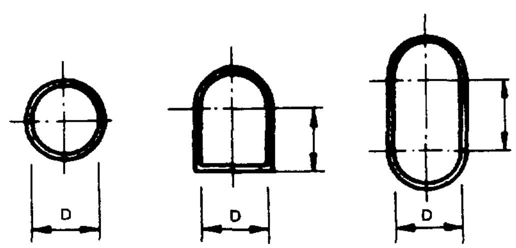
Bolt holes 9/16 ϕ



ALTERNATIVE SUPPORTS

SKIRT OPENINGS





TYPES OF SKIRT ACCESSES

VENT HOLES

In service of hydrocarbons or other combustible liquids or gases the skirts shall be provided with minimum of two 2 inch vent holes located as high as possible 180 degrees apart. The vent holes shall clear head insulation. For sleeve may be used coupling or pipe.

ACCESS OPENINGS

The shape of access openings may be circular or any other shapes. Circular access openings are used most frequently with pipe or bent plate sleeves. The projection of sleeve equals to the thickness of fireproofing or minimum 2 inches. The projection of sleeves shall be increased when necessary for reinforcing the skirt under certain loading conditions.

Diameter (D) = 16 - 24 inches

PIPE OPENINGS

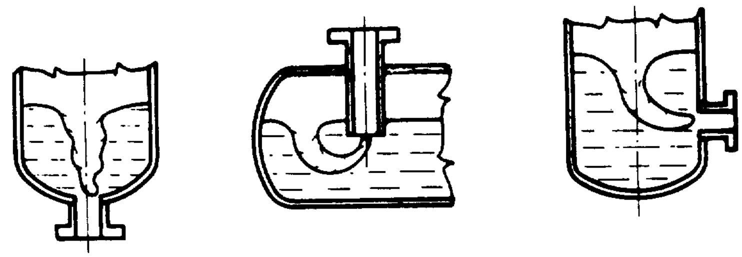
The shape of pipe openings are circular with a diameter of 1 inch larger than the diameter of flange. Sleeves should be provided as for access openings.

VORTEX BREAKER

The purpose of vortex breakers is to eliminate the undesirable vortexing of liquids.

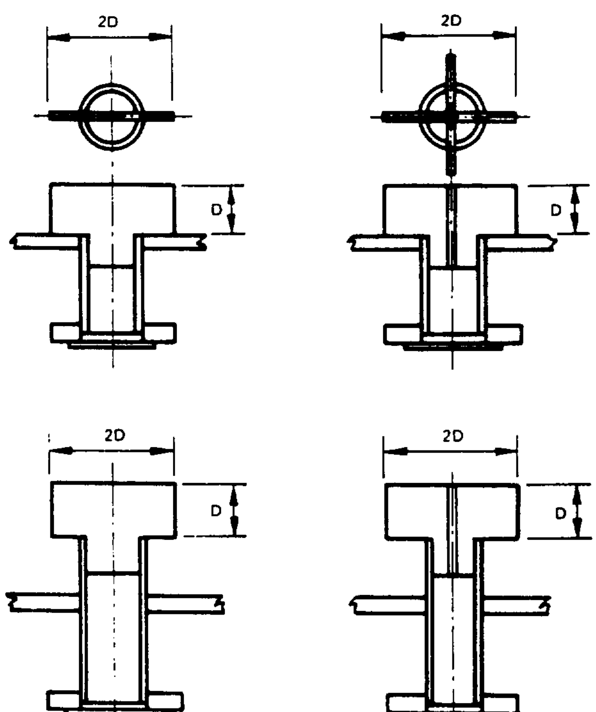
Cross and flat-plate baffles are frequently used with a width of two times the nozzle diameter.

For a high degree of effectiveness under severe swirling conditions the width of the baffle should be four times the nozzle diameter. The height above the outlet should be about half the nozzle diameter but may be several inches if required larger clearance for other reasons.

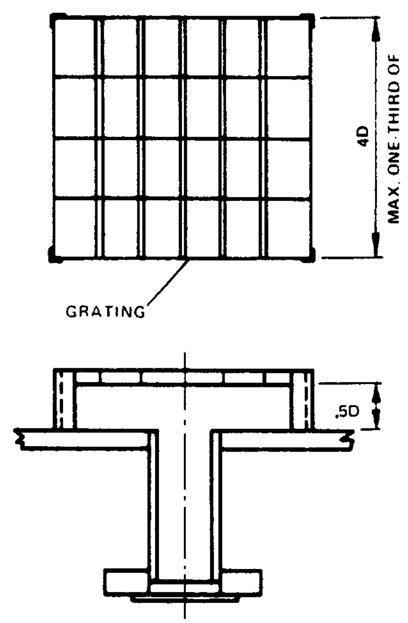


VORTEXING OF LIQUIDS

D = DIAMETER OF PIPE



FLAT AND CROSS PLATE BAFFLES



GRATING BAFFLE

Material: 1/4 carbon steel plate or grating with 1 x 1-1/8 bars.

Reference: F. M. Patterson "Vortexing can be prevented" The Oil and Gas Journal, August 4, 1969.

PART III.

MEASURES AND WEIGHTS

PROPERTIES OF PIPE

Schedule numbers and weight designations are in agreement with ANSI B36.10 for carbon and alloy steel pipe and ANSI B36.19 for stainless steel pipe.

Nom. pipe size	Schedule No.		Weight Desig-nation	Out-side diam. in.	In-side diam. in.	Wall thick-ness in.	Weight per foot lb.	Wt. of water per ft. pipe lb.	Outside surface per ft. sq. ft.	Inside surface per ft. sq. ft.	Trans-verse area sq. in.
	Carbon & alloy steels	Stain-less steels									
1/8	...	10S	....	.405	.307	.049	.186	.0320	.106	.0804	.0740
	40	40S	Std.	.405	.269	.068	.244	.0246	.106	.0705	.0568
	80	80S	X-Stg.	.405	.215	.095	.314	.0157	.106	.0563	.0364
1/4	...	10S	....	.540	.410	.065	.330	.0570	.141	.1073	.1320
	40	40S	Std.	.540	.364	.088	.424	.0451	.141	.0955	.1041
	80	80S	X-Stg.	.540	.302	.119	.535	.0310	.141	.0794	.0716
3/8	...	10S	....	.675	.545	.065	.423	.1010	.177	.1427	.2333
	40	40S	Std.	.675	.493	.091	.567	.0827	.177	.1295	.1910
	80	80S	X-Stg.	.675	.423	.126	.738	.0609	.177	.1106	.1405
1/2	...	10S	....	.840	.670	.083	.671	.1550	.220	.1764	.3568
	40	40S	Std.	.840	.622	.109	.850	.1316	.220	.1637	.3040
	80	80S	X-Stg.	.840	.546	.147	1.087	.1013	.220	.1433	.2340
	160	...	....	.840	.466	.187	1.310	.0740	.220	.1220	.1706
	...	...	XX-Stg.	.840	.252	.294	1.714	.0216	.220	.0660	.0499
3/4	...	10S	....	1.050	.834	.083	.857	.2660	.275	.2314	.6138
	40	40S	Std.	1.050	.824	.113	1.130	.2301	.275	.2168	.5330
	80	80S	X-Stg.	1.050	.742	.154	1.473	.1875	.275	.1948	.4330
	...	...	....	1.050	.675	.188	1.727	.1514	.275	.1759	.3570
	160	...	....	1.050	.614	.218	1.940	.1280	.275	.1607	.2961
	...	...	XX-Stg.	1.050	.434	.308	2.440	.0633	.275	.1137	.1479
1	...	10S	....	1.315	1.097	.109	1.404	.4090	.344	.2872	.9448
	40	40S	Std.	1.315	1.049	.133	1.678	.3740	.344	.2740	.8640
	80	80S	X-Stg.	1.315	.957	.179	2.171	.3112	.344	.2520	.7190
	...	...	....	1.315	.877	.219	2.561	.2614	.344	.2290	.6040
	160	...	....	1.315	.815	.250	2.850	.2261	.344	.2134	.5217
	...	...	XX-Stg.	1.315	.599	.358	3.659	.1221	.344	.1570	.2818
1 1/4	...	10S	....	1.660	1.442	.109	1.806	.7080	.434	.3775	1.633
	40	40S	Std.	1.660	1.380	.140	2.272	.6471	.434	.3620	1.495
	80	80S	X-Stg.	1.660	1.278	.191	2.996	.5553	.434	.3356	1.283
	160	...	....	1.660	1.160	.250	3.764	.4575	.434	.3029	1.057
	...	...	XX-Stg.	1.660	.896	.382	5.214	.2732	.434	.2331	.6305
1 1/2	...	10S	....	1.900	1.682	.109	2.085	.9630	.497	.4403	2.221
	40	40S	Std.	1.900	1.610	.145	2.717	.8820	.497	.4213	2.036
	80	80S	X-Stg.	1.900	1.500	.200	3.631	.7648	.497	.3927	1.767
	160	...	....	1.900	1.337	.281	4.862	.6082	.497	.3519	1.405
	...	...	XX-Stg.	1.900	1.100	.400	6.408	.4117	.497	.2903	.950
2	...	10S	....	2.375	2.157	.109	2.638	1.583	.622	.5647	3.654
	40	40S	Std.	2.375	2.067	.154	3.652	1.452	.622	.5401	3.355
	...	...	....	2.375	2.041	.167	3.938	1.420	.622	.5360	3.280

PROPERTIES OF PIPE (con't.)

Nominal pipe size	Schedule No. Carbon & alloy steels	Schedule No. Stainless steels	Weight designation	Outside diam. in.	Inside diam. in.	Wall thickness in.	Weight per foot lb.	Wt. of water per ft. pipe lb.	Outside surface per ft. sq. ft.	Inside surface per ft. sq. ft.	Transverse area sq. in.
2 (CONT.)	...	...	....	2.375	2.000	.188	4.380	1.363	.622	.5237	3.142
	80	80S	X-Stg.	2.375	1.939	.218	5.022	1.279	.622	.5074	2.953
	...	. .	....	2.375	1.875	.250	5.673	1.196	.622	.4920	2.761
	...	...	....	2.375	1.750	.312	6.883	1.041	.622	.4581	2.405
	160	...	....	2.375	1.689	.343	7.450	.767	.622	.4422	2.240
	...	...	XX-Stg.	2.375	1.503	.436	9.029	.769	.622	.3929	1.774
$2\frac{1}{2}$	...	10S	....	2.875	2.635	.120	3.53	2.360	.753	.6900	5.453
	40	40S	Std.	2.875	2.469	.203	5.79	2.072	.753	.6462	4.788
	...	...	...	2.875	2.441	.217	6.16	2.026	.753	.6381	4.680
	80	80S	X-Stg.	2.875	2.323	.276	7.66	1.834	.753	.6095	4.238
	160	...	....	2.875	2.125	.375	10.01	1.535	.753	.5564	3.547
	...	...	XX-Stg.	2.875	1.771	.552	13.69	1.067	.753	.4627	2.464
3	...	10S	....	3.500	3.260	.120	4.33	3.62	.916	.853	8.346
	...	...	....	3.500	3.250	.125	4.52	3.60	.916	.851	8.300
	...	...	....	3.500	3.204	.148	5.30	3.52	.916	.840	8.100
	...	...	....	3.500	3.124	.188	6.65	3.34	.916	.819	7.700
	40	40S	Std.	3.500	3.068	.216	7.57	3.20	.916	.802	7.393
	. .	.	....	3.500	3.018	.241	8.39	3.10	.916	.790	7.155
	...	...	....	3.500	2.992	254	8.80	3.06	.916	.785	7.050
	...	...	....	3.500	2.922	.289	9.91	2.91	.916	.765	6.700
	80	80S	X-Stg.	3.500	2.900	.300	10.25	2.86	.916	.761	6.605
	...	...	....	3.500	2.875	.312	10.64	2.81	.916	.753	6.492
	...	...	....	3.500	2.687	.406	13.42	2.46	.916	.704	5.673
	160	...	....	3.500	2.624	.438	14.32	2.34	.916	.687	5.407
	...	...	XX-Stg.	3.500	2.300	.600	18.58	1.80	.916	.601	4.155
$3\frac{1}{2}$	...	10S	....	4.000	3.760	.120	4.97	4.81	1.047	.984	11.10
	...	...	....	4.000	3.744	.128	5.38	4.78	1.047	.981	11.01
	...	...	....	4.000	3.732	.134	5.58	4.75	1.047	.978	10.95
	...	...	....	4.000	3.704	.148	6.26	4.66	1.047	.971	10.75
	...	...	. .	4.000	3.624	.188	7.71	4.48	1.047	.950	10.32
	40	40S	Std.	4.000	3.548	.226	9.11	4.28	1.047	.929	9.89
	. .			4.000	3.438	.281	11.17	4.02	1.047	.900	9.28
	80	80S	X-Stg.	4.000	3.364	.318	12.51	3.85	1.047	.880	8.89
	...	...		4.000	3.312	.344	13.42	3.73	1.047	.867	8.62
	...	...		4.000	3.062	.469	17.68	3.19	1.047	.802	7.37
	...	...	XX-Stg.	4.000	2.728	.636	22.85	2.53	1.047	.716	5.84
4	...	10S	...	4.500	4.260	.120	5.61	6.18	1.178	1.115	14.25
	...	...	....	4.500	4.244	.128	5.99	6.14	1.178	1.111	14.15
	...	...	. .	4.500	4.232	.134	6.26	6.11	1.178	1.110	14.10
	...	...	...	4.500	4.216	.142	6.61	6.06	1.178	1.105	13.98
	...	...	....	4.500	4.170	.165	7.64	5.92	1.178	1.093	13.67
	...	...	....	4.500	4.124	.188	8.56	5.80	1.178	1.082	13.39

PROPERTIES OF PIPE (con't.)

Nominal pipe size	Schedule No.		Weight designation	Outside diam. in.	Inside diam. in.	Wall thickness in.	Weight per foot lb.	Wt. of water per ft. pipe lb.	Outside surface per ft. sq. ft.	Inside surface per ft. sq. ft.	Transverse area sq. in.
	Carbon & alloy steels	Stainless steels									
4 (CONT.)	...	...	....	4.500	4.090	.205	9.39	5.71	1.178	1.071	13.15
	40	40S	Std.	4.500	4.026	.237	10.79	5.51	1.178	1.055	12.73
	...	...	....	4.500	4.000	.250	11.35	5.45	1.178	1.049	12.57
	...	...	....	4.500	3.958	.271	12.24	5.35	1.178	1.038	12.31
	...	...	....	4.500	3.938	.281	12.67	5.27	1.178	1.031	12.17
	...	...	....	4.500	3.900	.300	13.42	5.19	1.178	1.023	11.96
	...			4.500	3.876	.312	14.00	5.12	1.178	1.013	11.80
	80	80S	X-Stg.	4.500	3.826	.337	14.98	4.98	1.178	1.002	11.50
	...	...		4.500	3.750	.375	16.52	4.78	1.178	.982	11.04
	120	...	....	4.500	3.624	.438	19.00	4.47	1.178	.949	10.32
	...	...	....	4.500	3.500	.500	21.36	4.16	1.178	.916	9.62
	160	...	....	4.500	3.438	.531	22.60	4.02	1.178	.900	9.28
	...	...	XX-Stg.	4.500	3.152	.674	27.54	3.38	1.178	.826	7.80
5	...	10S	....	5.563	5.295	.134	7.770	9.54	1.456	1.386	22.02
	40	40S	Std.	5.563	5.047	.258	14.62	8.66	1.456	1.321	20.01
	...	...	....	5.563	4.859	.352	19.59	8.06	1.456	1.272	18.60
	80	80S	X-Stg.	5.563	4.813	.375	20.78	7.87	1.456	1.260	18.19
	...	...	....	5.563	4.688	.437	23.95	7.47	1.456	1.227	17.26
	120	...	....	5.563	4.563	.500	27.10	7.08	1.456	1.195	16.35
	160	...	....	5.563	4.313	.625	32.96	6.32	1.456	1.129	14.61
	...	...	XX-Stg.	5.563	4.063	.750	38.55	5.62	1.456	1.064	12.97
6	...	10S	....	6.625	6.357	.134	9.29	13.70	1.735	1.660	31.75
	...	...	....	6.625	6.287	.169	11.56	13.45	1.735	1.650	31.00
	...	...	....	6.625	6.265	.180	12.50	13.38	1.735	1.640	30.81
	...	...	....	6.625	6.249	.188	12.93	13.31	1.735	1.639	30.70
	...	...	....	6.625	6.187	.219	15.02	13.05	1.735	1.620	30.10
	...	...	....	6.625	6.125	.250	17.02	12.80	1.735	1.606	29.50
	...	...	....	6.625	6.071	.277	18.86	12.55	1.735	1.591	28.95
	40	40S	Std.	6.625	6.065	.280	18.97	12.51	1.735	1.587	28.99
	...	...	....	6.625	5.875	.375	25.10	11.75	1.735	1.540	27.10
	80	80S	X-Stg.	6.625	5.761	.432	28.57	11.29	1.735	1.510	26.07
	...	...	....	6.625	5.625	.500	32.79	10.85	1.735	1.475	24.85
	120	...	...	6.625	5.501	.562	36.40	10.30	1.735	1.470	23.77
	160	...	....	6.625	5.189	.718	45.30	9.16	1.735	1.359	21.15
	...	...	XX-Stg	6.625	4.897	.864	53.16	8.14	1.735	1.280	18.83
8	...	10S	....	8.625	8.329	.148	13.40	23.6	2.26	2.180	54.5
	...	...	....	8.625	8.309	.158	14.26	23.6	2.26	2.178	54.3
	...	...	....	8.625	8.295	.165	14.91	23.5	2.26	2.175	54.1
	...	...	....	8.625	8.249	.188	16.90	23.2	2.26	2.161	53.5
	...	...	....	8.625	8.219	.203	18.30	23.1	2.26	2.152	53.1
	...	...	....	8.625	8.187	.219	19.64	22.9	2.26	2.148	52.7

PROPERTIES OF PIPE (con't.)

Nominal pipe size	Schedule No.		Weight designation	Outside diam. in.	Inside diam. in.	Wall thickness in.	Weight per foot lb.	Wt. of water per ft. pipe lb.	Outside surface per ft. sq. ft.	Inside surface per ft. sq. ft.	Transverse area sq. in.
	Carbon & alloy steels	Stainless steels									
8 (CONT.)	...	...	....	8.625	8.149	.238	21.43	22.7	2.26	2.136	52.2
	20	...	....	8.625	8.125	.250	22.40	22.5	2.26	2.127	51.8
	30	...	....	8.625	8.071	.277	24.70	22.2	2.26	2.115	51.2
	40	40S	Std.	8.625	7.981	.322	28.55	21.6	2.26	2.090	50.0
	...	...	....	8.625	7.937	.344	30.40	21.4	2.26	2.078	49.5
	...	...	....	8.625	7.921	.352	31.00	21.3	2.26	2.072	49.3
	...	...	....	8.625	7.875	.375	33.10	21.1	2.26	2.062	48.7
	60	...	....	8.625	7.813	.406	35.70	20.8	2.26	2.045	47.9
	...	...	....	8.625	7.687	.469	40.83	20.1	2.26	2.013	46.4
	80	80S	X-Stg.	8.625	7.625	.500	43.39	19.8	2.26	2.006	45.6
	100	...	....	8.625	7.439	.593	50.90	18.8	2.26	1.947	43.5
	...	...	....	8.625	7.375	.625	53.40	18.5	2.26	1.931	42.7
	120	...	....	8.625	7.189	.718	60.70	17.6	2.26	1.882	40.6
	140	...	....	8.625	7.001	.812	67.80	16.7	2.26	1.833	38.5
	...	...	XX-Stg.	8.625	6.875	.875	72.42	16.1	2.26	1.800	37.1
	160	...	....	8.625	6.813	.906	74.70	15.8	2.26	1.784	36.4
10	...	10S	....	10.750	10.420	.165	18.65	36.9	2.81	2.73	85.3
	...	...	....	10.750	10.374	.188	21.12	36.7	2.81	2.72	84.5
	...	...	....	10.750	10.344	.203	22.86	36.5	2.81	2.71	84.0
	...	...	....	10.750	10.310	.219	24.60	36.2	2.81	2.70	83.4
	20	...	....	10.750	10.250	.250	28.03	35.9	2.81	2.68	82.6
	...	...	....	10.750	10.192	.279	31.20	35.3	2.81	2.66	81.6
	30	...	....	10.750	10.136	.307	34.24	35.0	2.81	2.65	80.7
	...	...	....	10.750	10.054	.348	38.66	34.4	2.81	2.64	79.3
	40	40S	Std.	10.750	10.020	.365	40.48	34.1	2.81	2.62	78.9
	...	...	....	10.750	9.960	.395	43.68	33.7	2.81	2.61	77.9
	60	80S	X-Stg.	10.750	9.750	.500	54.74	32.3	2.81	2.55	74.7
	...	...	....	10.750	9.687	.531	57.98	31.9	2.81	2.54	73.7
	80	...	....	10.750	9.564	.593	64.40	31.1	2.81	2.50	71.8
	100	...	....	10.750	9.314	.718	77.00	29.5	2.81	2.44	68.1
	...	...	....	10.750	9.250	.750	80.10	29.1	2.81	2.42	67.2
	120	...	....	10.750	9.064	.843	89.20	27.9	2.81	2.37	64.5
	140	...	....	10.750	8.750	1.000	104.20	26.1	2.81	2.29	60.1
	...	...	....	10.750	8.625	1.063	109.90	25.3	2.81	2.26	58.4
	160	...	....	10.750	8.500	1.125	116.00	24.6	2.81	2.22	56.7
12	...	10S	....	12.750	12.390	.180	24.16	52.2	3.34	3.24	120.6
	...	...	....	12.750	12.344	.203	27.2	52.0	3.34	3.23	119.9
	...	...	....	12.750	12.312	.219	29.3	51.7	3.34	3.22	119.1
	...	...	....	12.750	12.274	.238	31.8	51.5	3.34	3.22	118.5
	20	...	....	12.750	12.250	.250	33.4	51.3	3.34	3.12	118.0

PROPERTIES OF PIPE (con't.)

Nominal pipe size	Schedule No. Carbon & alloy steels	Schedule No. Stainless steels	Weight designation	Outside diam. in.	Inside diam. in.	Wall thickness in.	Weight per foot lb.	Wt. of water per ft. pipe lb.	Outside surface per ft. sq. ft.	Inside surface per ft. sq. ft.	Transverse area sq. in.
12 (CONT.)	...	...	....	12.750	12.192	.279	37.2	50.7	3.34	3.19	116.9
	...	...	....	12.750	12.150	.300	40.0	50.5	3.34	3.18	116.1
	30	...	....	12.750	12.090	.330	43.8	49.7	3.34	3.16	114.8
	...	...	...	12.750	12.062	.344	45.5	49.7	3.34	3.16	114.5
	...	40S	Std.	12.750	12.000	.375	49.6	48.9	3.34	3.14	113.1
	40	...		12.750	11.938	.406	53.6	48.5	3.34	3.13	111.9
	...	...	...	12.750	11.874	.438	57.5	48.2	3.34	3.11	111.0
	...	80S	X-Stg.	12.750	11.750	.500	65.4	46.9	3.34	3.08	108.4
	60		...	12.750	11.626	.562	73.2	46.0	3.34	3.04	106.2
		...	....	12.750	11.500	.625	80.9	44.9	3.34	3.01	103.8
	80	...	....	12.750	11.376	.687	88.6	44.0	3.34	2.98	101.6
	100	...	....	12.750	11.064	.843	108.0	41.6	3.34	2.90	96.1
	...	...	....	12.750	11.000	.875	110.9	41.1	3.34	2.88	95.0
	120	...	....	12.750	10.750	1.000	125.5	39.3	3.34	2.81	90.8
	140	...	....	12.750	10.500	1.125	140.0	37.5	3.34	2.75	86.6
		...	....	12.750	10.313	1.219	150.1	36.3	3.34	2.70	83.8
	160	...	....	12.750	10.126	1.312	161.0	34.9	3.34	2.65	80.5
14	...	...	....	14.000	13.624	.188	28	63.4	3.67	3.57	146.0
	...	...	....	14.000	13.560	.220	32	63.0	3.67	3.55	145.0
	...	...	...	14.000	13.524	.238	35	62.5	3.67	3.54	144.0
	10	...	...	14.000	13.500	.250	37	62.1	3.67	3.54	143.0
	20	...	....	14.000	13.375	.312	46	60.8	3.67	3.50	140.5
	30	...	Std.	14.000	13.250	.375	55	59.7	3.67	3.47	137.9
	...	...	....	14.000	13.188	.406	58	59.5	3.67	3.45	137.0
	40	...	....	14.000	13.124	.438	63	58.5	3.67	3.44	135.3
	...	...	...	14.000	13.062	.469	68	58.1	3.67	3.42	134.0
	...	...	X-Stg.	14.000	13.000	.500	72	57.4	3.67	3.40	132.7
	60	...	....	14.000	12.814	.593	85	55.9	3.67	3.35	129.0
	...	...	....	14.000	12.750	.625	89	55.3	3.67	3.34	127.7
	...	...	....	14.000	12.688	.656	94	54.7	3.67	3.32	126.4
	80	...	....	14.000	12.500	.750	107	51.2	3.67	3.27	122.7
	100		....	14.000	12.125	.937	131	50.0	3.67	3.17	115.5
	120	...	...	14.000	11.814	1.093	151	47.5	3.67	3.09	109.6
	140	...	....	14.000	11.500	1.250	171	45.0	3.67	3.01	103.9
	...	...	....	14.000	11.313	1.344	182	43.5	3.67	2.96	100.5
	160	...	....	14.000	11.188	1.406	190	42.6	3.67	2.93	98.3

PROPERTIES OF PIPE (con't.)

Nominal pipe size	Schedule No. Carbon & alloy steels	Schedule No. Stainless steels	Weight designation	Outside diam. in.	Inside diam. in.	Wall thickness in.	Weight per foot lb.	Wt. of water per ft. pipe lb.	Outside surface per ft. sq. ft.	Inside surface per ft. sq. ft.	Transverse area sq. in.
16	...	...	....	16.000	15.624	.188	32	83.3	4.20	4.09	192.0
	...	...	....	16.000	15.524	.238	40	82.5	4.20	4.06	190.0
	10	...	....	16.000	15.500	.250	42	82.1	4.20	4.06	189.0
	...	...	....	16.000	15.438	.281	47	81.2	4.20	4.04	187.0
	20	...	....	16.000	15.375	.312	52	80.1	4.20	4.03	185.6
		...	....	16.000	15.312	344	57	80.0	4.20	4.01	184.1
	30	...	Std.	16.000	15.250	.375	63	79.1	4.20	4.00	182.6
	...	...	....	16.000	15.188	.406	68	78.6	4.20	3.98	181.0
	...	...	....	16.000	15.124	.438	73	78.2	4.20	3.96	180.0
	...	...	....	16.000	15.062	.469	78	77.5	4.20	3.94	178.5
	40	...	X-Stg.	16.000	15.000	.500	83	76.5	4.20	3.93	176.7
	...	...	....	16.000	14.938	.531	88	75.8	4.20	3.91	175.2
	60	...	....	16.000	14.688	.656	108	73.4	4.20	3.85	169.4
	...	...	....	16.000	14.625	.687	112	72.7	4.20	3.83	168.0
	...	...	....	16.000	14.500	.750	122	71.5	4.20	3.80	165.1
	80	...	....	16.000	14.314	.843	137	69.7	4.20	3.75	160.9
	100	...	....	16.000	13.938	1.031	165	66.0	4.20	3.65	152.6
	120	...	....	16.000	13.564	1.218	193	62.6	4.20	3.55	144.5
	140.	...	....	16.000	13.124	1.438	224	58.6	4.20	3.44	135.3
	...	...	....	16.000	13.000	1.500	232	57.4	4.20	3.40	132.7
	160	...	....	16.000	12.814	1.593	245	55.9	4.20	3.35	129.0
18	10	...	....	18.000	17.500	.250	47	104.6	4.71	4.58	241.0
	20	...	....	18.000	17.375	.312	59	102.5	4.71	4.55	237.1
	...	...	Std.	18.000	17.250	.375	71	101.2	4.71	4.51	233.7
	30	...	....	18.000	17.124	.438	82	99.5	4.71	4.48	229.5
	...	...	X-Stg	18.000	17.000	.500	93	98.2	4.71	4.45	227.0
	40	...	....	18.000	16.876	.562	105	97.2	4.71	4.42	224.0
	...	...	....	18.000	16.813	.594	110	96.1	4.71	4.40	222.0
	...	...	....	18.000	16.750	.625	116	95.8	4.71	4.39	220.5
	60	...	....	18.000	16.500	.750	138	92.5	4.71	4.32	213.8
	...	...	....	18.000	16.375	.812	149	91.2	4.71	4.29	210.6
	80	...	....	18.000	16.126	.937	171	88.5	4.71	4.22	204.2
	100	...	....	18.000	15.688	1.156	208	83.7	4.71	4.11	193.3
	120	...	....	18.000	15.250	1.375	244	79.2	4.71	3.99	182.7
	140	...	....	18.000	14.876	1.562	275	75.3	4.71	3.89	173.8
	...	...	....	18.000	14.625	1.687	294	72.7	4.71	3.83	168.0
	160	...	....	18.000	14.438	1.781	309	71.0	4.71	3.78	163.7

PROPERTIES OF PIPE (con't.)

Nominal pipe size	Schedule No. Carbon & alloy steels	Schedule No. Stainless steels	Weight designation	Outside diam. in.	Inside diam. in.	Wall thickness in.	Weight per foot lb.	Wt. of water per ft. pipe lb.	Outside surface per ft. sq. ft.	Inside surface per ft. sq. ft.	Transverse area sq. in.
20	10	...	....	20.000	19.500	.250	53	130.0	5.24	5.11	299.0
	...	...	....	20.000	19.374	.313	66	128.1	5.24	5.08	295.0
	20	...	Std.	20.000	19.250	.375	79	126.0	5.24	5.04	291.1
	...	...	....	20.000	19.124	.438	92	125.1	5.24	5.01	288.0
	30	...	X-Stg.	20.000	19.000	.500	105	122.8	5.24	4.97	283.5
	...	...	....	20.000	18.875	.562	117	121.1	5.24	4.94	279.8
	40	...	....	20.000	18.814	.593	123	120.4	5.24	4.93	278.0
	...	...	....	20.000	18.750	.625	129	119.5	5.24	4.91	276.1
	60	...	....	20.000	18.376	.812	167	114.9	5.24	4.81	265.2
	...	...	....	20.000	18.250	.875	179	113.2	5.24	4.78	261.6
	...	...	....	20.000	18.188	.906	185	112.7	5.24	4.76	259.8
	80	...	....	20.000	17.938	1.031	209	109.4	5.24	4.80	252.7
	100	...	....	20.000	17.438	1.281	256	103.4	5.24	4.56	238.8
	120	...	...	20.000	17.000	1.500	297	98.3	5.24	4.45	227.0
	140	....	....	20.000	16.500	1.750	342	92.6	5.24	4.32	213.8
	...	....	....	20.000	16.313	1.844	357	90.5	5.24	4.27	209.0
	160	....	....	20.000	16.064	1.968	379	87.9	5.24	4.21	202.7
22	...	....	....	22.000	21.500	.250	58	157.4	5.76	5.63	363.1
	...	....	....	22.000	21.376	.312	72	155.6	5.76	5.60	358.9
	...	....	....	22.000	21.250	.375	87	153.7	5.76	5.56	354.7
	...	....	....	22.000	21.126	.437	103	152.0	5.76	5.53	350.5
	...	....	....	22.000	21.000	.500	115	150.2	5.76	5.50	346.4
	...	....	....	22.000	20.876	.562	129	148.4	5.76	5.47	342.3
	...	....	....	22.000	20.750	.625	143	146.6	5.76	5.43	338.2
	...	....	....	22.000	20.624	.688	157	144.8	5.76	5.40	334.1
	...	....	....	22.000	20.500	.750	170	143.1	5.76	5.37	330.1
24	10	....	....	24.000	23.500	.250	63	189.0	6.28	6.15	435.0
	...	....	....	24.000	23.376	.312	79	186.9	6.28	6.12	430.0
	20	....	Std.	24.000	23.250	.375	95	183.8	6.28	6.09	424.6
	...	....	..	24.000	23.125	.437	110	181.8	6.28	6.05	420.0
	...	....	X-Stg.	24.000	23.000	.500	125	181.0	6.28	6.02	416.0
	30	....	...	24.000	22.876	.562	141	178.5	6.28	5.99	411.0
	...	....	....	24.000	22.750	.625	156	175.9	6.28	5.96	406.5
	40	....	....	24.000	22.626	.687	171	174.2	6.28	5.92	402.1
	...	....	....	24.000	22.500	.750	186	172.1	6.28	5.89	397.6
	60	...	....	24.000	22.064	.968	238	165.8	6.28	5.78	382.3
	...	....	....	24.000	21.938	1.031	253	163.6	6.28	5.74	378.0
	80	....	....	24.000	21.564	1.218	297	158.2	6.28	5.65	365.2
	100	....	....	24.000	20.938	1.531	367	149.3	6.28	5.48	344.3

PROPERTIES OF PIPE (con't.)

Nominal pipe size	Schedule No.		Weight designation	Outside diam. in.	Inside diam. in.	Wall thickness in.	Weight per foot lb.	Wt. of water per ft. pipe lb.	Outside surface per ft. sq. ft.	Inside surface per ft. sq. ft.	Transverse area sq. in.
	Carbon & alloy steels	Stainless steels									
24 (CONT.)	120	....	....	24.000	20.376	1.812	429	141.4	6.28	5.33	326.1
	140	....	....	24.000	19.876	2.062	484	134.4	6.28	5.20	310.3
	...	....	....	24.000	19.625	2.187	510	130.9	6.28	5.14	302.0
	160	....	....	24.000	19.314	2.343	542	127.0	6.28	5.06	293.1
26	...	....	....	26.000	25.500	.250	67	221.4	6.81	6.68	510.7
	...	....	....	26.000	25.376	.312	84	219.2	6.81	6.64	505.8
	...	....	....	26.000	25.250	.375	103	217.1	6.81	6.61	500.7
	...	....	....	26.000	25.126	.437	119	215.0	6.81	6.58	495.8
	...	....	....	26.000	25.000	.500	136	212.8	6.81	6.54	490.9
	...	....	....	26.000	24.876	.562	153	210.7	6.81	6.51	486.0
	...	....	....	26.000	24.750	.625	169	208.6	6.81	6.48	481.1
	...	....	....	26.000	24.624	.688	186	206.4	6.81	6.45	476.2
	...	....	....	26.000	24.500	.750	202	204.4	6.81	6.41	471.4
30	10	....	....	30.000	29.376	.312	99	293.7	7.85	7.69	677.8
	...	....	....	30.000	29.250	.375	119	291.2	7.85	7.66	672.0
	...	....	....	30.000	29.125	.437	138	288.7	7.85	7.62	666.2
	20	....	....	30.000	29.000	.500	158	286.2	7.85	7.59	660.5
	...	....	....	30.000	28.875	.562	177	283.7	7.85	7.56	654.8
	30			30.000	28.750	.625	196	281.3	7.85	7.53	649.2

DIMENSIONS OF PIPE

ANSI B 36.10

1. All Dimensions are in inches
2. The Nominal Wall Thicknesses shown are subject to a 12.5% Mill Tolerance
3. Not included in standard ANSI B 36.10

Nominal Pipe Size	Outside Diameter	NOMINAL WALL THICKNESS													
		Sched. 10	Sched. 20	Sched. 30	Std. Weight	Sched. 40	Sched. 60	Extra Strong	Sched. 80	Sched. 100	Sched. 120	Sched. 140	Sched. 160	XX Strong	Nominal Pipe Size
⅛	0.405	- -	- -	- -	0.068	0.068	- -	0.095	0.095	- -	- -	- -	- -	- -	⅛
¼	0.540	- -	- -	- -	0.088	0.088	- -	0.119	0.119	- -	- -	- -	- -	- -	¼
⅜	0.675	- -	- -	- -	0.091	0.091	- -	0.126	0.126	- -	- -	- -	- -	- -	⅜
½	0.840	- -	- -	- -	0.109	0.109	- -	0.147	0.147	- -	- -	- -	0.187	0.294	½
¾	1.050	- -	- -	- -	0.113	0.113	- -	0.154	0.154	- -	- -	- -	0.218	0.308	¾
1	1.315	- -	- -	- -	0.133	0.133	- -	0.179	0.179	- -	- -	- -	0.250	0.358	1
1¼	1.660	- -	- -	- -	0.140	0.140	- -	0.191	0.191	- -	- -	- -	0.250	0.382	1¼
1½	1.900	- -	- -	- -	0.145	0.145	- -	0.200	0.200	- -	- -	- -	0.281	0.400	1½
2	2.375	- -	- -	- -	0.154	0.154	- -	0.218	0.218	- -	- -	- -	0.343	0.436	2
2½	2.875	- -	- -	- -	0.203	0.203	- -	0.276	0.276	- -	- -	- -	0.375	0.552	2½
3	3.500	- -	- -	- -	0.216	0.216	- -	0.300	0.300	- -	- -	- -	0.438	0.600	3
3½	4.000	- -	- -	- -	0.226	0.226	- -	0.318	0.318	- -	- -	- -	- -	0.636[3]	3½
4	4.500	- -	- -	- -	0.237	0.237	- -	0.337	0.337	- -	0.438	- -	0.531	0.674	4
5	5.563	- -	- -	- -	0.258	0.258	- -	0.375	0.375	- -	0.500	- -	0.625	0.750	5
6	6.625	- -	- -	- -	0.280	0.280	- -	0.432	0.432	- -	0.562	- -	0.718	0.864	6
8	8.625	- -	0.250	0.277	0.322	0.322	0.406	0.500	0.500	0.593	0.718	0.812	0.906	0.875	8
10	10.750	- -	0.250	0.307	0.365	0.365	0.500	0.500	0.593	0.718	0.843	1.000	1.125	- -	10
12	12.750	- -	0.250	0.330	0.375	0.406	0.562	0.500	0.687	0.843	1.000	1.125	1.312	- -	12
14	14.000	0.250	0.312	0.375	0.375	0.438	0.593	0.500	0.750	0.937	1.093	1.250	1.406	- -	14
16	16.000	0.250	0.312	0.375	0.375	0.500	0.656	0.500	0.843	1.031	1.218	1.438	1.593	- -	16
18	18.000	0.250	0.312	0.438	0.375	0.562	0.750	0.500	0.937	1.156	1.375	1.562	1.781	- -	18
20	20.000	0.250	0.375	0.500	0.375	0.593	0.812	0.500	1.031	1.281	1.500	1.750	1.968	- -	20
24	24.000	0.250	0.375	0.562	0.375	0.687	0.968	0.500	1.218	1.531	1.812	2.062	2.343	- -	24
30[3]	30.000	0.312	0.500	0.625	0.375[3]	- -	- -	0.500[3]	- -	- -	- -	- -	- -	- -	30

PRESSURE VESSEL HANDBOOK

Tenth Edition

NOTE:
The CODE "does not contain rules - [as it states in Par. U-2 (g)] - to cover all details of design and construction. Where complete details are not given . . . the manufacturer . . . shall provide details . . ."

BUILD
BETTER VESSEL
FASTER
AND MORE
ECONOMICALLY

Design and construction details **not covered by the code,** have been selected from generally accepted sources, utilizing the most practical and economical methods.

PRESSURE VESSEL PUBLISHING, INC. P.O. BOX 35365 TULSA, OK 74153

PROPERTIES OF STEEL TUBING

O D of Tubing Inches	Wall Thick-ness Inches	Internal Area Sq. In.	Sq. Ft. External Surface Per Ft. Length	Sq. Ft. Internal Surface Per Ft. Length	Theoretical Weight Per Ft. Length	I D Tubing Inches	Constant C*	O D / I D	Metal Area (Transverse Metal Area) Sq. In.
5/8	.125	.1104	.1636	.0982	.668	.375	172	1.667	.1964
5/8	.110	.1288	.1636	.1060	.605	.405	201	1.543	.1780
5/8	.105	.1353	.1636	.1086	.583	.415	211	1.506	.1715
5/8	.095	.1486	.1636	.1139	.538	.435	232	1.437	.1582
5/8	.085	.1626	.1636	.1191	.490	.455	254	1.374	.1442
5/8	.075	.1772	.1636	.1244	.441	.475	276	1.316	.1296
5/8	.065	.1924	.1636	.1296	.389	.495	300	1.263	.1144
5/8	.060	.2003	.1636	.1322	.362	.505	312	1.238	.1065
5/8	.055	.2083	.1636	.1348	.335	.515	325	1.214	.0985
5/8	.050	.2165	.1636	.1374	.307	.525	338	1.190	.0903
3/4	.150	.1590	.1963	.1178	.961	.450	248	1.667	.2827
3/4	.135	.1810	.1963	.1257	.887	.480	282	1.563	.2608
3/4	.125	.1964	.1963	.1309	.834	.500	306	1.500	.2454
3/4	.110	.2206	.1963	.1388	.752	.530	344	1.415	.2212
3/4	.105	.2290	.1963	.1414	.723	.540	357	1.389	.2128
3/4	.095	.2463	.1963	.1466	.665	.560	384	1.339	.1955
3/4	.085	.2642	.1963	.1518	.604	.580	412	1.293	.1776
3/4	.075	.2827	.1963	.1571	.541	.600	441	1.250	.1590
3/4	.065	.3019	.1963	.1623	.476	.620	471	1.210	.1399
3/4	.060	.3117	.1963	.1649	.442	.630	486	1.190	.1301
3/4	.055	.3217	.1963	.1676	.408	.640	502	1.172	.1201
3/4	.050	.3318	.1963	.1702	.374	.650	518	1.154	.1100
7/8	.150	.2597	.2291	.1505	1.161	.575	405	1.522	.3416
7/8	.135	.2875	.2291	.1584	1.067	.605	448	1.446	.3138
7/8	.125	.3068	.2291	.1636	1.001	.625	478	1.400	.2945
7/8	.110	.3370	.2291	.1715	.899	.655	526	1.336	.2644
7/8	.105	.3473	.2291	.1741	.863	.665	542	1.316	.2540
7/8	.095	.3685	.2291	.1793	.791	.685	575	1.277	.2328
7/8	.085	.3904	.2291	.1846	.717	.705	609	1.241	.2110
7/8	.075	.4128	.2291	.1898	.641	.725	644	1.207	.1885
7/8	.065	.4359	.2291	.1950	.562	.745	680	1.174	.1654
7/8	.060	.4477	.2291	.1977	.522	.755	698	1.159	.1536
7/8	.055	.4596	.2291	.2003	.482	.765	717	1.144	.1417
7/8	.050	.4717	.2291	.2029	.441	.775	736	1.129	.1296
1	.150	.3848	.2618	.1833	1.362	.700	600	1.429	.4006
1	.135	.4185	.2618	.1911	1.247	.730	653	1.370	.3669
1	.125	.4418	.2618	.1964	1.168	.750	689	1.333	.3436
1	.110	.4778	.2618	.2042	1.046	.780	745	1.282	.3076
1	.105	.4902	.2618	.2068	1.004	.790	764	1.266	.2952
1	.095	.5153	.2618	.2121	.918	.810	804	1.235	.2701
1	.085	.5411	.2618	.2173	.831	.830	844	1.205	.2443
1	.075	.5675	.2618	.2225	.741	.850	885	1.176	.2179
1	.065	.5945	.2618	.2278	.649	.870	927	1.149	.1909
1	.060	.6082	.2618	.2304	.602	.880	949	1.136	.1772
1	.055	.6221	.2618	.2330	.555	.890	970	1.124	.1633
1	.050	.6362	.2618	.2356	.507	.900	992	1.111	.1492

$$\text{* Liquid velocity in feet/second} = \frac{\text{pounds per tube per hour}}{\text{C x specific gravity of liquid}}$$

Specific gravity of water at 60 deg. F = 1.0

Courtesy of HEAT EXCHANGE INSTITUTE

PROPERTIES OF TUBING

O.D. of Tubing	BWG Gage	Thick-ness Inches	Internal Area Sq. In.	Sq. Ft. External Surface per Ft. Length	Sq. Ft. Internal Surface per Ft. Length	Weight per Ft. Length Adm. Lbs.	Weight per Ft. Length Copper Lbs.	Weight per Ft. Length Steel Lbs.	I.D. Tubing Inches	Constant C*	O D / I D	Area Metal (Transverse Metal Area)
5/8	10	.134	.1001	.1636	.0935	.766	.801	.703	.357	156	1.751	.2067
5/8	11	.120	.1164	.1636	.1008	.705	.738	.647	.385	182	1.623	.1904
5/8	12	.109	.1301	.1636	.1066	.655	.685	.601	.407	203	1.536	.1767
5/8	13	.095	.1486	.1636	.1139	.586	.613	.538	.435	232	1.437	.1582
5/8	14	.083	.1655	.1636	.1202	.524	.548	.480	.459	258	1.362	.1413
5/8	15	.072	.1817	.1636	.1259	.464	.485	.425	.481	283	1.299	.1251
5/8	16	.065	.1924	.1636	.1296	.424	.443	.389	.495	300	1.263	.1144
5/8	17	.058	.2035	.1636	.1333	.383	.400	.351	.509	317	1.228	.1033
5/8	18	.049	.2181	.1636	.1380	.329	.344	.301	.527	340	1.186	.0887
5/8	19	.042	.2299	.1636	.1416	.285	.298	.262	.541	359	1.155	.0769
5/8	20	.035	.2419	.1636	.1453	.240	.251	.221	.555	377	1.126	.0649
5/8	22	.028	.2543	.1636	.1490	.195	.204	.179	.569	397	1.098	.0525
3/4	10	.134	.1825	.1963	.1262	.961	1.005	.882	.482	285	1.556	.2593
3/4	11	.120	.2043	.1963	.1335	.880	.920	.807	.510	319	1.471	.2375
3/4	12	.109	.2223	.1963	.1393	.813	.851	.746	.532	347	1.410	.2195
3/4	13	.095	.2463	.1963	.1466	.724	.758	.665	.560	384	1.339	.1955
3/4	14	.083	.2679	.1963	.1529	.644	.674	.591	.584	418	1.284	.1739
3/4	15	.072	.2884	.1963	.1587	.568	.594	.521	.606	450	1.238	.1534
3/4	16	.065	.3019	.1963	.1623	.518	.542	.476	.620	471	1.210	.1399
3/4	17	.058	.3157	.1963	.1660	.467	.489	.429	.634	492	1.183	.1261
3/4	18	.049	.3339	.1963	.1707	.400	.418	.367	.652	521	1.150	.1079
3/4	19	.042	.3484	.1963	.1744	.346	.362	.318	.666	543	1.126	.0934
3/4	20	.035	.3632	.1963	.1780	.291	.305	.267	.680	566	1.103	.0786
3/4	22	.028	.3783	.1963	.1817	.235	.246	.216	.694	590	1.081	.0635
7/8	10	.134	.2894	.2291	.1589	1.156	1.209	1.060	.607	451	1.442	.3119
7/8	11	.120	.3167	.2291	.1662	1.055	1.103	.968	.635	494	1.378	.2846
7/8	12	.109	.3390	.2291	.1720	.972	1.017	.892	.657	529	1.332	.2623
7/8	13	.095	.3685	.2291	.1793	.863	.902	.791	.685	575	1.277	.2328
7/8	14	.083	.3948	.2291	.1856	.765	.800	.702	.709	616	1.234	.2065
7/8	15	.072	.4197	.2291	.1914	.673	.704	.617	.731	655	1.197	.1816
7/8	16	.065	.4359	.2291	.1950	.613	.641	.562	.745	680	1.174	.1654
7/8	17	.058	.4525	.2291	.1987	.552	.577	.506	.759	706	1.153	.1489
7/8	18	.049	.4742	.2291	.2034	.471	.493	.432	.777	740	1.126	.1272
7/8	19	.042	.4914	.2291	.2071	.407	.426	.374	.791	766	1.106	.1099
7/8	20	.035	.5090	.2291	.2107	.342	.358	.314	.805	794	1.087	.0924
7/8	22	.028	.5268	.2291	.2144	.276	.289	.253	.819	822	1.068	.0745
1	10	.134	.4208	.2618	.1916	1.351	1.413	1.239	.732	656	1.366	.3646
1	11	.120	.4536	.2618	.1990	1.229	1.286	1.128	.760	707	1.316	.3318
1	12	.109	.4803	.2618	.2047	1.131	1.182	1.037	.782	749	1.279	.3051
1	13	.095	.5153	.2618	.2121	1.001	1.047	.918	.810	804	1.235	.2701
1	14	.083	.5463	.2618	.2183	.886	.927	.813	.834	852	1.199	.2391
1	15	.072	.5755	.2618	.2241	.778	.814	.714	.856	898	1.168	.2099
1	16	.065	.5945	.2618	.2278	.708	.740	.649	.870	927	1.149	.1909
1	17	.058	.6138	.2618	.2314	.636	.665	.584	.884	957	1.131	.1716
1	18	.049	.6390	.2618	.2361	.542	.567	.498	.902	997	1.109	.1464
1	19	.042	.6590	.2618	.2398	.468	.490	.430	.916	1028	1.092	.1264
1	20	.035	.6793	.2618	.2435	.393	.411	.361	.930	1059	1.075	.1061
1	22	.028	.6999	.2618	.2471	.317	.331	.291	.944	1092	1.059	.0855

$$\text{*Liquid velocity in feet/second} = \frac{\text{pounds per tube per hour}}{\text{C x specific gravity of liquid}}$$

Specific gravity of water at 60 deg. F = 1.0

Courtesy of HEAT EXCHANGE INSTITUTE

Weights of other materials — Multiply carbon steel weights by the following factors:

90-10 Cu. Ni. Alloy 706 - 1.140
70-30 Cu. Ni. Alloy 715 - 1.140
70-30 Ni. Cu. Alloy 400 - 1.126
TP304 Stainless Steel - 1.013

HEADS

For vessels of small and medium diameters ellipsoidal heads are used most commonly, while large diameter vessels are usually built with hemispherical or flanged and dished heads.

Heads may be of seamless or welded construction.

STRAIGHT FLANGE

Formed heads butt-welded to the shell need not have straight flange when the head is not thicker than the shell according to the Code Par. UG-32 & 33, but in practice heads except hemisphericals are used with straight flanges.
The usual length of straight flanges: 2 inches for ellipsoidal, 1 1/2 inches for flanged and dished and 0 inches for hemispherical heads.

Formed heads thicker than the shell and butt-welded to it shall have straight flange.

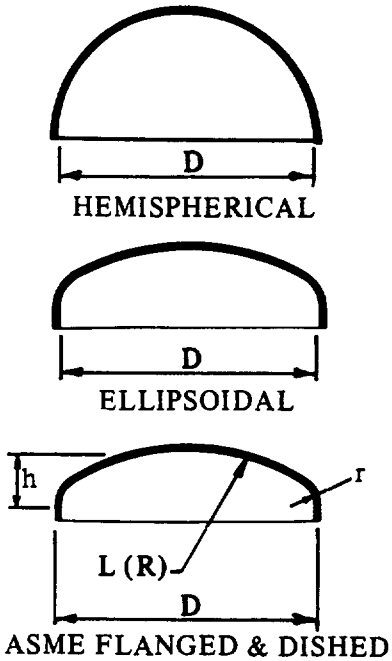
On the following pages the data of the most commonly used heads are listed.
The dimensions of flanged and dished heads meet the requirements of ASME Code.

WEIGHT OF HEADS See tables beginning on page 374

VOLUME OF HEADS See page 416

SURFACE OF HEADS See page 425

DIMENSIONS OF HEADS



SYMBOLS USED IN THE TABLES

D = inside diameter of hemispherical and ellipsoidal heads, outside diameter of ASME flanged & dished heads.

h = inside depth of dish of F & D heads

L(R) = inside radius of dish of ASME flanged & dished heads as used in formulas for internal or external pressure.

M = factor used in formulas for internal pressure.

r = inside knuckle radius of ASME flanged & dished heads.

t = wall thickness, nominal or minimum.

ALL DIMENSIONS IN INCHES

DIAMETER D		WALL THICKNESS							
		3/8	1/2	5/8	3/4	7/8	1	1 1/8	1 1/4
14	L (R)	12	12	12					
	r	1.125	1.500	1.875					
	h	2.625	2.750	2.938					
	M	1.56	1.46	1.39					
16	L (R)	15	15	14	14				
	r	1.125	1.500	1.875	2.250				
	h	2.750	2.875	3.188	3.375				
	M	1.65	1.54	1.44	1.36				
18	L (R)	18	16	15	15	18			
	r	1.125	1.500	1.875	2.250	2.625			
	h	2.875	3.313	3.563	3.750	3.625			
	M	1.75	1.56	1.46	1.39	1.41			
20	L (R)	18	18	18	18	18	18		
	r	1.250	1.500	1.875	2.250	2.625	3.000		
	h	3.500	3.563	3.750	3.875	4.063	4.250		
	M	1.69	1.62	1.52	1.46	1.41	1.36		
22	L (R)	21	20	20	20	20	20	20	
	r	1.375	1.500	1.875	2.250	2.625	3.000	3.375	
	h	3.688	3.813	4.000	4.188	4.313	4.500	4.688	
	M	1.72	1.65	1.56	1.50	1.44	1.39	1.36	
24	L (R)	24	24	24	24	24	24	24	24
	r	1.500	1.500	1.875	2.250	2.625	3.000	3.375	3.750
	h	3.875	3.813	4.000	4.188	4.375	4.563	4.813	5.000
	M	1.75	1.75	1.65	1.58	1.50	1.46	1.41	1.39

DIMENSIONS OF HEADS

ALL DIMENSIONS IN INCHES

DIAMETER D		WALL THICKNESS								
		3/8	1/2	5/8	3/4	7/8	1	1 1/8	1 1/4	1 3/8
26	L (R)	24	24	24	24	24	24	24	24	24
	r	1.625	1.625	1.875	2.250	2.625	3.000	3.375	3.750	4.125
	h	4.500	4.438	4.500	4.688	4.875	5.000	5.188	5.375	5.625
	M	1.72	1.72	1.65	1.56	1.50	1.46	1.41	1.39	1.36
28	L (R)	26	26	26	26	24	24	24	24	24
	r	1.750	1.750	1.875	2.250	2.625	3.000	3.375	3.750	4.125
	h	4.813	4.750	4.750	4.938	5.375	5.563	5.688	5.875	6.063
	M	1.72	1.72	1.69	1.60	1.50	1.46	1.41	1.39	1.36
30	L (R)	30	30	30	30	30	30	30	30	30
	r	1.875	1.875	1.875	2.250	2.625	3.000	3.375	3.750	4.125
	h	4.875	4.813	4.813	5.000	5.125	5.375	5.500	5.750	5.938
	M	1.75	1.75	1.75	1.65	1.60	1.54	1.50	1.46	1.44
32	L (R)	30	30	30	30	30	30	30	30	30
	r	2.000	2.000	2.000	2.250	2.625	3.000	3.375	3.750	4.125
	h	5.563	5.500	5.375	5.500	5.625	5.813	6.000	6.188	6.375
	M	1.72	1.72	1.72	1.65	1.60	1.54	1.50	1.50	1.44
34	L (R)	34	34	30	30	30	30	30	30	30
	r	2.125	2.125	2.125	2.250	2.625	3.000	3.375	3.750	4.125
	h	5.563	5.500	6.000	6.063	6.188	6.313	6.438	6.625	6.813
	M	1.75	1.75	1.69	1.65	1.60	1.54	1.54	1.46	1.44
36	L (R)	36	36	36	36	36	36	36	36	36
	r	2.250	2.250	2.250	2.250	2.625	3.000	3.375	3.750	4.125
	h	5.938	5.875	5.813	5.750	5.938	6.125	6.313	6.500	6.688
	M	1.75	1.75	1.75	1.75	1.69	1.62	1.58	1.52	1.52
38	L (R)	36	36	36	36	36	36	36	36	36
	r	2.375	2.375	2.375	2.375	2.625	3.000	3.375	3.750	4.125
	h	6.500	6.438	6.375	6.375	6.438	6.563	6.750	6.938	7.125
	M	1.72	1.72	1.72	1.72	1.69	1.62	1.60	1.52	1.48
40	L (R)	40	40	36	36	36	36	36	36	36
	r	2.500	2.500	2.500	2.500	2.625	3.000	3.375	3.750	4.125
	h	6.625	6.563	6.938	7.000	7.000	7.125	7.313	7.438	7.625
	M	1.69	1.69	1.69	1.69	1.69	1.62	1.58	1.52	1.48
42	L (R)	40	40	40	40	40	40	36	36	36
	r	2.625	2.625	2.625	2.625	2.625	3.000	3.375	3.750	4.125
	h	7.188	7.125	7.063	7.000	7.000	7.125	7.125	8.000	8.125
	M	1.72	1.72	1.72	1.72	1.72	1.65	1.56	1.52	1.48
48	L (R)	42	42	42	42	42	42	42	42	42
	r	3.000	3.000	3.000	3.000	3.000	3.000	3.375	3.750	4.125
	h	8.000	8.750	8.688	8.625	8.563	8.500	8.625	8.813	9.000
	M	1.69	1.69	1.69	1.69	1.69	1.69	1.62	1.58	1.54
54	L (R)	54	48	48	48	48	48	48	48	48
	r	3.250	3.250	3.250	3.250	3.250	3.250	3.375	3.750	4.125
	h	8.938	9.750	9.750	9.625	9.500	9.375	9.438	9.625	9.750
	M	1.77	1.72	1.72	1.72	1.72	1.72	1.69	1.65	1.60
60	L (R)	60	60	54	54	54	54	54	54	54
	r	3.625	3.625	3.625	3.625	3.625	3.625	3.625	3.750	4.125
	h	10.000	9.875	10.688	10.625	10.563	10.500	10.438	10.438	10.563
	M	1.77	1.77	1.72	1.72	1.72	1.72	1.72	1.69	1.65

DIMENSIONS OF HEADS

ALL DIMENSIONS IN INCHES

DIAMETER D		WALL THICKNESS 1½	1⅝	1¾	1⅞	2	2¼	2½	2¾	3
26	L (R)									
	r									
	h									
	M									
28	L (R)									
	r									
	h									
	M									
30	L (R)	30	30							
	r	4.500	4.875							
	h	6.125	6.375							
	M	1.39	1.36							
32	L (R)	30	30	30						
	r	4.500	4.875	5.250						
	h	6.563	6.750	6.938						
	M	1.39	1.36	1.34						
34	L (R)	30	30	30						
	r	4.500	4.875	5.250						
	h	7.000	7.188	7.375						
	M	1.39	1.36	1.34						
36	L (R)	36	36	36	36					
	r	4.500	4.875	5.250	5.625					
	h	6.875	7.063	7.313	7.500					
	M	1.46	1.44	1.41	1.39					
38	L (R)	36	36	36	36	36				
	r	4.500	4.875	5.250	5.625	6.000				
	h	7.313	7.500	7.813	7.875	8.063				
	M	1.46	1.44	1.41	1.39	1.36				
40	L (R)	36	36	36	36	36				
	r	4.500	4.875	5.250	5.625	6.000				
	h	7.813	8.000	8.125	8.313	8.500				
	M	1.46	1.44	1.41	1.39	1.36				
42	L (R)	36	36	36	36	36				
	r	4.500	4.875	5.250	5.625	6.000				
	h	8.313	8.438	8.625	8.813	8.938				
	M	1.46	1.44	1.41	1.39	1.36				
48	L (R)	42	42	42	42	42	42	42		
	r	4.500	4.875	5.250	5.625	6.000	6.750	7.500		
	h	9.188	9.250	9.438	9.563	9.750	10.125	10.500		
	M	1.52	1.48	1.46	1.44	1.41	1.36	1.34		
54	L (R)	48	48	48	48	48	48	48	48	
	r	4.500	4.875	5.250	5.625	6.000	6.750	7.500	8.250	
	h	9.875	10.063	10.188	10.375	10.563	10.875	11.250	11.625	
	M	1.56	1.54	1.50	1.48	1.46	1.41	1.39	1.36	
60	L (R)	54	54	54	54	54	54	54	54	54
	r	4.500	4.875	5.250	5.625	6.000	6.750	7.500	8.250	9.000
	h	10.688	10.875	11.000	11.188	11.313	11.688	12.000	12.375	12.750
	M	1.62	1.58	1.54	1.52	1.50	1.46	1.41	1.39	1.36

DIMENSIONS OF HEADS

ALL DIMENSIONS IN INCHES

DIAMETER D		WALL THICKNESS								
		3/8	1/2	5/8	3/4	7/8	1	1 1/8	1 1/4	1 3/8
66	L (R)	66	66	60	60	60	60	60	60	60
	r	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.125
	h	11.000	10.938	11.750	11.625	11.563	11.500	11.438	11.375	11.375
	M	1.77	1.77	1.72	1.72	1.72	1.72	1.72	1.72	1.72
72	L (R)	72	72	72	72	66	66	66	66	66
	r	4.375	4.375	4.375	4.375	4.375	4.375	4.375	4.375	4.375
	h	12.000	11.938	11.875	11.875	12.625	12.500	12.438	12.375	12.313
	M	1.77	1.77	1.77	1.77	1.72	1.72	1.72	1.72	1.72
78	L (R)	78	72	72	72	72	72	72	72	72
	r	4.750	4.750	4.750	4.750	4.750	4.750	4.750	4.750	4.750
	h	13.000	13.813	13.750	13.688	13.563	13.500	13.438	13.375	13.313
	M	1.77	1.72	1.72	1.72	1.72	1.72	1.72	1.72	1.72
84	L (R)	84	84	84	84	84	84	78	78	78
	r	5.125	5.125	5.125	5.125	5.125	5.125	5.125	5.125	5.125
	h	14.000	13.938	13.875	13.813	13.750	13.688	14.438	14.375	14.313
	M	1.77	1.77	1.77	1.77	1.77	1.77	1.72	1.72	1.72
90	L (R)	90	84	84	84	84	84	84	84	84
	r	5.500	5.500	5.500	5.500	5.500	5.500	5.500	5.500	5.500
	h	15.125	15.813	15.750	15.688	15.625	15.563	15.500	15.438	15.313
	M	1.77	1.72	1.72	1.72	1.72	1.72	1.72	1.72	1.72
96	L (R)	96	90	90	90	90	90	90	90	84
	r	5.875	5.875	5.875	5.875	5.875	5.875	5.875	5.875	5.875
	h	16.125	16.875	16.813	16.750	16.625	16.563	16.500	16.438	17.313
	M	1.77	1.72	1.72	1.72	1.72	1.72	1.72	1.72	1.72
102	L (R)	96	96	96	96	96	96	90	90	90
	r	6.125	6.125	6.125	6.125	6.125	6.125	6.125	6.125	6.125
	h	17.938	17.875	17.750	17.688	17.625	17.563	18.500	18.375	18.250
	M	1.75	1.75	1.75	1.75	1.75	1.75	1.72	1.72	1.72
108	L (R)	102	102	102	102	102	102	96	96	96
	r	6.500	6.500	6.500	6.500	6.500	6.500	6.500	6.500	6.500
	h	18.938	18.875	18.750	18.750	18.688	18.563	19.438	19.375	19.313
	M	1.75	1.75	1.75	1.75	1.75	1.75	1.72	1.72	1.72
114	L (R)		108	108	108	108	108	108	108	108
	r		6.875	6.875	6.875	6.875	6.875	6.875	6.875	6.875
	h		19.875	19.813	19.750	19.685	19.625	19.563	19.500	19.438
	M		1.75	1.75	1.75	1.75	1.75	1.75	1.75	1.75
120	L (R)		114	114	114	114	114	108	108	108
	r		7.250	7.250	7.250	7.250	7.250	7.250	7.250	7.250
	h		20.875	20.813	20.750	20.688	20.625	21.500	21.438	21.375
	M		1.75	1.75	1.75	1.75	1.75	1.72	1.72	1.72
126	L (R)		120	120	120	120	120	120	120	114
	r		7.625	7.625	7.625	7.625	7.625	7.625	7.625	7.625
	h		21.875	21.813	21.750	21.688	21.625	21.563	21.500	22.313
	M		1.75	1.75	1.75	1.75	1.75	1.75	1.75	1.72
132	L (R)			126	126	120	120	120	120	120
	r			8.000	8.000	8.000	8.000	8.000	8.000	8.000
	h			22.875	22.813	23.688	23.563	23.500	23.438	23.750
	M			1.75	1.75	1.72	1.72	1.72	1.72	1.72

DIMENSIONS OF HEADS

ALL DIMENSIONS IN INCHES

DIAMETER D		WALL THICKNESS								
		1½	1⅝	1¾	1⅞	2	2¼	2½	2¾	3
66	L (R)	60	60	60	60	60	60	60	60	60
	r	4.500	4.875	5.250	5.625	6.000	6.750	7.500	8.250	9.000
	h	11.500	11.688	11.813	12.000	12.125	12.438	12.813	13.125	13.500
	M	1.65	1.62	1.58	1.58	1.54	1.50	1.46	1.41	1.39
72	L (R)	66	66	66	66	66	66	66	66	66
	r	4.500	4.875	5.250	5.625	6.000	6.750	7.500	8.250	9.000
	h	12.313	12.500	12.625	12.750	12.938	13.250	13.563	13.938	14.313
	M	1.72	1.69	1.65	1.60	1.58	1.54	1.50	1.46	1.44
78	L (R)	72	72	72	72	72	72	72	72	72
	r	4.75	4.875	5.250	5.625	6.000	6.750	7.500	8.250	9.000
	h	13.250	13.250	13.438	13.563	13.750	14.063	14.375	14.750	15.063
	M	1.72	1.72	1.69	1.65	1.62	1.56	1.52	1.48	1.46
84	L (R)	78	78	78	78	78	78	78	78	78
	r	5.125	5.125	5.250	5.625	6.000	6.750	7.500	8.250	9.000
	h	14.250	14.188	14.250	14.375	14.500	14.875	15.188	15.500	15.875
	M	1.72	1.72	1.72	1.69	1.65	1.60	1.56	1.52	1.48
90	L (R)	84	84	84	84	84	84	84	84	84
	r	5.500	5.500	5.500	5.625	6.000	6.750	7.500	8.250	9.000
	h	15.250	15.188	15.125	15.188	15.313	15.625	16.000	16.313	16.625
	M	1.72	1.72	1.72	1.72	1.69	1.62	1.58	1.54	1.52
96	L (R)	84	84	84	84	84	84	84	84	84
	r	5.875	5.875	5.875	5.875	6.000	6.750	7.500	8.250	9.000
	h	17.250	17.125	17.063	17.000	17.063	17.313	17.625	17.875	18.188
	M	1.69	1.69	1.69	1.69	1.69	1.62	1.58	1.54	1.52
102	L (R)	90	90	90	90	90	90	90	90	90
	r	6.125	6.125	6.125	6.125	6.125	6.750	7.50	8.250	9.000
	h	18.125	18.125	18.063	18.000	17.938	18.125	18.375	18.688	19.000
	M	1.72	1.72	1.72	1.72	1.72	1.65	1.62	1.58	1.54
108	L (R)	96	96	96	96	96	96	96	96	96
	r	6.500	6.500	6.500	6.500	6.500	6.750	7.500	8.250	9.000
	h	19.250	19.125	19.063	19.000	18.938	18.938	19.188	19.500	19.813
	M	1.72	1.72	1.72	1.72	1.72	1.69	1.65	1.60	1.56
114	L (R)	108	102	102	102	102	102	102	102	102
	r	6.875	6.875	6.875	6.875	6.875	6.875	7.500	8.250	9.000
	h	19.313	20.125	20.063	20.000	19.938	19.813	20.000	20.312	20.563
	M	1.75	1.72	1.72	1.72	1.72	1.72	1.69	1.62	1.60
120	L (R)	108	108	108	108	108	108	108	108	108
	r	7.250	7.250	7.250	7.250	7.250	7.250	7.500	8.250	9.000
	h	21.313	21.250	21.188	21.063	20.938	20.813	20.813	21.125	21.438
	M	1.72	1.72	1.72	1.72	1.72	1.72	1.72	1.65	1.62
126	L (R)	114	114	114	114	114	114	114	114	114
	r	7.625	7.625	7.625	7.625	7.625	7.625	7.625	8.250	9.000
	h	22.250	22.188	22.125	22.063	21.938	21.813	21.625	21.938	22.188
	M	1.72	1.72	1.72	1.72	1.72	1.72	1.72	1.69	1.65
132	L (R)	120	120	120	120	120	120	120	120	120
	r	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.250	9.000
	h	23.313	23.250	23.125	23.063	23.000	22.875	22.750	22.750	23.000
	M	1.72	1.72	1.72	1.72	1.72	1.72	1.72	1.72	1.65

DIMENSIONS OF HEADS

ALL DIMENSIONS IN INCHES

DIAMETER D		WALL THICKNESS 5/8	3/4	7/8	1	1 1/8	1 1/4	1 3/8	1 1/2
138	L (R)	132	132	132	132	132	132	132	132
	r	8.375	8.375	8.375	8.375	8.375	8.375	8.375	8.375
	h	23.938	23.875	23.813	23.750	23.688	23.625	23.563	23.500
	M	1.75	1.75	1.75	1.75	1.75	1.75	1.75	1.75
144	L (R)	132	132	132	132	132	132	132	132
	r	8.750	8.750	8.750	8.750	8.750	8.750	8.750	8.750
	h	25.875	25.813	25.750	25.625	25.563	25.500	25.438	25.313
	M	1.72	1.72	1.72	1.72	1.72	1.72	1.72	1.72

DIAMETER D	SEE PAGE 325	WALL THICKNESS 1 5/8	1 3/4	1 7/8	2	2 1/4	2 1/2	2 3/4	3
138	L (R)	132	132	132	130	130	130	130	130
	r	8.375	8.375	8.375	8.375	8.375	8.375	8.375	9.000
	h	23.438	23.375	23.313	23.500	23.375	23.250	23.125	23.250
	M	1.75	1.75	1.75	1.72	1.72	1.72	1.72	1.69
144	L (R)	132	132	132	132	132	132	132	132
	r	8.750	8.750	8.750	8.750	8.750	8.750	8.750	9.000
	h	25.250	25.188	25.125	25.063	24.938	24.813	24.625	24.625
	M	1.72	1.72	1.72	1.72	1.72	1.72	1.72	1.72

TOLERANCES

WALL THICKNESS (APPROXIMATION) *

MINIMUM REQ'D. THICKNESS	HEMISPHERICAL	OTHER TYPES: UP TO 150" I.D. incl.	OTHER TYPES: OVER 150" I.D.
To 1" excl.	0.1875	0.0625	0.1250
1" To 2" "	0.3750	0.1250	0.1250
2" To 3" "	0.6250	0.2500	0.2500
3" To 3.5" "	0.7500	0.3750	0.3750
3.5" To 4" "	1.1250	0.500	0.5000
4" To 4.5" "	1.5000	0.6250	0.6250
4.5" To 5" "	1.7500	0.7500	0.7500
5" To 5.5" "	2.0000	0.8750	0.8750
5.5" & Over	2.0000	1.0000	1.0000

* Specify minimum thickness (if required) when ordering.

INSIDE DEPTH OF DISH (h)

48" O.D. and under plus 0.5" minus 0"

Over 48" O.D. to 96" O.D. incl. plus 0.75", minus 0" Over 96" O.D. plus 1", minus 0"

OUT OF ROUNDNESS

Within the limits permitted by the Code.

FLANGES

FLANGE FACING FINISH

In pressure vessel construction only gasket seats of flanges, studded openings, etc. require special finish beyond that afforded by turning, grinding or milling.

The surface finish for flange facing shall have certain roughness regulated by Standard ANSI B16.5. The roughness is repetitive deviation from the nominal surface having specified depth and width.

Raised faced flange shall have serrated finish having 24 to 40 grooves per inch. The cutting tool shall have an approximate 0.06 in. or larger radius resulting 500 microinch approximate roughness /ANSI B16.5, 6.3.4.1./

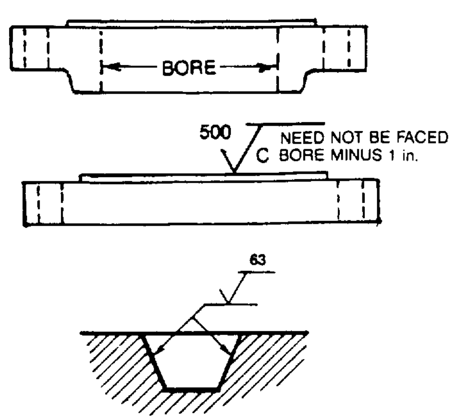
The side wall surface of gasket groove of ring joint flange shall not exceed 63 microinch roughness. /ANSI B16.5-6.3.4.3./

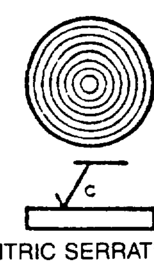
Other finishes may be furnished by agreement between user and manufacturer.

The finish of contact faces shall be judged by visual comparison with Standard ANSI B46-1.

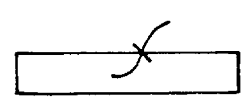
The center part of blind flanges need not to be finished within a diameter which equals or less than the bore minus one inch of the joining flange. /ANSI B16.5-6.3.3/

Surface symbol used to designate roughness √‾ is placed either on the line indicating the surface or on a leader pointing to the surface as shown below. The numbers: 500 and 63 indicate the height of roughness; letter "c" the direction of surface pattern: "concentric-serrated".





CONCENTRIC SERRATED FINISH



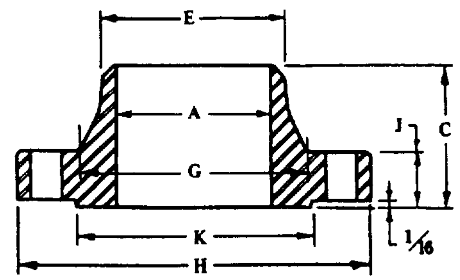
SYMBOL USED IN PAST PRACTICE

150 lb. FLANGES

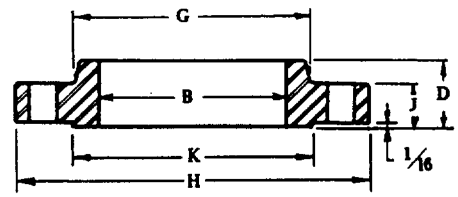
STANDARD ANSI B16.5

1. All dimensions are in inches.
2. Material most commonly used, forged steel SA 181. Available also in stainless steel, alloy steel and non-ferrous metal.
3. The 1/16 in. raised face is included in dimensions C, D and J.
4. The lengths of stud bolts do not include the height of crown.
5. Bolt holes are 1/8 in. larger than bolt diameters.
6. Flanges bored to dimensions shown unless otherwise specified.
7. Flanges for pipe sizes 22, 26, 28 and 30 are not covered by ANSI B16.5.

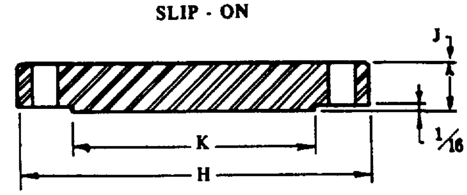
SEE FACING PAGE FOR DIMENSION K AND DATA ON BOLTING.



WELDING NECK

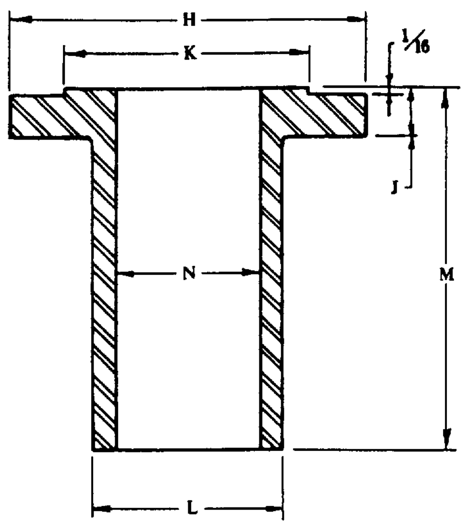


SLIP - ON



BLIND

Nominal Pipe Size	Diameter of Bore		Length Through Hub		Diameter of Hub at Point of Welding	Diameter of Hub at Base	Outside Diameter of Flange	Thickness of Flange
	A	B	C	D	E	G	H	J
1/2	.62	.88	1 7/8	5/8	.84	1 3/16	3 1/2	7/16
3/4	.82	1.09	2 1/16	5/8	1.05	1 1/2	3 7/8	1/2
1	1.05	1.36	2 3/16	11/16	1.32	1 15/16	4 1/4	9/16
1 1/4	1.38	1.70	2 1/4	13/16	1.66	2 5/16	4 5/8	5/8
1 1/2	1.61	1.95	2 7/16	7/8	1.90	2 9/16	5	11/16
2	2.07	2.44	2 1/2	1	2.38	3 1/16	6	3/4
2 1/2	2.47	2.94	2 3/4	1 1/8	2.88	3 9/16	7	7/8
3	3.07	3.57	2 3/4	1 3/16	3.50	4 1/4	7 1/2	15/16
3 1/2	3.55	4.07	2 13/16	1 1/4	4.00	4 13/16	8 1/2	15/16
4	4.03	4.57	3	1 5/16	4.50	5 5/16	9	15/16
5	5.05	5.66	3 1/2	1 7/16	5.56	6 7/16	10	15/16
6	6.07	6.72	3 1/2	1 9/16	6.63	7 9/16	11	1
8	7.98	8.72	4	1 3/4	8.63	9 11/16	13 1/2	1 1/8
10	10.02	10.88	4	1 15/16	10.75	12	16	1 3/16
12	12.00	12.88	4 1/2	2 3/16	12.75	14 3/8	19	1 1/4
14	13.25	14.14	5	2 1/4	14.00	15 3/4	21	1 3/8
16	15.25	16.16	5	2 1/2	16.00	18	23 1/2	1 7/16
18	17.25	18.18	5 1/2	2 11/16	18.00	19 7/8	25	1 9/16
20	19.25	20.20	5 11/16	2 7/8	20.00	22	27 1/2	1 11/16
22	21.25	22.22	5 7/8	3 1/8	22.00	24 1/4	29 1/2	1 13/16
24	23.25	24.25	6	3 1/4	24.00	26 1/8	32	1 7/8
26	To be specified	26.25	5	3 3/8	26.00	28 1/2	34 1/4	2
28		28.25	5 1/16	3 7/16	28.00	30 3/4	36 1/2	2 1/16
30		30.25	5 1/8	3 1/2	30.00	32 3/4	38 3/4	2 1/8



150 lb.
LONG WELDING NECK

1. All dimensions are in inches.
2. Material most commonly used, forged steel SA 181. Available also in stainless steel, alloy steel and non-ferrous metal.
3. The 1/16 in. raised face is included in dimensions J and M.
4. The length of bolts do not include the height of crown.
5. Bolt holes are 1/8 in. larger than bolt diameters.
6. Dimensions, M (length of welding necks) are based on data of major manufacturers. Long welding necks with necks longer than listed are available on special order.

SEE FACING PAGE FOR DIMENSION J.

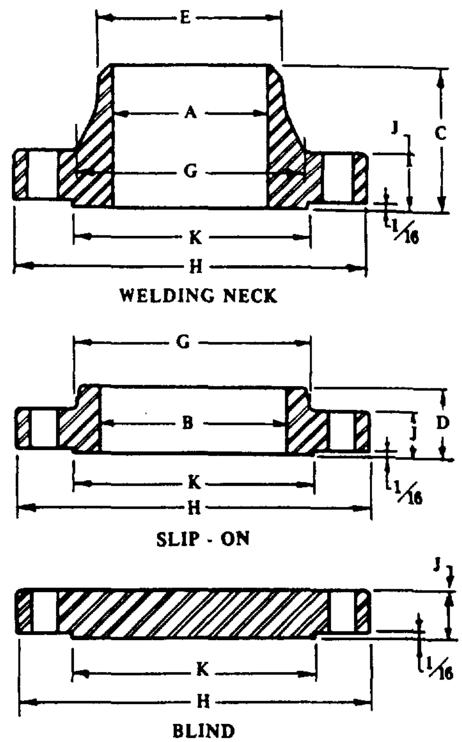
Outside Diameter of Raised Face	No. of Holes	Diam. of Bolts	Bolt Circle	Length of Bolts		Outside Diameter	Length	Diameter of Bore	Nominal Pipe Size
				1/16 Raised Face	Ring Joint				
K						L	M	N	
1⅜	4	½	2⅜	2½	- -				½
1 11/16	4	½	2¾	2½	- -				¾
2	4	½	3⅛	2¾	3¼	2			1
2½	4	½	3½	2¾	3¼	2⅜			1¼
2⅞	4	½	3⅞	3	3½	2⅝			1½
3⅝	4	⅝	4¾	3¼	3¾	3¼	9		2
4⅛	4	⅝	5½	3½	4	3¾			2½
5	4	⅝	6	3¾	4¼	4¼			3
5½	8	⅝	7	3¾	4¼	4⅞			3½
6 3/16	8	⅝	7½	3¾	4¼	5½		Same as nominal pipe size	4
7 5/16	8	¾	8½	4	4½	6½			5
8½	8	¾	9½	4	4½	7¾	12		6
10⅝	8	¾	11¾	4¼	4¾	9¾			8
12¾	12	⅞	14¼	4¾	5¼	12			10
15	12	⅞	17	4¾	5¼	14⅜			12
16¼	12	1	18¾	5¼	5¾	16			14
18½	16	1	21¼	5½	6	18			16
21	16	1⅛	22¾	6	6½	20			18
23	20	1⅛	25	6¼	6¾	22			20
	20	1¼	27¼	6½	7		10-14		22
27¼	20	1¼	29½	7	7½	26¼			24
29¼	24	1¼	31¾	7	- -	28½			26
31¼	28	1¼	34	7	- -	30½			28
33¾	28	1¼	36	7¼	- -	32½			30

300 lb. FLANGES

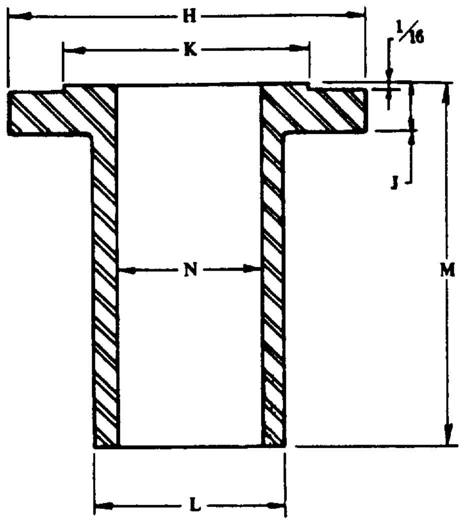
STANDARD ANSI B16.5

1. All dimensions are in inches.
2. Material most commonly used, forged steel SA 181. Available also in stainless steel, alloy steel and non-ferrous metal.
3. The 1/16 in. raised face is included in dimensions C, D and J.
4. The lengths of stud bolts do not include the height of crown.
5. Bolt holes are 1/8 in. larger than bolt diameters.
6. Flanges bored to dimensions shown unless otherwise specified.
7. Flanges for pipe sizes 22, 26, 28 and 30 are not covered by ANSI B16.5.

SEE FACING PAGE FOR DIMENSION K AND DATA ON BOLTING.



Nominal Pipe Size	Diameter of Bore		Length Through Hub		Diameter of Hub at Point of Welding	Diameter of Hub at Base	Outside Diameter of Flange	Thickness of Flange
	A	B	C	D	E	G	H	J
1/2	.62	.88	2 1/16	7/8	.84	1 1/2	3 3/4	9/16
3/4	.82	1.09	2 1/4	1	1.05	1 7/8	4 5/8	5/8
1	1.05	1.36	2 7/16	1 1/16	1.32	2 1/8	4 7/8	11/16
1 1/4	1.38	1.70	2 9/16	1 1/16	1.66	2 1/2	5 1/4	3/4
1 1/2	1.61	1.95	2 11/16	1 3/16	1.90	2 3/4	6 1/8	13/16
2	2.07	2.44	2 3/4	1 5/16	2.38	3 5/16	6 1/2	7/8
2 1/2	2.47	2.94	3	1 1/2	2.88	3 15/16	7 1/2	1
3	3.07	3.57	3 1/8	1 11/16	3.50	4 5/8	8 1/4	1 1/8
3 1/2	3.55	4.07	3 3/16	1 3/4	4.00	5 1/4	9	1 3/16
4	4.03	4.57	3 3/8	1 7/8	4.50	5 3/4	10	1 1/4
5	5.05	5.66	3 7/8	2	5.56	7	11	1 3/8
6	6.07	6.72	3 7/8	2 1/16	6.63	8 1/8	12 1/2	1 7/16
8	7.98	8.72	4 3/8	2 7/16	8.63	10 1/4	15	1 5/8
10	10.02	10.88	4 5/8	2 5/8	10.75	12 5/8	17 1/2	1 7/8
12	12.00	12.88	5 1/8	2 7/8	12.75	14 3/4	20 1/2	2
14	13.25	14.14	5 5/8	3	14.00	16 3/4	23	2 1/8
16	15.25	16.16	5 3/4	3 1/4	16.00	19	25 1/2	2 1/4
18	17.25	18.18	6 1/4	3 1/2	18.00	21	28	2 3/8
20	19.25	20.20	6 3/8	3 3/4	20.00	23 1/8	30 1/2	2 1/2
22	21.25	22.22	6 1/2	4	22.00	25 1/4	33	2 5/8
24	23.25	24.25	6 5/8	4 3/16	24.00	27 5/8	36	2 3/4
26	To be	26.25	7 1/4	7 1/4	26 1/4	28 3/8	38 1/4	3 1/8
28	speci-	28.25	7 3/4	7 3/4	28 1/4	30 1/2	40 3/4	3 3/8
30	fied	30.25	8 1/4	8 1/4	30 1/4	32 9/16	43	3 5/8



300 lb.
LONG WELDING NECK

1. All dimensions are in inches.
2. Material most commonly used, forged steel SA 181. Available also in stainless steel, alloy steel and non-ferrous metal.
3. The 1/16 in. raised face is included in dimensions J and M.
4. The length of bolts do not include the height of crown.
5. Bolt holes are 1/8 in. larger than bolt diameters.
6. Dimensions, M (length of welding necks) are based on data of major manufacturers. Long welding necks with necks longer than listed are available on special order.

SEE FACING PAGE FOR DIMENSION J.

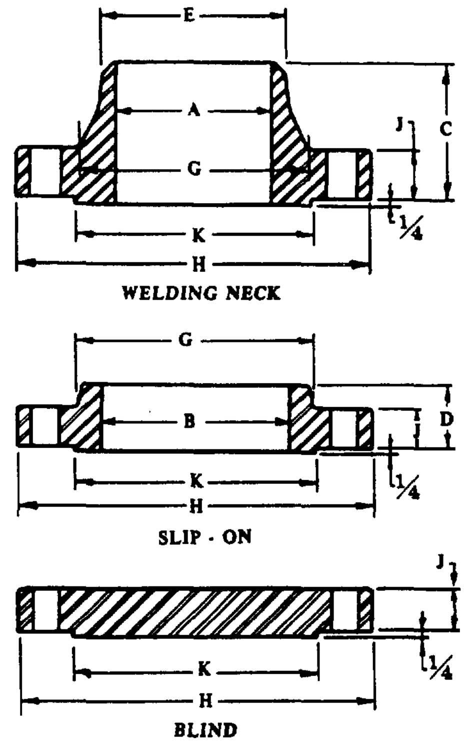
Outside Diameter of Raised Face	No. of Holes	Diam. of Bolts	Bolt Circle	Length of Bolts		Outside Diameter	Length	Diameter of Bore	Nominal Pipe Size
				1/16 Raised Face	Ring Joint				
K						L	M	N	
1⅜	4	½	2⅝	2¾	3				½
1 11/16	4	⅝	3¼	3	3½				¾
2	4	⅝	3½	3¼	3¾	2⅛			1
2½	4	⅝	3⅞	3¼	3¾	2½			1¼
2⅞	4	¾	4½	3¾	4¼	2¾			1½
3⅝	8	⅝	5	3½	4¼	3 5/16	9		2
4⅛	8	¾	5⅞	4	4¾	3 15/16			2½
5	8	¾	6⅝	4¼	5	4⅝			3
5½	8	¾	7¼	4½	5¼	5¼			3½
6 3/16	8	¾	7⅞	4½	5¼	5¾			4
7 5/16	8	¾	9¼	4¾	5½	7			5
8½	12	¾	10⅝	5	5¾	8⅛		Same as nominal pipe size	6
10⅝	12	⅞	13	5½	6¼	10¼	12		8
12¾	16	1	15¼	6¼	7	12⅝			10
15	16	1⅛	17¾	6¾	7½	14¾			12
16¼	20	1⅛	20¼	7	7¾	16¾			14
18½	20	1¼	22½	7½	8¼	19			16
21	24	1¼	24¾	7¾	8½	21			18
23	24	1¼	27	8¼	9	23⅛			20
25¼	24	1½	29¼	8¾	9¾				22
27¼	24	1½	32	9¼	10¼	27⅝	10-14		24
29½	28	1⅝	34½	10	11	29½			26
31½	28	1⅝	37	10½	11½	31½			28
33¾	28	1¾	39¼	11¼	12¼	33¾			30

400 lb. FLANGES

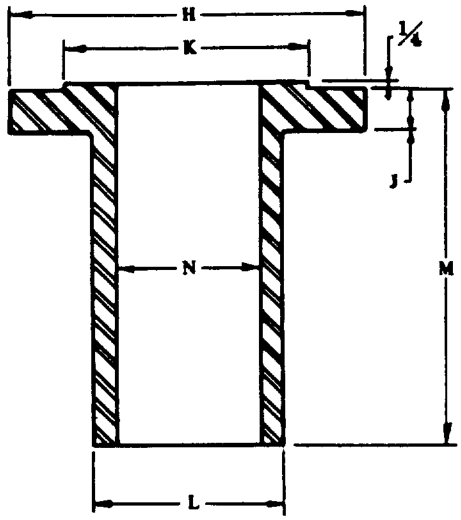
STANDARD ANSI B16.5

1. All dimensions are in inches.
2. Material most commonly used, forged steel SA 105. Available also in stainless steel, alloy steel and non-ferrous metal.
3. The 1/4 in. raised face is not included in dimensions C, D and J.
4. The lengths of stud bolts do not include the height of crown.
5. Bolt holes are 1/8 in. larger than bolt diameters.
6. Flanges bored to dimensions shown unless otherwise specified.
7. Flanges for pipe sizes 22, 26, 28 and 30 are not covered by ANSI B16.5.

SEE FACING PAGE FOR DIMENSION K AND DATA ON BOLTING.



Nominal Pipe Size	Diameter of Bore		Length Through Hub		Diameter of Hub at Point of Welding	Diameter of Hub at Base	Outside Diameter of Flange	Thickness of Flange
	A	B	C	D	E	G	H	J
½	To be specified by purchaser	.88	2 1/16	7/8	.84	1 1/2	3 3/4	9/16
¾		1.09	2 1/4	1	1.05	1 7/8	4 5/8	5/8
1		1.36	2 7/16	1 1/16	1.32	2 1/8	4 7/8	11/16
1¼		1.70	2 5/8	1 1/8	1.66	2 1/2	5 1/4	13/16
1½		1.95	2 3/4	1 1/4	1.90	2 3/4	6 1/8	7/8
2		2.44	2 7/8	1 7/16	2.38	3 5/16	6 1/2	1
2½		2.94	3 1/8	1 5/8	2.88	3 15/16	7 1/2	1 1/8
3		3.57	3 1/4	1 13/16	3.50	4 5/8	8 1/4	1 1/4
3½		4.07	3 3/8	1 15/16	4.00	5 1/4	9	1 3/8
4		4.57	3 1/2	2	4.50	5 3/4	10	1 3/8
5		5.66	4	2 1/8	5.56	7	11	1 1/2
6		6.72	4 1/16	2 1/4	6.63	8 1/8	12 1/2	1 5/8
8		8.72	4 5/8	2 11/16	8.63	10 1/4	15	1 7/8
10		10.88	4 7/8	2 7/8	10.75	12 5/8	17 1/2	2 1/8
12		12.88	5 3/8	3 1/8	12.75	14 3/4	20 1/2	2 1/4
14		14.14	5 7/8	3 5/16	14.00	16 3/4	23	2 3/8
16		16.1.6	6	3 11/16	16.00	19	25 1/2	2 1/2
18		18.18	6 1/2	3 7/8	18.00	21	28	2 5/8
20		20.20	6 5/8	4	20.00	23 1/8	30 1/2	2 3/4
22		22.22	6 3/4	4 1/4	22.00	25 1/4	33	2 7/8
24		24.25	6 7/8	4 1/2	24.00	27 5/8	36	3
26		26.25	7 5/8	7 5/8	26 5/16	28 5/8	38 1/4	3 1/2
28		28.25	8 1/8	8 1/8	28 5/16	30 13/16	40 3/4	3 3/4
30		30.25	8 5/8	8 5/8	30 5/16	32 15/16	43	4



400 lb.
LONG WELDING NECK

1. All dimensions are in inches.
2. Material most commonly used, forged steel SA 105. Available also in stainless steel, alloy steel and non-ferrous metal.
3. The 1/4 in. raised face is not included in thickness J but is included in length M.
4. The length of bolts do not include the height of crown.
5. Bolt holes are 1/8 in. larger than bolt diameters.
6. Dimensions, M (length of welding necks) are based on data of major manufacturers. Long welding necks with necks longer than listed are available on special order.

SEE FACING PAGE FOR DIMENSION J.

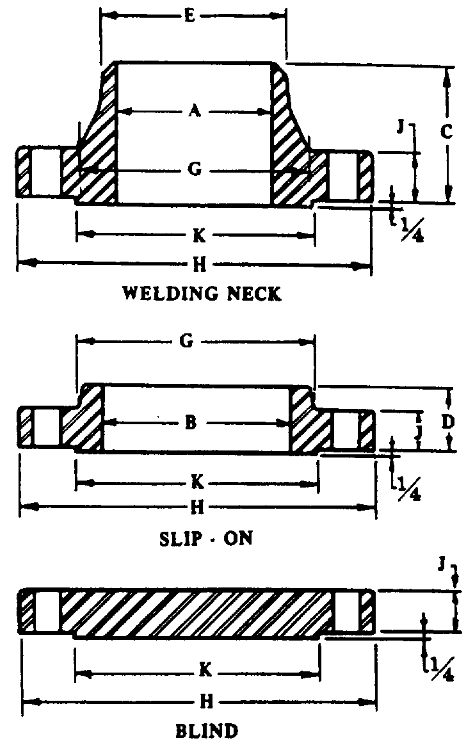
Outside Diameter of Raised Face	No. of Holes	Diam. of Bolts	Bolt Circle	Length of Bolts		Outside Diameter	Length	Diameter of Bore	Nominal Pipe Size
K				¼" Raised Face	Ring Joint	L	M	N	
1⅜	4	½	2⅝	3¼	3			Same as nominal pipe size	½
1 11/16	4	⅝	3¼	3½	3½				¾
2	4	⅝	3½	3¾	3¾	2⅛			1
2½	4	⅝	3⅞	4	4	2½			1¼
2⅞	4	¾	4½	4¼	4¼	2¾			1½
3⅝	8	⅝	5	4¼	4½	3 5/16	9		2
4⅛	8	¾	5⅞	4¾	5	3 15/16			2½
5	8	¾	6⅝	5	5¼	4⅝			3
5½	8	⅞	7¼	5½	5¾	5¼			3½
6 3/16	8	⅞	7⅞	5½	5¾	5¾			4
7 5/16	8	⅞	9¼	5¾	6	7			5
8½	12	⅞	10⅝	6	6¼	8⅛	12		6
10⅝	12	1	13	6¾	7	10¼			8
12¾	16	1⅛	15¼	7½	7¾	12⅝			10
15	16	1¼	17¾	8	8¼	14¾			12
16¼	20	1¼	20¼	8¼	8½	16¾			14
18½	20	1⅜	22½	8¾	9	19			16
21	24	1⅜	24¾	9	9¼	21			18
23	24	1½	27	9¾	10	23⅛	10-14		20
25¼	24	1⅝	29¼	10	10½				22
27¼	24	1¾	32	10¾	11¼	27⅝			24
29½	28	1¾	34½	11½	12				26
31½	28	1⅞	37	12¼	12¾				28
33¾	28	2	39¼	13	13½				30

600 lb. FLANGES

STANDARD ANSI B16.5

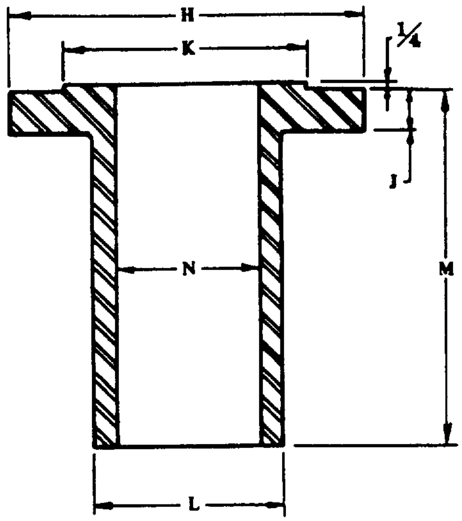
1. All dimensions are in inches.
2. Material most commonly used, forged steel SA 105. Available also in stainless steel, alloy steel and non-ferrous metal.
3. The 1/4 in. raised face is not included in dimensions C, D and J.
4. The lengths of stud bolts do not include the height of crown.
5. Bolt holes are 1/8 in. larger than bolt diameters.
6. Flanges bored to dimensions shown unless otherwise specified.
7. Flanges for pipe sizes 22, 26, 28 and 30 are not covered by ANSI B16.5.

SEE FACING PAGE FOR DIMENSION K AND DATA ON BOLTING.



Nominal Pipe Size	Diameter of Bore		Length Through Hub		Diameter of Hub at Point of Welding	Diameter of Hub at Base	Outside Diameter of Flange	Thickness of Flange
	A	B	C	D	E	G	H	J
½	To be specified by purchaser	.88	2 1/16	⅞	.84	1½	3¾	9/16
¾		1.09	2¼	1	1.05	1⅞	4⅝	⅝
1		1.36	2 7/16	1 1/16	1.32	2⅛	4⅞	11/16
1¼		1.70	2⅝	1⅛	1.66	2½	5¼	13/16
1½		1.95	2¾	1¼	1.90	2¾	6⅛	⅞
2		2.44	2⅞	1 7/16	2.38	3 5/16	6½	1
2½		2.94	3⅛	1⅝	2.88	3 15/16	7½	1⅛
3		3.57	3¼	1 13/16	3.50	4⅝	8¼	1¼
3½		4.07	3⅜	1 15/16	4.00	5¼	9	1⅜
4		4.57	4	2⅛	4.50	6	10¾	1½
5		5.66	4½	2⅜	5.56	7 7/16	13	1¾
6		6.72	4⅝	2⅝	6.63	8¾	14	1⅞
8		8.72	5¼	3	8.63	10¾	16½	2 3/16
10		10.88	6	3⅜	10.75	13½	20	2½
12		12.88	6⅛	3⅝	12.75	15¾	22	2⅝
14		14.14	6½	3 11/16	14.00	17	23¾	2¾
16		16.16	7	4 3/16	16.00	19½	27	3
18		18.18	7¼	4⅝	18.00	21½	29¼	3¼
20		20.20	7½	5	20.00	24	32	3½
22		22.22	7¾	5¼	22.00	26¼	34¼	3¾
24		24.25	8	5½	24.00	28¼	37	4
26		26.25	8¾	8¾	26 7/16	29 7/16	40	4¼
28		28.25	9¼	9¼	28½	31⅝	42¼	4⅜
30		30.25	9¾	9¾	30½	33 15/16	44½	4½

600 lb.
LONG WELDING NECK



1. All dimensions are in inches.
2. Material most commonly used, forged steel SA 105. Available also in stainless steel, alloy steel and non-ferrous metal.
3. The 1/4 in. raised face is not included in thickness J but is included in length M.
4. The length of bolts do not include the height of crown.
5. Bolt holes are 1/8 in. larger than bolt diameters.
6. Dimensions, M (length of welding necks) are based on data of major manufacturers. Long welding necks with necks longer than listed are available on special order.

SEE FACING PAGE FOR DIMENSION J.

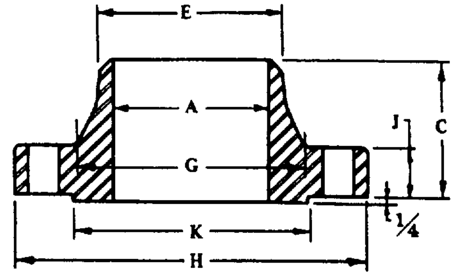
Outside Diameter of Raised Face K	No. of Holes	Diam. of Bolts	Bolt Circle	Length of Bolts: ¼" Raised Face	Length of Bolts: Ring Joint	Outside Diameter L	Length M	Diameter of Bore N	Nominal Pipe Size
1⅜	4	½	2⅝	3¼	3				½
1¹¹⁄₁₆	4	⅝	3¼	3½	3½				¾
2	4	⅝	3½	3¾	3¾	2⅛			1
2½	4	⅝	3⅞	4	4	2½			1¼
2⅞	4	¾	4½	4¼	4¼	2¾			1½
3⅝	8	⅝	5	4¼	4½	3⁵⁄₁₆	9		2
4⅛	8	¾	5⅞	4¾	5	3¹⁵⁄₁₆			2½
5	8	¾	6⅝	5	5¼	4⅝			3
5½	8	⅞	7¼	5½	5¾	5¼			3½
6³⁄₁₆	8	⅞	8½	5¾	6	6			4
7⁵⁄₁₆	8	1	10½	6½	6¾	7½			5
8½	12	1	11½	6¾	7	8¾			6
10⅝	12	1⅛	13¾	7¾	7¾	10¾	12	Same as nominal pipe size	8
12¾	16	1¼	17	8½	8¾	13½			10
15	20	1¼	19¼	8¾	9	15¾			12
16¼	20	1⅜	20¾	9¼	9½	17			14
18½	20	1½	23¾	10	10¼	19½			16
21	20	1⅝	25¾	10¾	11	21½			18
23	24	1⅝	28½	11½	11¾	24	12-20		20
25¼	24	1¾	30⅝	12	12½				22
27¼	24	1⅞	33	13	13¼	28¼			24
29½	28	1⅞	36	13¼	13¾				26
31½	28	2	38	13¾	14¼				28
33¾	28	2	40¼	14	14½				30

900 lb. FLANGES

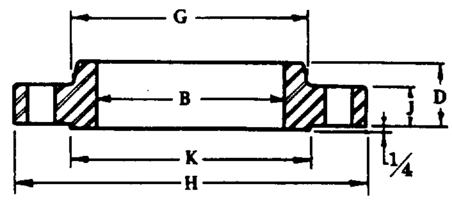
STANDARD ANSI B16.5

1. All dimensions are in inches.
2. Material most commonly used, forged steel SA 105. Available also in stainless steel, alloy steel and non-ferrous metal.
3. The 1/4 in. raised face is not included in dimensions C, D and J.
4. The lengths of stud bolts do not include the height of crown.
5. Bolt holes are 1/8 in. larger than bolt diameters.
6. Flanges bored to dimensions shown unless otherwise specified.
7. Flanges for pipe sizes 26, 28 and 30 are not covered by ANSI B16.5.

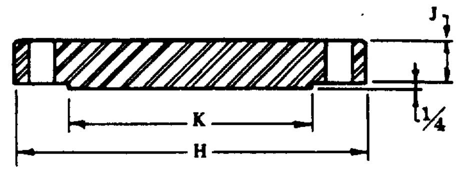
SEE FACING PAGE FOR DIMENSION K AND DATA ON BOLTING.



WELDING NECK



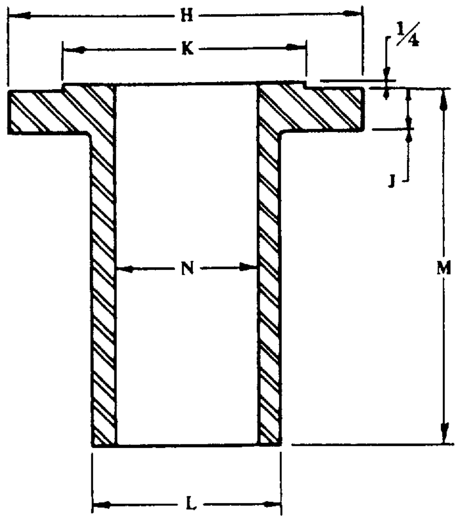
SLIP - ON



BLIND

Nominal Pipe Size	Diameter of Bore		Length Through Hub		Diameter of Hub at Point of Welding	Diameter of Hub at Base	Outside Diameter of Flange	Thickness of Flange
	A	B	C	D	E	G	H	J
½	To be specified by purchaser	.88	2⅜	1¼	.84	1½	4¾	⅞
¾		1.09	2¾	1⅜	1.05	1¾	5⅛	1
1		1.36	2⅞	1⅝	1.32	2 1/16	5⅞	1⅛
1¼		1.70	2⅞	1⅝	1.66	2½	6¼	1⅛
1½		1.95	3¼	1¾	1.90	2¾	7	1¼
2		2.44	4	2¼	2.38	4⅛	8½	1½
2½		2.94	4⅛	2½	2.88	4⅞	9⅝	1⅝
3		3.57	4	2⅛	3.50	5	9½	1½
4		4.57	4½	2¾	4.50	6¼	11½	1¾
5		5.66	5	3⅛	5.56	7½	13¾	2
6		6.72	5½	3⅜	6.63	9¼	15	2 3/16
8		8.72	6⅜	4	8.63	11¾	18½	2½
10		10.88	7¼	4¼	10.75	14½	21½	2¾
12		12.88	7⅞	4⅝	12.75	16½	24	3⅛
14		14.14	8⅜	5⅛	14.00	17¾	25¼	3⅜
16		16.16	8½	5¼	16.00	20	27¾	3½
18		18.18	9	6	18.00	22¼	31	4
20		20.20	9¾	6¼	20.00	24½	33¾	4¼
24		24.25	11½	8	24.00	29½	41	5½
26		26.25	11¼	11¼	26⅝	30½	42¾	5½
28		28.25	11¾	11¾	28 11/16	32¾	46	5⅝
30		30.25	12¼	12¼	30¾	35	48½	5⅞

900 lb.
LONG WELDING NECK



1. All dimensions are in inches.
2. Material most commonly used, forged steel SA 105. Available also in stainless steel, alloy steel and non-ferrous metal.
3. The 1/4 in. raised face is not included in thickness J but is included in length M.
4. The length of bolts do not include the height of crown.
5. Bolt holes are 1/8 in. larger than bolt diameters.
6. Dimensions, M (length of welding necks) are based on data of major manufacturers. Long welding necks with necks longer than listed are available on special order.

SEE FACING PAGE FOR DIMENSION J.

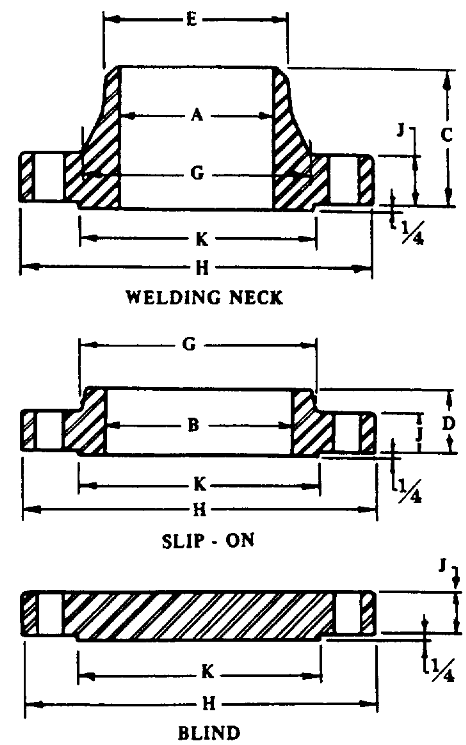
Outside Diameter of Raised Face	No. of Holes	Diam. of Bolts	Bolt Circle	Length of Bolts		Outside Diameter	Length	Diameter of Bore	Nominal Pipe Size
				1/4" Raised Face	Ring Joint				
K						L	M	N	
1 3/8	4	3/4	3 1/4	4 1/4	4 1/4			Same as nominal pipe size	1/2
1 11/16	4	3/4	3 1/2	4 1/2	4 1/2				3/4
2	4	7/8	4	5	5	2 1/16	9		1
2 1/2	4	7/8	4 3/8	5	5	2 1/2			1 1/4
2 7/8	4	1	4 7/8	5 1/2	5 1/2	2 3/4			1 1/2
3 5/8	8	7/8	6 1/2	5 3/4	5 3/4	4 1/8			2
4 1/8	8	1	7 1/2	6 1/4	6 1/4	4 7/8	12		2 1/2
5	8	7/8	7 1/2	5 3/4	6	5			3
6 3/16	8	1 1/8	9 1/4	6 3/4	7	6 1/4			4
7 5/16	8	1 1/4	11	7 1/2	7 3/4	7 1/2			5
8 1/2	12	1 1/8	12 1/2	7 3/4	7 3/4	9 1/4			6
10 5/8	12	1 3/8	15 1/2	8 3/4	9	11 3/4			8
12 3/4	16	1 3/8	18 1/2	9 1/4	9 1/2	14 1/2	12-20		10
15	20	1 3/8	21	10	10 1/4	16 1/2			12
16 1/4	20	1 1/2	22	10 3/4	11 1/4	17 3/4			14
18 1/2	20	1 5/8	24 1/4	11 1/4	11 3/4	20			16
21	20	1 7/8	27	12 3/4	13 1/2	22 1/4			18
23	20	2	29 1/2	13 1/2	14 1/4	24 1/2			20
27 1/4	20	2 1/2	35 1/2	17 1/4	17 3/4	29 1/2			24
29 1/2	20	2 3/4	37 1/2	17 1/2	18 3/4				26
31 1/2	20	3	40 1/4	18 1/4	19 1/2				28
33 3/4	20	3	42 3/4	18 3/4	20				30

1500 lb. FLANGES

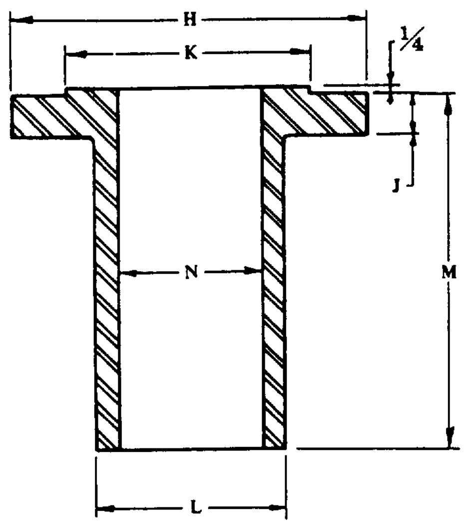
STANDARD ANSI B16.5

1. All dimensions are in inches.
2. Material most commonly used, forged steel SA 105. Available also in stainless steel, alloy steel and non-ferrous metal.
3. The 1/4 in. raised face is not included in dimensions C, D and J.
4. The lengths of stud bolts do not include the height of crown.
5. Bolt holes are 1/8 in. larger than bolt diameters.
6. Flanges bored to dimensions shown unless otherwise specified.

SEE FACING PAGE FOR DIMENSION K AND DATA ON BOLTING.



Nominal Pipe Size	Diameter of Bore		Length Through Hub		Diameter of Hub at Point of Welding	Diameter of Hub at Base	Outside Diameter of Flange	Thickness of Flange
	A	B	C	D	E	G	H	J
½	To be specified by purchaser	.88	2⅜	1¼	.84	1½	4¾	⅞
¾		1.09	2¾	1⅜	1.05	1¾	5⅛	1
1		1.36	2⅞	1⅝	1.32	2 1/16	5⅞	1⅛
1¼		1.70	2⅞	1⅝	1.66	2½	6¼	1⅛
1½		1.95	3¼	1¾	1.90	2¾	7	1¼
2		2.44	4	2¼	2.38	4⅛	8½	1½
2½		2.94	4⅛	2½	2.88	4⅞	9⅝	1⅝
3		3.57	4⅝	2⅞	3.50	5¼	10½	1⅞
4		4.57	4⅞	3 9/16	4.50	6⅜	12¼	2⅛
5		5.66	6⅛	4⅛	5.56	7¾	14¾	2⅞
6		6.72	6¾	4 11/16	6.63	9	15½	3¼
8		8.72	8⅜	5⅝	8.63	11½	19	3⅝
10		10.88	10	6¼	10.75	14½	23	4¼
12		12.88	11⅛	7⅛	12.75	17¾	26½	4⅞
14		--	11¾	--	14.00	19½	29½	5¼
16		--	12¼	--	16.00	21¾	32½	5¾
18		--	12⅞	--	18.00	23½	36	6⅜
20		--	14	--	20.00	25¼	38¾	7
24		--	16	--	24.00	30	46	8



1500 lb.
LONG WELDING NECK

1. All dimensions are in inches.
2. Material most commonly used, forged steel SA 105. Available also in stainless steel, alloy steel and non-ferrous metal.
3. The 1/4 in. raised face is not included in thickness J but is included in length M.
4. The length of bolts do not include the height of crown.
5. Bolt holes are 1/8 in. larger than bolt diameters.
6. Dimensions, M (length of welding necks) are based on data of major manufacturers. Long welding necks with necks longer than listed are available on special order.

SEE FACING PAGE FOR DIMENSION J.

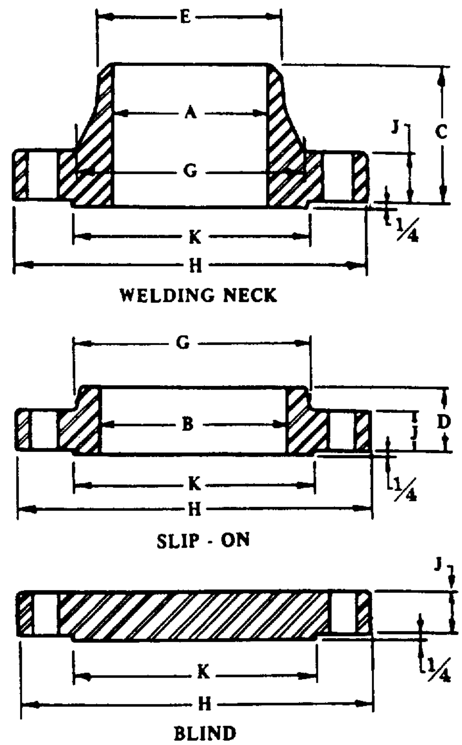
Outside Diameter of Raised Face	No. of Holes	Diam. of Bolts	Bolt Circle	Length of Bolts		Outside Diameter	Length	Diameter of Bore	Nominal Pipe Size
K				¼" Raised Face	Ring Joint	L	M	N	
1 3/8	4	3/4	3 1/4	4 1/4	4 1/4			Same as nominal pipe size	1/2
1 11/16	4	3/4	3 1/2	4 1/2	4 1/2				3/4
2	4	7/8	4	5	5	2 1/16			1
2 1/2	4	7/8	4 3/8	5	5	2 1/2	9		1 1/4
2 7/8	4	1	4 7/8	5 1/2	5 1/2	2 3/4			1 1/2
3 5/8	8	7/8	6 1/2	5 3/4	5 3/4	4 1/8			2
4 1/8	8	1	7 1/2	6 1/4	6 1/4	4 7/8			2 1/2
5	8	1 1/8	8	7	7	5 1/4			3
6 3/16	8	1 1/4	9 1/2	7 3/4	7 3/4	6 3/8			4
7 5/16	8	1 1/2	11 1/2	9 3/4	9 3/4	7 3/4	12		5
8 1/2	12	1 3/8	12 1/2	10 1/4	10 1/2	9			6
10 5/8	12	1 5/8	15 1/2	11 1/2	12	11 1/2			8
12 3/4	12	1 7/8	19	13 1/4	13 3/4	14 1/2			10
15	16	2	22 1/2	14 3/4	15 1/2	17 3/4			12
16 1/4	16	2 1/4	25	16	17	19 1/2			14
18 1/2	16	2 1/2	27 3/4	17 1/2	18 1/2	21 3/4	12-20		16
21	16	2 3/4	30 1/2	19 1/2	20 1/2	23 1/2			18
23	16	3	32 3/4	21 1/2	22 1/2	25 1/4			20
27 1/4	16	3 1/2	39	24 1/2	25 3/4	30			24

2500 lb. FLANGES

STANDARD ANSI B16.5

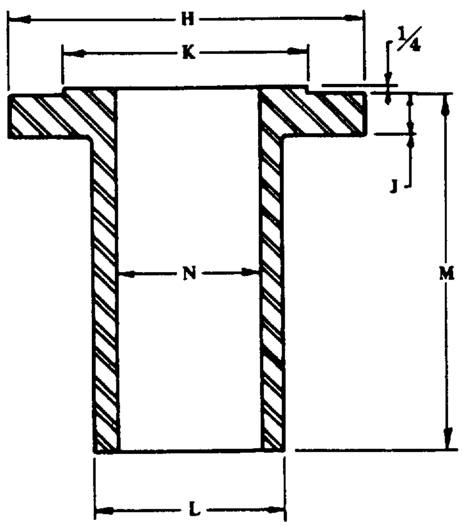
1. All dimensions are in inches.
2. Material most commonly used, forged steel SA 105. Available also in stainless steel, alloy steel and non-ferrous metal.
3. The 1/4 in. raised face is not included in dimensions C, D and J.
4. The lengths of stud bolts do not include the height of crown.
5. Bolt holes are 1/8 in. larger than bolt diameters.
6. Flanges bored to dimensions shown unless otherwise specified.

SEE FACING PAGE FOR DIMENSION K AND DATA ON BOLTING.



Nominal Pipe Size	Diameter of Bore		Length Through Hub		Diameter of Hub at Point of Welding	Diameter of Hub at Base	Outside Diameter of Flange	Thickness of Flange
	A	B	C	D	E	G	H	J
1/2	To be specified by purchaser	.88	2 7/8	1 9/16	.84	1 11/16	5 1/4	1 3/16
3/4		1.09	3 1/8	1 11/16	1.05	2	5 1/2	1 1/4
1		1.36	3 1/2	1 7/8	1.32	2 1/4	6 1/4	1 3/8
1 1/4		1.70	3 3/4	2 1/16	1.66	2 7/8	7 1/4	1 1/2
1 1/2		1.95	4 3/8	2 3/8	1.90	3 1/8	8	1 3/4
2		2.44	5	2 3/4	2.38	3 3/4	9 1/4	2
2 1/2		2.94	5 5/8	3 1/8	2.88	4 1/2	10 1/2	2 1/4
3		3.57	6 5/8	3 5/8	3.50	5 1/4	12	2 5/8
4		4.57	7 1/2	4 1/4	4.50	6 1/2	14	3
5		5.66	9	5 1/8	5.56	8	16 1/2	3 5/8
6		6.72	10 3/4	6	6.63	9 1/4	19	4 1/4
8		8.72	12 1/2	7	8.63	12	21 3/4	5
10		10.88	16 1/2	9	10.75	14 3/4	26 1/2	6 1/2
12		12.88	18 1/4	10	12.75	17 3/8	30	7 1/4

2500 lb.
LONG WELDING NECK

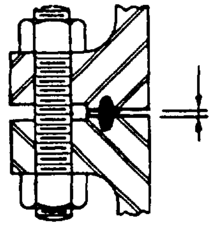


1. All dimensions are in inches.
2. Material most commonly used, forged steel SA 105. Available also in stainless steel, alloy steel and non-ferrous metal.
3. The 1/4 in. raised face is not included in thickness J but is included in length M.
4. The length of bolts do not include the height of crown.
5. Bolt holes are 1/8 in. larger than bolt diameters.
6. Dimensions, M (length of welding necks) are based on data of major manufacturers. Long welding necks with necks longer than listed are available on special order.

SEE FACING PAGE FOR DIMENSION J.

Outside Diameter of Raised Face	No. of Holes	Diam. of Bolts	Bolt Circle	Length of Bolts		Outside Diameter	Length	Diameter of Bore	Nominal Pipe Size
				¼" Raised Face	Ring Joint				
K						L	M	N	
1⅜	4	¾	3½	5¼	5¼				½
1 11/16	4	¾	3¾	5¼	5¼				¾
2	4	⅞	4¼	5¾	5¾	2¼	9		1
2½	4	1	5⅛	6¼	6½	2⅞			1¼
2⅞	4	1⅛	5¾	7	7¼	3⅛			1½
3⅝	8	1	6¾	7¼	7½	3¾			2
4⅛	8	1⅛	7¾	8	8¼	4½			2½
5	8	1¼	9	9	9¼	5¼	12		3
6 3/16	8	1½	10¾	10¼	10¾	6½		Same as nominal pipe size	4
7 5/16	8	1¾	12¾	12	12¾	8			5
8½	8	2	14½	13¼	14½	9¼			6
10⅝	12	2	17¼	15¼	16	12			8
12¾	12	2½	21¼	19½	20½	14¾			10
15	12	2¾	24⅜	21½	22½	17⅜	12-20		12

RING JOINT FLANGES



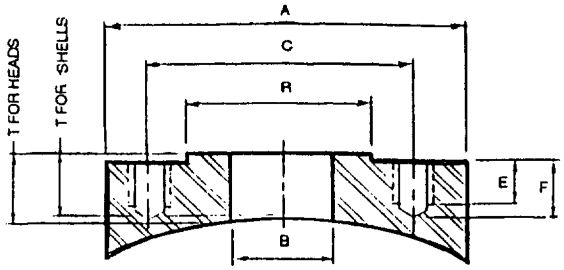
APPROXIMATE DISTANCE BETWEEN FLANGES

Nominal Pipe Size	Pressure Rating lb.						
	150	300	400	600	900	1500	2500
	Distance, inches						
½	1/8	1/8	1/8	1/8	—	—	5/32
¾	5/32	5/32	5/32	5/32	5/32	5/32	5/32
1	5/32	5/32	5/32	5/32	5/32	5/32	5/32
1¼	5/32	5/32	5/32	5/32	5/32	5/32	1/8
1½	5/32	5/32	5/32	5/32	5/32	5/32	1/8
2	5/32	7/32	3/16	3/16	1/8	1/8	1/8
2½	5/32	7/32	3/16	3/16	1/8	1/8	1/8
3	5/32	7/32	3/16	3/16	5/32	1/8	1/8
4	5/32	7/32	7/32	3/16	5/32	1/8	5/32
5	5/32	7/32	7/32	3/16	5/32	1/8	5/32
6	5/32	7/32	7/32	3/16	5/32	1/8	5/32
8	5/32	7/32	7/32	3/16	5/32	5/32	3/16
10	5/32	7/32	7/32	3/16	5/32	5/32	1/4
12	5/32	7/32	7/32	3/16	5/32	3/16	5/16
14	1/8	7/32	7/32	3/16	5/32	7/32	—
16	1/8	7/32	7/32	3/16	5/32	5/16	—
18	1/8	7/32	7/32	3/16	3/16	5/16	—
20	1/8	7/32	7/32	3/16	3/16	3/8	—
22	—	1/4	1/4	7/32	—	—	—
24	1/8	1/4	1/4	7/32	7/32	7/16	—

RING NUMBERS

Pressure Class lb.	Nominal Pipe Size: ½	¾	1	1¼	1½	2	2½	3	3½	4
150	...	...	R15	R17	R19	R22	R25	R29	R33	R36
300, 400, 600	R11	R13	R16	R18	R20	R23	R26	R31	R34	R37
900	...	...	...	...	...	...	...	R31	...	R37
1500	R12	R14	R16	R18	R20	R24	R27	R35	...	R39
2500	R13	R16	R18	R21	R23	R26	R28	R32	...	R38

Pressure Class lb.	Nominal Pipe Size: 5	6	8	10	12	14	16	18	20	24
150	R40	R43	R48	R52	R56	R59	R64	R68	R72	R76
300, 400, 600	R41	R45	R49	R53	R57	R61	R65	R69	R73	R77
900	R41	R45	R49	R53	R57	R62	R66	R70	R74	R78
1500	R44	R46	R50	R54	R58	R63	R67	R71	R75	R79
2500	R42	R47	R51	R55	R60	...	...	...	...	...



STUDDING OUTLETS

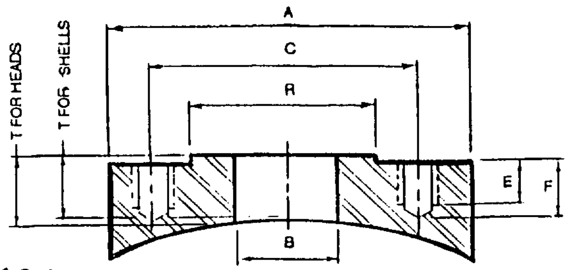
All dimensions are in inches. Material most commonly used, forged steel SA-105.

150 lb

SIZE (BORE) B	THICK T	OD A	RF OD R	STUD CIRCLE C	STUDS NO. J	STUDS SIZE M	STUDS TPI I	TAP DEPTH E	HOLE DEPTH F
1/2	1.50	3.50	1.38	2.38	4	1/2	13	0.75	1.25
3/4	1.50	3.88	1.69	2.75	4	1/2	13	0.75	1.25
1	1.50	4.25	2.00	3.12	4	1/2	13	0.75	1.25
1 1/4	1.50	4.62	2.50	3.50	4	1/2	13	0.75	1.25
1 1/2	1.50	5.00	2.88	3.88	4	1/2	13	0.75	1.25
2	1.75	6.00	3.62	4.75	4	5/8	11	0.94	1.50
2 1/2	1.75	7.00	4.12	5.50	4	5/8	11	0.94	1.50
3	1.75	7.50	5.00	6.00	4	5/8	11	0.94	1.50
3 1/2	1.75	8.50	5.50	7.00	8	5/8	11	0.94	1.50
4	1.75	9.00	6.19	7.50	8	5/8	11	0.94	1.50
5	2.00	10.00	7.31	8.50	8	3/4	10	1.12	1.75
6	2.00	11.00	8.50	9.50	8	3/4	10	1.12	1.75
8	2.00	13.50	10.62	11.75	8	3/4	10	1.12	1.75
10	2.25	16.00	12.75	14.25	12	7/8	9	1.31	2.00
12	2.25	19.00	15.00	17.00	12	7/8	9	1.31	2.00
14	2.56	21.00	16.25	18.75	12	1	8	1.50	2.31
16	2.56	23.50	18.50	21.25	16	1	8	1.50	2.31
18	2.75	25.00	21.00	22.75	16	1 1/8	8	1.69	2.50
20	2.75	27.50	23.00	25.00	20	1 1/8	8	1.69	2.50
24	3.00	32.00	27.25	29.50	20	1 1/4	8	1.88	2.75

300 lb

SIZE (BORE) B	THICK T	OD A	RF OD R	STUD CIRCLE C	STUDS NO. J	STUDS SIZE M	STUDS TPI I	TAP DEPTH E	HOLE DEPTH F
1/2	1.50	3.75	1.38	2.62	4	1/2	13	0.75	1.25
3/4	1.75	4.62	1.69	3.25	4	5/8	11	0.94	1.50
1	1.75	4.88	2.00	3.50	4	5/8	11	0.94	1.50
1 1/4	1.75	5.25	2.50	3.88	4	5/8	11	0.94	1.50
1 1/2	2.00	6.12	2.88	4.50	4	3/4	10	1.12	1.75
2	1.75	6.50	3.62	5.00	8	5/8	11	0.94	1.50
2 1/2	2.00	7.50	4.12	5.88	8	3/4	10	1.12	1.75
3	2.00	8.25	5.00	6.62	8	3/4	10	1.12	1.75
3 1/2	2.00	9.00	5.50	7.25	8	3/4	10	1.12	1.75
4	2.00	10.00	6.19	7.88	8	3/4	10	1.12	1.75
5	2.00	11.00	7.31	9.25	8	3/4	10	1.12	1.75
6	2.00	12.50	8.50	10.62	12	3/4	10	1.12	1.75
8	2.25	15.00	10.62	13.00	12	7/8	9	1.31	2.00
10	2.56	17.50	12.75	15.25	16	1	8	1.50	2.31
12	2.75	20.50	15.00	17.75	16	1 1/8	8	1.69	2.50
14	2.75	23.00	16.25	20.25	20	1 1/8	8	1.69	2.50
16	3.00	25.50	18.50	22.50	20	1 1/4	8	1.88	2.75
18	3.00	28.00	21.00	24.75	24	1 1/4	8	1.88	2.75
20	3.00	30.50	23.00	27.00	24	1 1/4	8	1.88	2.75
24	3.44	36.00	27.25	32.00	24	1 1/2	8	2.25	3.19



STUDDING OUTLETS

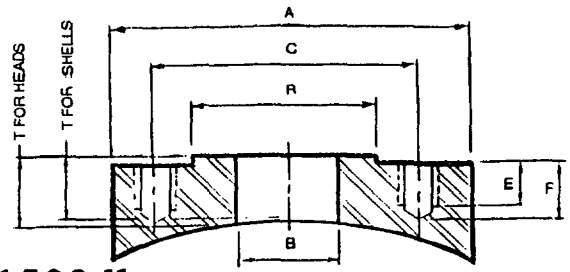
All dimensions are in inches.
Material most commonly used, forged steel SA-105.

600 lb

SIZE (BORE) B	THICK T	OD A	RF OD R	STUD CIRCLE C	STUDS NO. J	STUDS SIZE M	STUDS TPI I	TAP DEPTH E	HOLE DEPTH F
1/2	1.69	3.75	1.38	2.62	4	1/2	13	0.75	1.25
3/4	1.94	4.62	1.69	3.25	4	5/8	11	0.94	1.50
1	1.94	4.88	2.00	3.50	4	5/8	11	0.94	1.50
1 1/4	1.94	5.25	2.50	3.88	4	5/8	11	0.94	1.50
1 1/2	2.19	6.12	2.88	4.50	4	3/4	10	1.12	1.75
2	1.94	6.50	3.62	5.00	8	5/8	11	0.94	1.50
2 1/2	2.19	7.50	4.121	5.88	8	3/4	10	1.12	1.75
3	2.19	8.25	5.00	6.62	8	3/4	10	1.12	1.75
3 1/2	2.44	9.00	5.50	7.25	8	7/8	9	1.31	2.00
4	2.44	10.75	6.19	8.50	8	7/8	9	1.31	2.00
5	2.75	13.00	7.31	10.50	8	1	8	1.50	2.31
6	2.75	14.00	8.50	11.50	12	1	8	1.50	2.31
8	2.94	16.50	10.62	13.75	12	1 1/8	8	1.69	2.50
10	3.19	20.00	12.75	17.00	16	1 1/4	8	1.88	2.75
12	3.19	22.00	15.00	19.25	20	1 1/4	8	1.88	2.75
14	3.44	23.75	16.25	20.75	20	1 3/8	8	2.06	3.00
16	3.62	27.00	18.50	23.75	20	1 1/2	8	2.25	3.19
18	3.88	29.25	21.00	25.75	20	1 5/8	8	2.44	3.44
20	3.88	32.00	23.00	28.50	24	1 5/8	8	2.44	3.44
24	4.31	37.00	27.25	33.00	24	1 7/8	8	2.81	3.88

900 lb

SIZE (BORE) B	THICK T	OD A	RF OD R	STUD CIRCLE C	STUDS NO. J	STUDS SIZE M	STUDS TPI I	TAP DEPTH E	HOLE DEPTH F
1/2	2.19	4.75	1.38	3.25	4	3/4	10	1.12	1.75
3/4	2.19	5.12	1.69	3.50	4	3/4	10	1.12	1.75
1	2.44	5.88	2.00	4.00	4	7/8	9	1.31	2.00
1 1/4	2.44	6.25	2.50	4.38	4	7/8	9	1.31	2.00
1 1/2	2.75	7.00	2.88	4.88	4	1	8	1.50	2.31
2	2.44	8.50	3.62	6.50	8	7/8	9	1.31	2.00
2 1/2	2.75	9.62	4.12	7.50	8	1	8	1.50	2.31
3	2.44	9.50	5.00	7.50	8	7/8	9	1.31	2.00
4	2.94	11.50	6.19	9.25	8	1 1/8	8	1.69	2.50
5	3.19	13.75	7.31	11.00	8	1 1/4	8	1.88	2.75
6	2.94	15.00	8.50	12.50	12	1 1/8	8	1.69	2.50
8	3.44	18.50	10.62	15.50	12	1 3/8	8	2.06	3.00
10	3.44	21.50	12.75	18.50	16	1 3/8	8	2.06	3.00
12	3.44	24.00	15.00	21.00	20	1 3/8	8	2.06	3.00
14	3.62	25.25	16.25	22.00	20	1 1/2	8	2.25	3.19
16	3.88	27.75	18.50	24.25	20	1 5/8	8	2.44	3.44
18	4.31	31.00	21.00	27.00	20	1 7/8	8	2.81	3.88
20	4.56	33.75	23.00	29.50	20	2	8	3.00	4.12
24	5.50	41.00	27.25	35.50	20	2 1/2	8	3.75	5.06



STUDDING OUTLETS

All dimensions are in inches. Material most commonly used, forged steel SA-105.

1500 lb

SIZE (BORE) B	THICK T	OD A	RF OD R	STUD CIRCLE C	STUDS NO. J	STUDS SIZE M	STUDS TPI I	TAP DEPTH E	HOLE DEPTH F
1/2	2.19	4.75	1.38	3.25	4	3/4	10	1.12	1.75
3/4	2.19	5.12	1.69	3.50	4	3/4	10	1.12	1.75
1	2.44	5.88	2.00	4.00	4	7/8	9	1.31	2.00
1 1/4	2.44	6.25	2.50	4.38	4	7/8	9	1.31	2.00
1 1/2	2.75	7.00	2.88	4.88	4	1	8	1.50	2.31
2	2.44	8.50	3.62	6.50	8	7/8	9	1.31	2.00
2 1/2	2.75	9.62	4.12	7.50	8	1	8	1.50	2.31
3	2.94	10.50	5.00	8.00	8	1 1/8	8	1.69	2.50
4	3.19	12.25	6.19	9.50	8	1 1/4	8	1.88	2.75
5	3.62	14.75	7.31	11.50	8	1 1/2	8	2.25	3.19
6	3.44	15.50	8.50	12.50	12	1 3/8	8	2.06	3.00
8	3.88	19.00	10.62	15.50	12	1 5/8	8	2.44	3.44
10	4.31	23.00	12.75	19.00	12	1 7/8	8	2.81	3.88
12	4.56	26.50	15.00	22.50	16	2	8	3.00	4.12
14	5.00	29.50	16.25	25.00	16	2 1/4	8	3.38	4.56
16	5.50	32.50	18.50	27.75	16	2 1/2	8	3.75	5.06
18	5.94	36.00	21.00	30.50	16	2 3/4	8	4.12	5.50
20	6.38	38.75	23.00	32.75	16	3	8	4.50	5.94
24	7.31	46.00	27.25	39.00	16	3 1/2	8	5.25	6.88

2500 lb

SIZE (BORE) B	THICK T	OD A	RF OD R	STUD CIRCLE C	STUDS NO. J	STUDS SIZE M	STUDS TPI I	TAP DEPTH E	HOLE DEPTH F
1/2	2.19	5.25	1.38	3.50	4	3/4	10	1.12	1.75
3/4	2.19	5.50	1.69	3.75	4	3/4	10	1.12	1.75
1	2.44	6.25	2.00	4.25	4	7/8	9	1.31	2.00
1 1/4	2.75	7.25	2.50	5.12	4	1	8	1.50	2.31
1 1/2	2.94	8.00	2.88	5.75	4	1 1/8	8	1.69	2.50
2	2.75	9.25	3.62	6.75	8	1	8	1.50	2.31
2 1/2	2.94	10.50	4.12	7.75	8	1 1/8	8	1.69	2.50
3	3.19	12.00	5.00	9.00	8	1 1/4	8	1.88	2.75
4	3.62	14.00	6.19	10.75	8	1 1/2	8	2.25	3.19
5	4.12	16.50	7.31	12.75	8	1 3/4	8	2.62	3.69
6	4.56	19.00	8.50	14.50	8	2	8	3.00	4.12
8	4.56	21.75	10.62	17.25	12	2	8	3.00	4.12
10	5.50	26.50	12.75	21.25	12	2 1/2	8	3.75	5.06
12	5.94	30.00	15.00	24.38	12	2 3/4	8	4.12	5.50

The studding outlets tabulated comply with the requirements of ASME Code Sect. VIII. Div. 1.

The tabulated dimensions of thickness, T are the minimums required.

The outlets are available also in stainless and other alloy steels.

Air test holes are optional.

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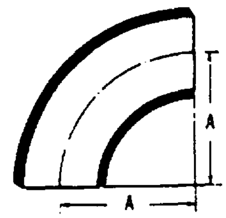
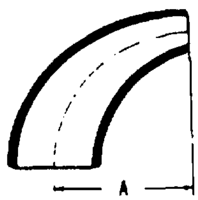
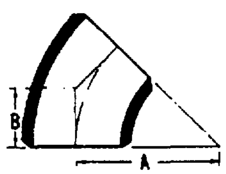


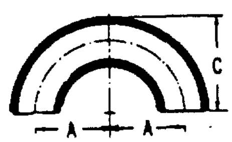
90° Long Radius Elbow



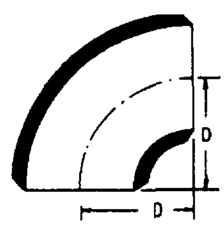
90° Long Radius Reducing Elbow



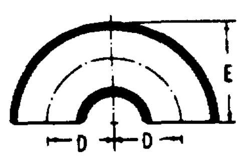
45° Long Radius Elbow



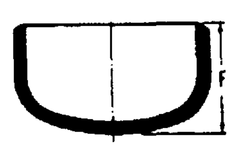
180° Long Radius Elbow



90° Short Radius Elbow



180° Short Radius Return



Cap

WELDING FITTINGS

ANSI B 16.9

1. All dimensions are in inches.
2. Welding fitting material conforms to SA 234 grade WPB.
3. Sizes 22, 26 and 30 in. are not covered by ANSI B 16.9.
4. For wall thicknesses see page 322.
5. Dimension F_1 applies to standard and X-STG. caps. Dimension F_2 applies to heavier weight caps.

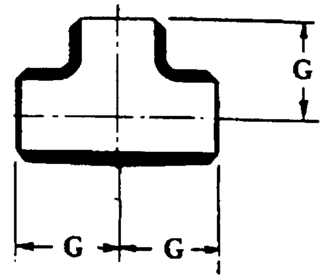
Nominal Pipe Size	Dimensions							
	Outside Diameter	A	B	C	D	E	F_1^5	F_2^5
½	0.840	1½	5/8	1 7/8	....	....	1	....
¾	1.050	1 1/8	7/16	1 11/16	....	....	1½	....
1	1.315	1½	7/8	2 3/16	1	1 5/8	1½	1½
1¼	1.660	1 7/8	1	2¾	1¼	2 1/16	1½	1½
1½	1.900	2¼	1 1/8	3¼	1½	2 7/16	1½	1½
2	2.375	3	1 3/8	4 3/16	2	3 3/16	1½	1¾
2½	2.875	3¾	1¾	5 3/16	2½	3 15/16	1½	2
3	3.500	4½	2	6¼	3	4¾	2	2½
3½	4.000	5¼	2¼	7¼	3½	5½	2½	3
4	4.500	6	2½	8¼	4	6¼	2½	3
5	5.563	7½	3 1/8	10 5/16	5	7¾	3	3½
6	6.625	9	3¾	12 15/16	6	9 5/16	3½	4
8	8.625	12	5	16 5/16	8	12 5/16	4	5
10	10.750	15	6¼	20 3/8	10	15 3/8	5	6
12	12.750	18	7½	24 3/8	12	18 3/8	6	7
14	14.000	21	8¾	28	14	21	6½	7½
16	16.000	24	10	32	16	24	7	8
18	18.000	27	11¼	36	18	27	8	9
20	20.000	30	12½	40	20	30	9	10
22	22.000	33	13½	44	....	....	10	10
24	24.000	36	15	48	24	36	10½	12
26	26.000	39	16	52	....	....	10½	....
30	30.000	45	18½	60	30	45	10½	....

WELDING FITTINGS

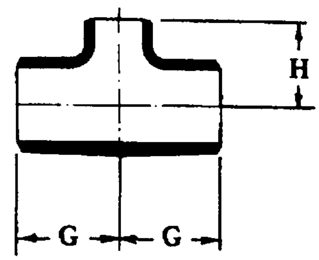
ANSI B 16.9

1. All dimensions are in inches
2. Welding fitting material conforms to SA 234 grade WPB.
3. Sizes 22, 26 and 30 in. are not covered by ANSI B 16.9.
4. For wall thicknesses see page 322.

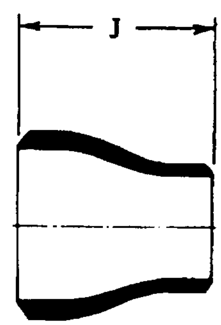
Nominal Pipe Size	Dimensions				
	Outlet	Outside Diameter	G	H	J
½	½	.840	1	1	....
	⅜	.675	1	1	....
¾	¾	1.050	1⅛	1⅛	....
	½	.840	1⅛	1⅛	1½
1	1	1.315	1½	1½	....
	¾	1.050	1½	1½	2
	½	.840	1½	1½	2
1¼	1¼	1.660	1⅞	1⅞	....
	1	1.315	1⅞	1⅞	2
	¾	1.050	1⅞	1⅞	2
	½	.840	1⅞	1⅞	2
1½	1½	1.900	2¼	2¼	....
	1¼	1.660	2¼	2¼	2½
	1	1.315	2¼	2¼	2½
	¾	1.050	2¼	2¼	2½
	½	.840	2¼	2¼	2½
2	2	2.375	2½	2½	....
	1½	1.900	2½	2⅜	3
	1¼	1.660	2½	2¼	3
	1	1.315	2½	2	3
	¾	1.050	2½	1¾	3
2½	2½	2.875	3	3	....
	2	2.375	3	2¾	3½
	1½	1.900	3	2⅝	3½
	1¼	1.660	3	2½	3½
	1	1.315	3	2¼	3½
3	3	3.500	3⅜	3⅜	....
	2½	2.875	3⅜	3¼	3½
	2	2.375	3⅜	3	3½
	1½	1.900	3⅜	2⅞	3½
	1¼	1.660	3⅜	2¾	3½
3½	3½	4.000	3¾	3¾	....
	3	3.500	3¾	3⅝	4
	2½	2.875	3¾	3½	4
	2	2.375	3¾	3¼	4
	1½	1.900	3¾	3⅛	4
4	4	4.500	4⅛	4⅛	....
	3½	4.000	4⅛	4	4
	3	3.500	4⅛	3⅞	4
	2½	2.875	4⅛	3¾	4
	2	2.375	4⅛	3½	4
	1½	1.900	4⅛	3⅜	4



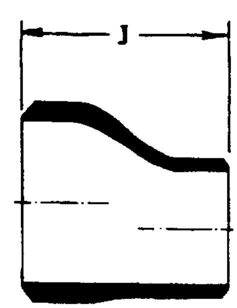
Tee



Reducing Tee



Concentric Reducer

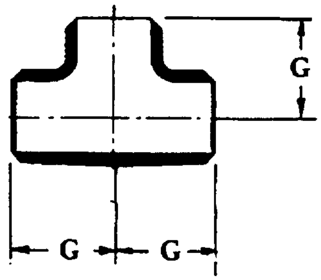


Eccentric Reducer

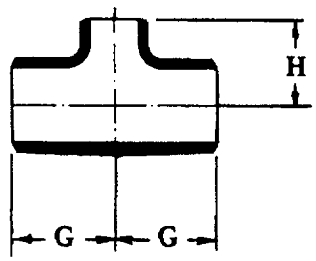
WELDING FITTINGS

ANSI B 16.9

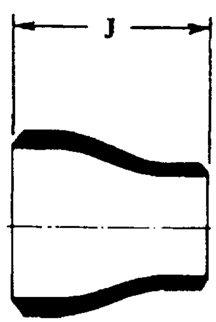
1. All dimensions are in inches
2. Welding fitting material conforms to SA 234 grade WPB.
3. Sizes 22, 26 and 30 in. are not covered by ANSI B 16.9.
4. For wall thicknesses see page 322.



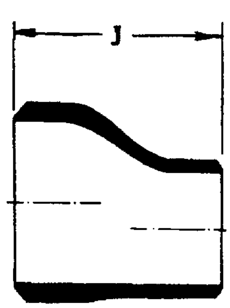
Tee



Reducing Tee



Concentric Reducer



Eccentric Reducer

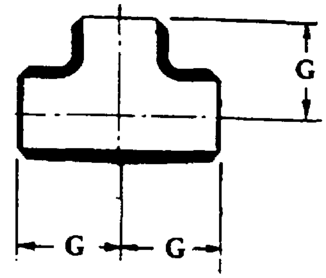
Nominal Pipe Size	Dimensions				
	Outlet	Outside Diameter	G	H	J
5	5	5.563	4⅞	4⅞	....
	4	4.500	4⅞	4⅝	5
	3½	4.000	4⅞	4½	5
	3	3.500	4⅞	4⅜	5
	2½	2.875	4⅞	4¼	5
	2	2.375	4⅞	4⅛	5
6	6	6.625	5⅝	5⅝	....
	5	5.563	5⅝	5⅜	5½
	4	4.500	5⅝	5⅛	5½
	3½	4.000	5⅝	5	5½
	3	3.500	5⅝	4⅞	5½
	2½	2.875	5⅝	4¾	5½
8	8	8.625	7	7	....
	6	6.625	7	6⅝	6
	5	5.563	7	6⅜	6
	4	4.500	7	6⅛	6
	3½	4.000	7	6	6
10	10	10.750	8½	8½	....
	8	8.625	8½	8	7
	6	6.625	8½	7⅝	7
	5	5.563	8½	7½	7
	4	4.500	8½	7¼	7
12	12	12.750	10	10	....
	10	10.750	10	9½	8
	8	8.625	10	9	8
	6	6.625	10	8⅝	8
	5	5.563	10	8½	8
14	14	14.000	11	11	...
	12	12.750	11	10⅝	13
	10	10.750	11	10⅛	13
	8	8.625	11	9¾	13
	6	6.625	11	9⅜	13
16	16	16.000	12	12	....
	14	14.000	12	12	14
	12	12.750	12	11⅝	14
	10	10.750	12	11⅛	14
	8	8.625	12	10¾	14
	6	6.625	12	10⅛	14
18	18	18.000	13½	13½	....
	16	16.000	13½	13	15
	14	14.000	13½	13	15

WELDING FITTINGS

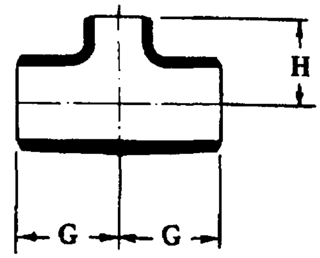
ANSI B 16.9

1. All dimensions are in inches
2. Welding fitting material conforms to SA 234 grade WPB.
3. Sizes 22, 26 and 30 in. are not covered by ANSI B 16.9.
4. For wall thicknesses see page 322.

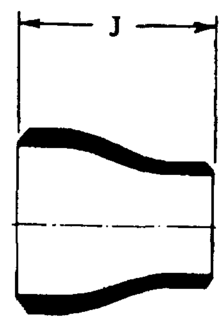
Nominal Pipe Size	Dimensions				
	Outlet	Outside Diameter	G	H	J
18	12	12.750	13½	12⅝	15
	10	10.750	13½	12⅛	15
	8	8.625	13½	11¾	15
20	20	20.000	15	15	....
	18	18.000	15	14½	20
	16	16.000	15	14	20
	14	14.000	15	14	20
	12	12.750	15	13⅝	20
	10	10.750	15	13⅛	20
	8	8.625	15	12¾	20
22	22	22.000	16½	16½	....
	20	20.000	16½	16	20
	18	18.000	16½	15½	20
	16	16.000	16½	15	20
	14	14.000	16½	15	20
	12	12.750	16½	14⅝	....
	10	10.750	16½	14⅛	....
24	24	24.000	17	17	....
	22	22.000	17	17	20
	20	20.000	17	17	20
	18	18.000	17	16½	20
	16	16.000	17	16	20
	14	14.000	17	16	20
	12	12.750	17	15⅝	20
	10	10.750	17	15⅛	20
30	30	30.000	22	22	....
	24	24.000	22	21	24
	22	22.000	22	20½	24
	20	20.000	22	20	24
	18	18.000	22	19½	....
	16	16.000	22	19	....



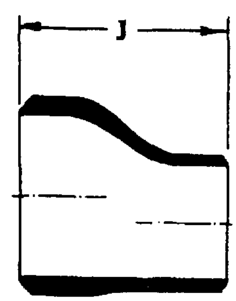
Tee



Reducing Tee

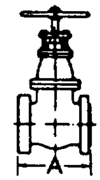


Concentric Reducer



Eccentric Reducer

FACE-TO-FACE DIMENSIONS OF FLANGED STEEL
GATE VALVES
(WEDGE AND DOUBLE DISC)



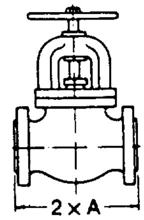
Raised Face

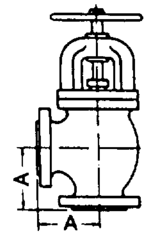
Nominal Size, Inches	Pressure, Lb. per Sq. In. — Dimension A, Inches				Nominal Size, Inches	Pressure, Lb. per Sq. In. — Dimension A, Inches		
	150	300	400	600		900	1500	2500
1	—	—	8½	8½	1	10	10	12⅛
1¼	—	—	9	9	1¼	11	11	13¾
1½	—	7½	9½	9½	1½	12	12	15⅛
2	7	8½	11½	11½	2	14½	14½	17¾
2½	7½	9½	13	13	2½	16½	16½	20
3	8	11⅛	14	14	3	15	18½	22¾
3½	8½	11⅞	—	—	4	18	21½	26½
4	9	12	16	17	5	22	26½	31¼
5	10	15	18	20	6	24	27¾	36
6	10½	15⅞	19½	22	8	29	32¾	40¼
8	11½	16½	23½	26	10	33	39	50
10	13	18	26½	31	12	38	44½	56
12	14	19¾	30	33	14	40½	49½	—
14 OD	15	30	32½	35	16	44½	54½	—
16 OD	16	33	35½	39	18	48	60½	—
18 OD	17	36	38½	43	20	52	65½	—
20 OD	18	39	41½	47	24	61	76½	—
24 OD	20	45	48½	55				

Ring Type Joint

Nominal Size, Inches	Pressure, Lb. per Sq. In. — Dimension A, Inches				Nominal Size, Inches	Pressure, Lb. per Sq. In. — Dimension A, Inches		
	150	300	400	600		900	1500	2500
1	5½	—	8½	8½	1	10	10	12⅛
1¼	6	—	9	9	1¼	11	11	13⅞
1½	7	8	9½	9½	1½	12	12	15¼
2	7½	9⅛	11⅝	11⅝	2	14⅝	14⅝	17⅞
2½	8	10⅛	13⅛	13⅛	2½	16⅝	16⅝	20¼
3	8½	11¾	14⅛	14⅛	3	15⅛	18⅝	23
4	9½	12⅝	16⅛	17⅛	4	18⅛	21⅝	26⅞
5	10½	15⅝	18⅛	20⅛	5	22⅛	26⅝	31¾
6	11	16½	19⅝	22⅛	6	24⅛	28	36½
8	12	17⅛	23⅝	26⅛	8	29⅛	33⅛	40⅞
10	13½	18⅝	26⅝	31⅛	10	33⅛	39⅜	50⅞
12	14½	20⅜	30⅛	33⅛	12	38⅛	45⅛	56⅞
14	15½	30⅝	32⅝	35⅛	14	40⅞	50¼	—
16	16½	33⅝	35⅝	39⅛	16	44⅞	55⅜	—
18	17½	36⅝	38⅝	43⅛	18	48½	61⅜	—
20	18½	39¾	41¾	47¼	20	52½	66⅜	—
24	20½	45⅞	48⅞	55⅜	24	61¾	77⅝	—

FACE-TO-FACE DIMENSIONS OF FLANGED STEEL
GLOBE AND ANGLE VALVES





Raised Face

Nominal Size, Inches	Class, lb 150	300	400	600
	Dimension 2 x A, Inches			
½	—	—	—	—
¾	—	—	7½	7½
1	—	—	8½	8½
1¼	—	—	9	9
1½	—	—	9½	9½
2	8	10½	11½	11½
2½	8½	11½	13	13
3	9½	12½	14	14
3½	10½	13¼	—	—
4	11½	14	16	17
5	14	15¾	18	20
6	16	17½	19½	22
8	19½	22	23½	26

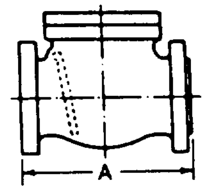
Nominal Size, Inches	Pressure, Lb. per Sq. In. 900	1500	2500
	Dimension 2 x A, Inches		
½	—	—	10⅜
¾	9	9	10¾
1	10	10	12⅛
1¼	11	11	13¾
1½	12	12	15⅛
2	14½	14½	17¾
2½	16½	16½	20
3	15	18½	22¾
4	18	21½	26½
5	22	26½	31¼
6	24	27¾	36
8	29	32¾	40¼
10	33	39	50
12	38	44½	56
14	40½	49½	—

Ring Type Joint

Nominal Size, Inches	Pressure, Lb. per Sq. In. 150	300	400	600
	Dimension 2 x A, Inches			
½	—	6 7/16	6 7/16	6 7/16
¾	—	7½	7½	7½
1	—	8½	8½	8½
1¼	—	9	9	9
1½	7	9½	9½	9½
2	8½	11⅛	11⅝	11⅝
2½	9	12⅛	13⅛	13⅛
3	—	13⅛	14⅛	14⅛
4	12	14⅝	16⅛	17⅛
5	14½	16⅜	18⅛	20⅛
6	16½	18⅛	19⅝	22⅛
8	20	22⅝	23⅝	26⅛
10	25	25⅛	26⅝	31⅛
12	28	28⅝	30⅛	33⅛
14	31½	—	—	—
16	36½	—	—	—

Nominal Size, Inches	Pressure, Lb. per Sq. In. 900	1500	2500
	Dimension 2 x A, Inches		
½	—	—	10⅜
¾	9	9	10¾
1	10	10	12⅛
1¼	11	11	13⅞
1½	12	12	15¼
2	14⅝	14⅝	17⅞
2½	16⅝	16⅝	20¼
3	15⅛	18⅝	23
4	18⅛	21⅝	26⅞
5	22⅛	26⅝	31¾
6	24⅛	28	36½
8	29⅛	33⅛	40⅞
10	33⅛	39⅜	50⅞
12	38⅛	45⅛	56⅞
14	40⅞	50¼	—

FACE-TO-FACE DIMENSIONS OF FLANGED STEEL
SWING CHECK VALVES



Raised Face

Nominal Size, Inches	Pressure, Lb. per Sq. In. — Dimension A, Inches			
	150	300	400	600
2	8	10½	11½	11½
2½	8½	11½	13	13
3	9½	12½	14	14
3½	10½	13¼	—	—
4	11½	14	16	17
5	13	15¾	—	—
6	14	17½	19½	22
8	—	21	23½	26
10	—	24½	26½	31
12	—	28	30	33

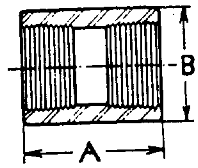
Nominal Size, Inches	Pressure, Lb. per Sq. In. — Dimension A, Inches		
	900	1500	2500
½	—	—	10⅜
¾	9	9	10¾
1	10	10	12⅛
1¼	11	11	13¾
1½	12	12	15⅛
2	14½	14½	17¾
2½	16½	16½	20
3	15	18½	22¾
4	18	21½	26½
5	22	26½	31¼
6	24	27¾	36
8	29	32¾	40¼
10	33	39	50
12	38	44½	56
14	40½	49½	—

Ring Type Joint

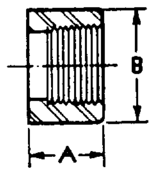
Nominal Size, Inches	Pressure, Lb. per Sq. In. — Dimension A, Inches			
	150	300	400	600
½	4 11/16	—	6 7/16	6 7/16
¾	5⅛	—	7½	7½
1	5½	9	8½	8½
1¼	6	9½	9	9
1½	7	10	9½	9½
2	8½	11⅛	11⅝	11⅝
2½	9	12⅛	13⅛	13⅛
3	10	13⅛	14⅛	14⅛
4	12	14⅝	16⅛	17⅛
5	13½	16⅜	18⅛	20⅛
6	14½	18⅛	19⅝	22⅛
8	20	21⅝	23⅝	26⅛
10	25	25⅛	26⅝	31⅛
12	28	28⅝	30⅛	33⅛
14	31½	—	—	—

Nominal Size, Inches	Pressure, Lb. per Sq. In. — Dimension A, Inches		
	900	1500	2500
½	—	—	10⅜
¾	9	9	10¾
1	10	10	12⅛
1¼	11	11	13⅞
1½	12	12	15¼
2	14⅝	14⅝	17⅞
2½	16⅝	16⅝	20¼
3	15⅛	18⅝	23
4	18⅛	21⅝	26⅞
5	22⅛	26⅝	31¾
6	24⅛	28	36½
8	29⅛	33⅛	40⅞
10	33⅛	39⅜	50⅞
12	38⅛	45⅛	56⅞
14	40⅞	50¼	—

Reference: Face-to-Face and End-to-End Dimensions of Ferrous Valves
American National Standard ANSI B16.10-1973



Full Coupling



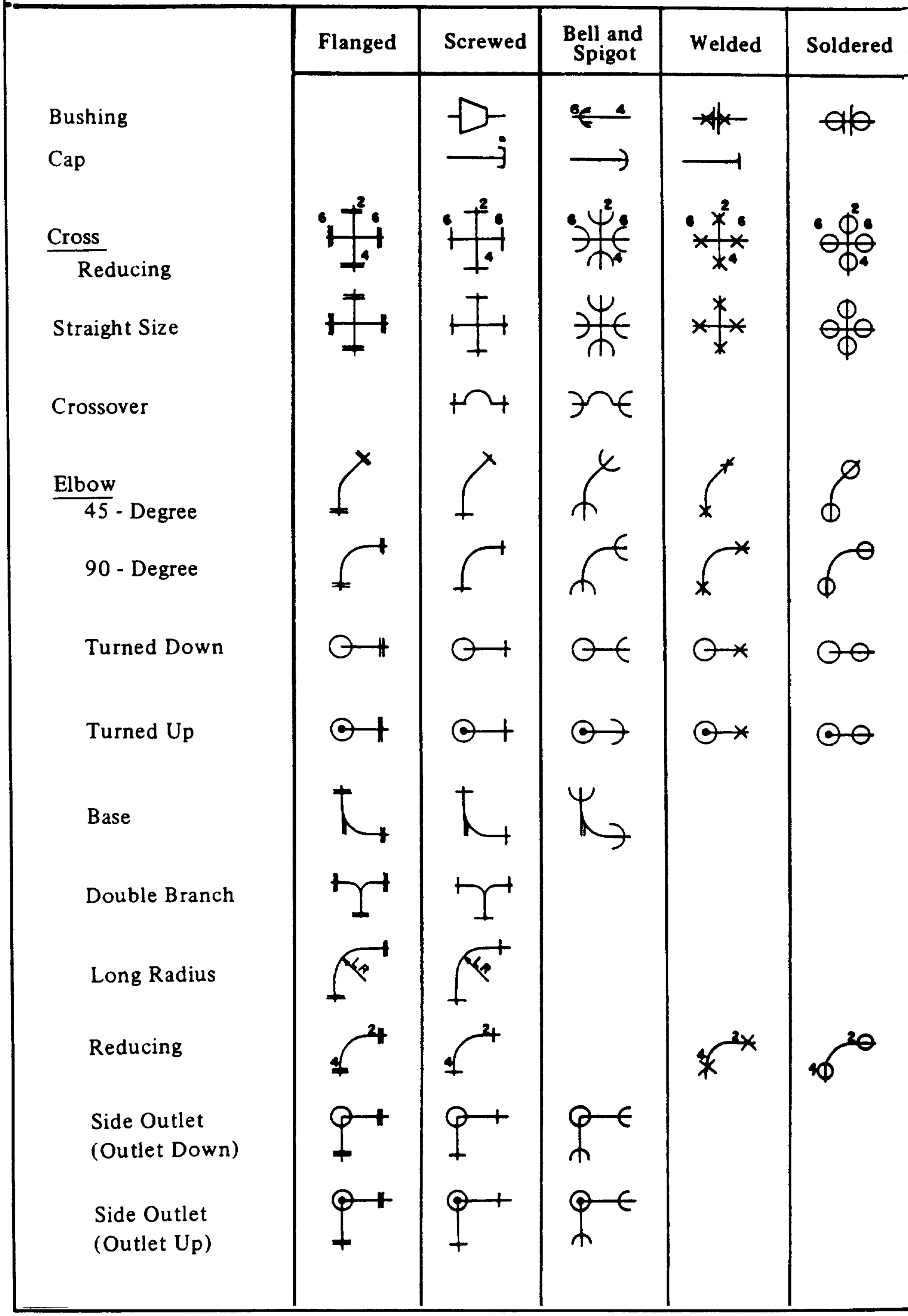
Half Coupling

SCREWED COUPLINGS

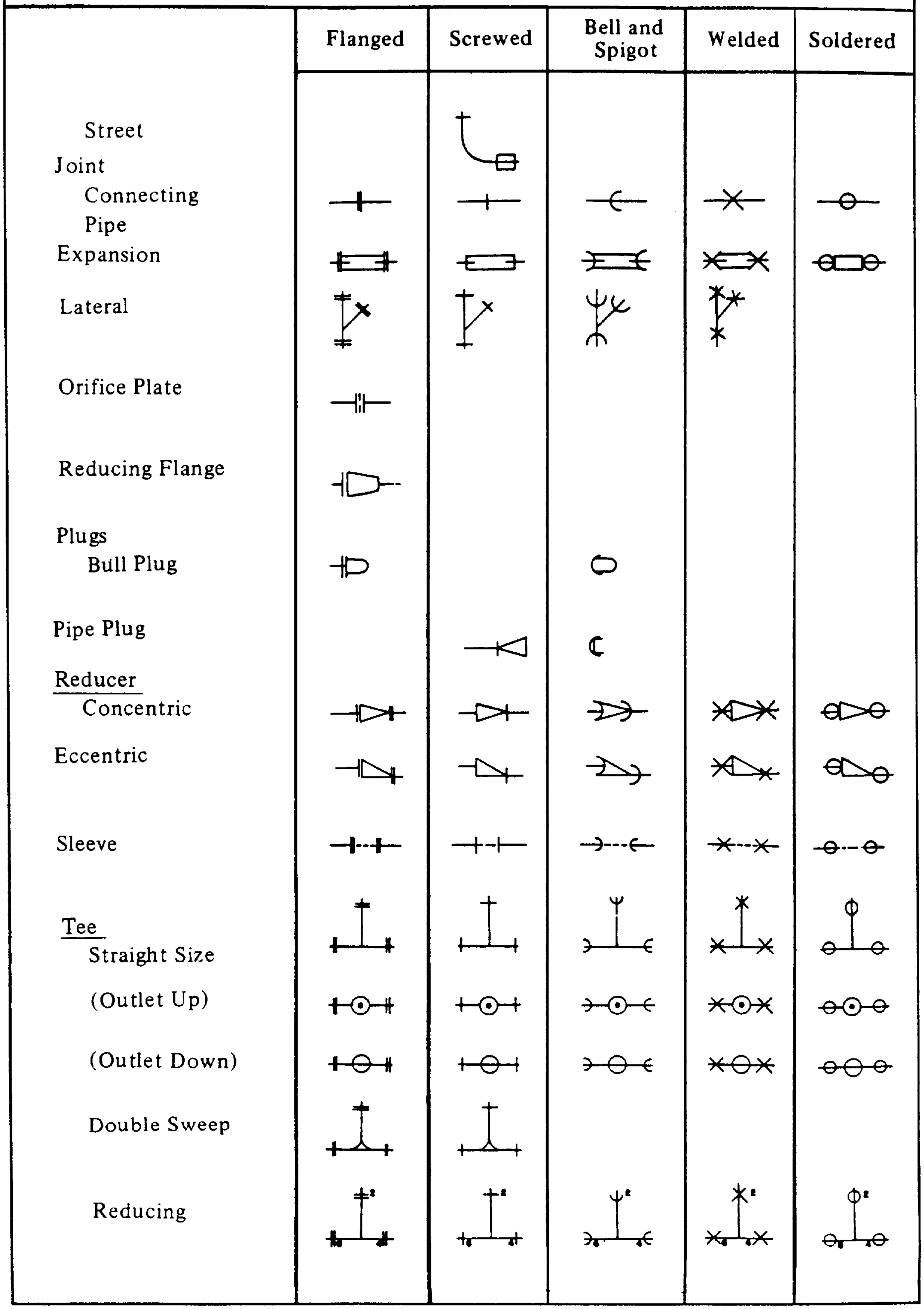
1. All dimensions are in inches.
2. Material forged carbon steel conforms to the requirements of Specification SA-105.
3. Threads comply with ANSI Standard B2.1-1968.

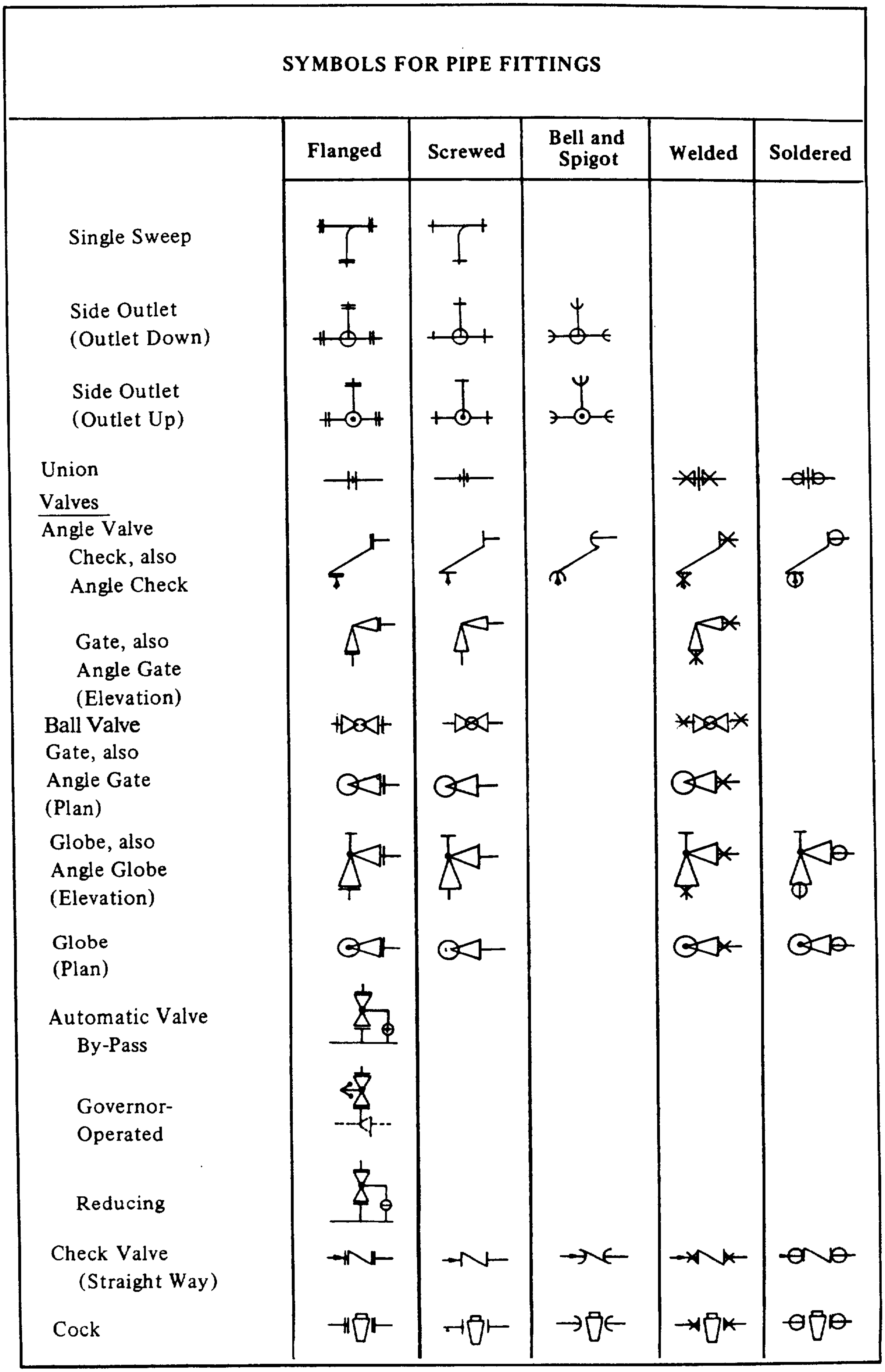
Nominal Pipe Size	Full Coupling				Half Coupling			
	3000 lb		6000 lb		3000 lb		6000 lb	
	Length A	Diameter B	Length A	Diameter B	Length A	Diameter B	Length A	Diameter B
1/8	1 1/4	3/4	1 1/4	7/8	5/8	3/4	5/8	7/8
1/4	1 3/8	3/4	1 3/8	1	11/16	3/4	11/16	1
3/8	1 1/2	7/8	1 1/2	1 1/4	3/4	7/8	3/4	1 1/4
1/2	1 7/8	1 1/8	1 7/8	1 1/2	15/16	1 1/8	15/16	1 1/2
3/4	2	1 3/8	2	1 3/4	1	1 3/8	1	1 3/4
1	2 3/8	1 3/4	2 3/8	2 1/4	1 3/16	1 3/4	1 3/16	2 1/4
1 1/4	2 5/8	2 1/4	2 5/8	2 1/2	1 5/16	2 1/4	1 5/16	2 1/2
1 1/2	3 1/8	2 1/2	3 1/8	3	1 9/16	2 1/2	1 9/16	3
2	3 3/8	3	3 3/8	3 5/8	1 11/16	3	1 11/16	3 5/8
2 1/2	3 5/8	3 5/8	3 5/8	4 1/4	1 13/16	3 5/8	1 13/16	4 1/4
3	4 1/4	4 1/4	4 1/4	5	2 1/8	4 1/4	2 1/8	5
3 1/2	4 1/2	4 3/4	4 1/2	5 3/4	2 1/4	4 3/4	2 1 /4	5 3/4
4	4 3/4	5 1/2	4 3&4	6 1/4	2 3/8	5 1/2	2 3/8	6 1/4

SYMBOLS FOR PIPE FITTINGS
American Standard: ANSI Z32.2.3



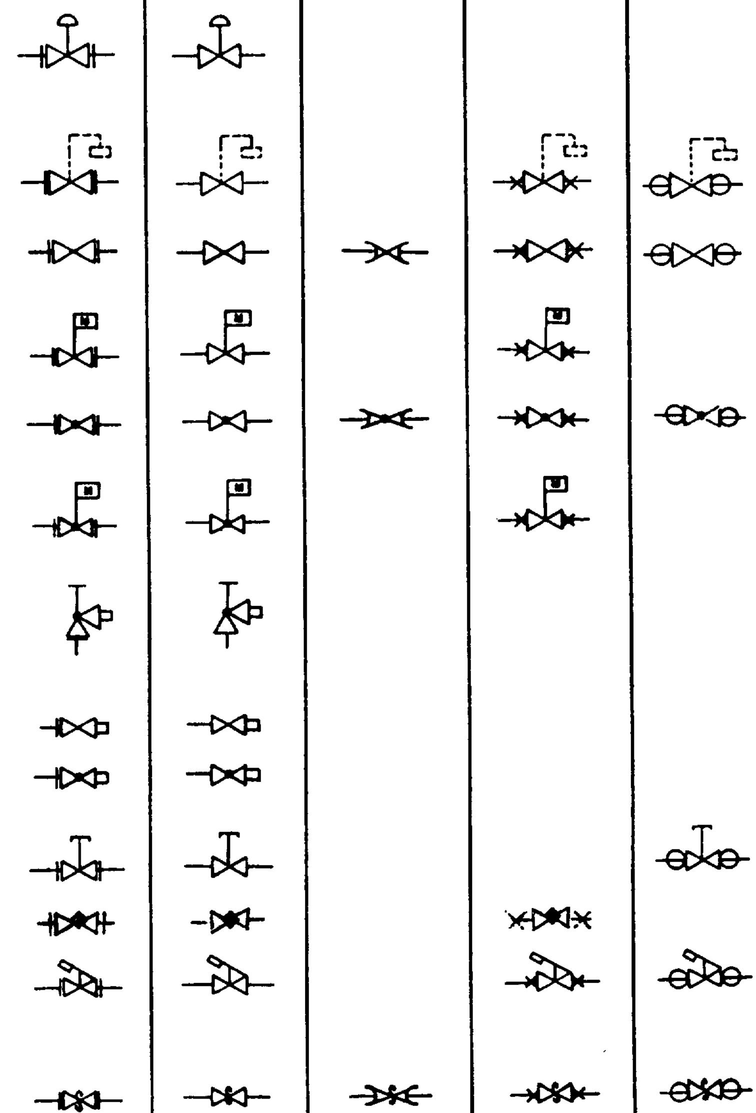
SYMBOLS FOR PIPE FITTINGS




SYMBOLS FOR PIPE FITTINGS
Flanged
Screwed
Bell and Spigot
Welded
Soldered
Single Sweep
Side Outlet (Outlet Down)
Side Outlet (Outlet Up)
Union
Valves
Angle Valve
Check, also Angle Check
Gate, also Angle Gate (Elevation)
Ball Valve
Gate, also Angle Gate (Plan)
Globe, also Angle Globe (Elevation)
Globe (Plan)
Automatic Valve By-Pass
Governor-Operated
Reducing
Check Valve (Straight Way)
Cock

SYMBOLS FOR PIPE FITTINGS

	Flanged	Screwed	Bell and Spigot	Welded	Soldered
Diaphragm Valve					
Float Valve					
Gate Valve					
Motor-Operated					
Globe Valve					
Motor-Operated					
Hose Valve, also Hose Globe					
Angle, also Hose Angle					
Gate					
Globe					
Lockshield Valve					
Plug Valve					
Quick Opening or Butterfly Valve					
Safety Valve					



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DESIGN OF PROCESS EQUIPMENT

THIRD EDITION by Kanti K. Mahajan - $78

346 Pages • 50 Illustrations, Tables, Design Forms

TABLE OF CONTENTS

The material of this book is selected very judiciously with the needs of practical men in mind. It is a well organized presentation of subjects, each complete in itself.

Ample charts and tables make important data clear at a glance. The problems are solved by quick step-by-step calculations, illustrations and examples.

About the Author . . . Kanti K. Mahajan is a registered professional engineer in the states of Kansas, California and Texas. He received his bachelor and master of science degrees in mechanical engineering from the University of Houston. He has been involved with the field of heat exchanger and pressure vessel design for the past seventeen years. He is currently a principal mechanical engineer with the Fluor Engineers, Inc., Irvine, CA, Prior to that he was a senior vessel engineer with Litwin Engineers & Construction, Inc., Wichita, KS.

PRESSURE VESSEL PUBLISHING, INC. P.O. BOX 35365 TULSA, OK 74153

WEIGHTS

1. The tables on the following pages show the weights of different vessel components made of steel.

2. All weights are calculated with the theoretical weight of steel: 1 cubic inch = 0.28333 pounds.

3. To obtain the actual weight of a vessel, add 6% to the total weight. This will cover the overweights of material which comes from the manufacturing tolerances and the weight of the weldings.

4. The weights of shells shown in the tables refer to one lineal foot of shell-length. The weights tabulated in columns headed by "I.S." and "O.S." are the weights of shell when the given diameter signifies inside or outside diameter.

5. The weights of the heads include:
   - A. For ellipsodial heads: 2 inch straight flange or the wall thickness, whichever is greater.
   - B. For ASME flanged and dished heads: 1½ inch straight flange.
   - C. For hemispherical heads: 0 inch straight flange.

6. The weights of pipe fittings made by different manufacturers show in many cases considerable deviations, which reflect manufacturing differences. The weights of pipe fittings shown in these tables refer to the products of Ladish Company.

7. All dimensions in inches.
   All weights in pounds.

WEIGHT OF SHELLS & HEADS

DIAM. VESSEL	WALL THICKNESS 1/4" SHELL I.S.	1/4" SHELL O.S.	1/4" HEAD ELLIP	1/4" HEAD F.&D.	1/4" HEAD HEMIS	5/16" SHELL I.S.	5/16" SHELL O.S.	5/16" HEAD ELLIP	5/16" HEAD F.&D.	5/16" HEAD HEMIS
12	33	31	22	14	20	41	39	28	19	26
14	38	36	28	19	28	48	46	35	24	35
16	44	42	33	23	36	54	52	41	29	46
18	49	49	41	28	46	61	59	51	35	58
20	54	52	47	35	56	68	66	58	43	71
22	60	58	55	41	68	74	72	69	51	85
24	65	63	62	47	81	81	79	78	58	101
26	70	68	70	55	95	88	86	87	69	119
28	76	74	78	62	110	94	92	100	78	138
30	81	79	89	70	126	101	99	114	87	158
32	86	84	100	80	143	108	106	129	100	179
34	92	90	113	89	161	114	112	144	111	202
36	97	95	128	98	180	121	119	160	123	226
38	102	100	139	110	201	128	126	177	138	256
40	108	106	156	120	222	134	133	195	150	279
42	113	111	165	131	245	141	139	214	163	307
48	129	127	215	168	320	161	159	285	210	400
54	145	143	270	210	404	182	179	351	263	506
60	161	159	330	257	498	202	199	434	322	624
66	177	175	398	309	602	222	219	520	386	755
72	193	191	453	365	717	243	239	598	456	897
78	209	207	543	421	840	263	259	695	532	1052
84	225	223	624	492	974	283	279	806	614	1220
90	241	239	723	556	1118	303	299	925	702	1399
96	257	255	820	637	1272	324	319	1050	796	1592
102	273	271	922	710	1435	344	339	1180	896	1796
108	289	287	1031	801	1608	364	359	1320	1001	2013
114	305	303	1150	883	1792	385	379	1468	1104	2242
120	321	319	1255	984	1985	405	399	1622	1230	2484
126	337	335	1445	1075	2188	425	419	1820	1344	2738
132	353	351	1590	1186	2401	446	439	1990	1482	3004
138	369	367	1730	1286	2624	466	459	2160	1607	3282
144	385	383	1880	1406	2856	486	480	2350	1758	3573

WEIGHT OF SHELLS & HEADS

DIAM. VESSEL	WALL THICKNESS									
	3/8"					7/16"				
	SHELL		HEAD			SHELL		HEAD		
	I.S.	O.S.	ELLIP	F.&D.	HEMIS	I.S.	O.S.	ELLIP	F.&D.	HEMIS
12	50	47	33	22	32	58	54	41	26	37
14	58	55	42	28	43	67	63	49	33	50
16	66	63	50	35	55	77	73	61	41	65
18	74	71	61	42	70	86	82	71	52	82
20	82	79	70	52	85	95	91	85	61	100
22	90	87	82	61	103	105	101	97	71	121
24	98	95	94	70	122	114	110	109	82	143
26	106	103	105	82	143	123	119	122	97	168
28	114	111	121	94	166	133	129	141	109	194
30	122	119	137	105	190	142	138	160	122	223
32	130	127	154	121	216	151	148	180	141	253
34	138	135	173	134	243	161	157	191	156	285
36	146	143	192	147	272	170	166	224	172	319
38	154	151	213	165	303	179	176	248	192	355
40	162	159	234	180	336	189	185	273	210	393
42	170	167	257	196	370	198	194	300	229	433
48	194	191	331	252	482	226	222	386	295	564
54	218	215	415	316	609	254	250	484	368	712
60	242	239	508	386	751	282	278	592	450	877
66	266	263	610	463	907	310	306	711	540	1060
72	290	287	718	547	1079	338	334	842	639	1260
78	314	311	836	638	1265	366	362	983	745	1478
84	338	335	965	737	1466	394	391	1136	860	1713
90	362	359	1110	842	1682	422	419	1298	983	1965
96	386	383	1260	955	1912	450	447	1473	1115	2234
102	410	407	1419	1075	2158	478	475	1658	1254	2521
108	434	431	1582	1202	2418	506	503	1854	1402	2825
114	458	455	1760	1335	2694	534	531	2061	1558	3146
120	482	479	1950	1476	2984	562	559	2249	1722	3484
126	506	503	2170	1624	3288	591	587	2530	1894	3840
132	530	527	2490	1779	3608	619	615	2790	2075	4213
138	554	551	2595	1928	3942	647	643	3025	2264	4604
144	579	576	2820	2110	4292	675	671	3300	2461	5011

WEIGHT OF SHELLS & HEADS

DIAM. VESSEL	WALL THICKNESS									
	1/2"					9/16"				
	SHELL		HEAD			SHELL		HEAD		
	I.S.	O.S.	ELLIP	F.&D.	HEMIS	I.S.	O.S.	ELLIP	F.&D.	HEMIS
12	67	61	47	30	43	76	69	52	35	49
14	78	72	56	38	58	88	81	63	44	65
16	88	82	70	47	75	100	93	78	54	85
18	99	93	81	59	94	112	105	91	67	106
20	110	104	97	70	115	124	117	109	78	131
22	120	114	110	81	139	136	129	124	91	157
24	131	125	125	94	165	148	141	143	107	186
26	142	136	140	110	193	160	153	162	124	218
28	152	146	161	125	223	172	165	181	140	252
30	163	157	182	140	255	184	177	205	157	288
32	174	168	206	161	290	196	189	231	181	327
34	184	178	230	178	327	208	201	259	200	369
36	195	189	256	196	366	220	213	288	220	413
38	206	200	283	220	407	232	225	319	247	459
40	217	211	313	240	450	244	237	352	270	508
42	227	221	343	261	496	256	249	386	294	560
48	259	253	442	337	646	292	285	497	379	728
54	291	285	553	421	815	328	321	622	473	919
60	323	317	677	514	1005	364	357	762	578	1133
66	355	349	813	617	1214	400	393	915	694	1368
72	387	381	962	730	1443	436	429	1083	821	1626
78	419	413	1124	852	1692	472	465	1264	958	1906
84	451	445	1298	983	1960	508	501	1460	1106	2209
90	483	477	1484	1124	2248	544	537	1669	1264	2533
96	515	509	1683	1274	2557	580	573	1894	1433	2880
102	547	541	1894	1433	2884	617	610	2131	1612	3249
108	579	573	2119	1602	3232	653	646	2384	1802	3640
114	611	605	2355	1780	3599	689	682	2650	2002	4054
120	647	638	2571	1968	3986	725	718	2892	2214	4489
126	676	670	2890	2165	4393	761	754	3234	2435	4947
132	708	702	3340	2372	4820	797	790	3660	2668	5427
138	740	734	3460	2588	5266	833	826	3897	2911	5930
144	777	766	3760	2813	5732	869	862	4240	3165	6454

WEIGHT OF SHELLS & HEADS

DIAM. VESSEL	WALL THICKNESS									
	5/8"					11/16"				
	SHELL		HEAD			SHELL		HEAD		
	I.S.	O.S.	ELLIP	F.&D.	HEMIS	I.S.	O.S.	ELLIP	F.&D.	HEMIS
12	84	76	58	40	55	93	83	64	44	61
14	97	89	70	50	73	108	98	79	55	81
16	111	103	87	61	95	122	112	95	67	105
18	124	116	101	74	119	137	127	113	83	132
20	137	129	121	86	146	152	142	133	97	162
22	151	143	138	101	176	166	156	154	113	194
24	164	156	161	121	208	181	171	177	133	230
26	177	169	180	138	243	196	186	198	151	269
28	191	183	201	156	281	211	201	221	171	311
30	204	196	228	175	322	225	215	251	195	355
32	218	210	257	201	365	240	230	283	221	403
34	231	223	288	223	411	255	245	317	245	454
36	244	236	326	245	460	269	259	353	270	508
38	258	250	355	275	512	284	274	390	302	565
40	271	263	391	300	566	299	289	430	330	625
42	284	276	428	327	623	313	303	471	360	688
48	324	316	552	421	811	357	347	607	458	895
54	364	356	691	526	1024	401	391	760	579	1129
60	404	396	846	643	1261	445	435	931	707	1390
66	444	436	1017	772	1523	489	479	1118	849	1677
72	484	476	1203	912	1810	533	523	1323	1003	1994
78	524	516	1405	1065	2121	577	567	1545	1171	2337
84	564	556	1622	1229	2458	621	611	1784	1352	2707
90	604	596	1855	1405	2818	665	655	2041	1545	3104
96	644	636	2104	1592	3204	710	700	2315	1751	3529
102	685	677	2368	1791	3614	754	744	2605	1970	3980
108	725	717	2648	2003	4049	798	788	2913	2203	4459
114	765	757	2944	2225	4509	842	832	3239	2448	4965
120	805	797	3213	2460	4993	886	876	3535	2706	5498
126	848	837	3578	2706	5502	930	920	3910	2977	6058
132	885	877	3980	2965	6036	974	964	4317	3261	6646
138	925	917	4325	3234	6595	1018	1008	4703	3557	7261
144	965	957	4720	3516	7178	1062	1052	5185	3868	7902

WEIGHT OF SHELLS & HEADS

DIAM. VESSEL	WALL THICKNESS									
	3/4"					13/16"				
	SHELL		HEAD			SHELL		HEAD		
	I.S.	O.S.	ELLIP	F.&D.	HEMIS	I.S.	O.S.	ELLIP	F.&D.	HEMIS
12	102	90	70	48	67	111	97	76	53	73
14	118	106	88	60	90	128	114	95	67	98
16	134	122	104	74	116	146	132	113	82	126
18	150	138	126	92	145	163	149	136	100	158
20	166	154	145	108	177	180	166	157	117	193
22	182	170	171	126	213	198	184	185	137	232
24	198	186	193	145	252	215	201	209	160	275
26	214	202	216	165	295	233	219	234	182	321
28	230	218	241	187	340	250	236	261	412	370
30	246	234	274	216	389	267	253	304	234	423
32	262	250	309	241	442	285	271	335	261	480
34	278	266	345	267	497	302	288	378	289	541
36	294	282	393	294	556	319	305	425	323	605
38	310	298	425	330	618	337	323	470	357	672
40	326	314	469	361	684	354	340	508	391	743
42	342	330	514	393	753	371	357	567	425	818
48	390	378	662	505	979	423	409	729	547	1063
54	438	426	829	631	1234	475	461	911	683	1340
60	486	474	1015	772	1520	527	513	1107	836	1650
66	534	522	1220	926	1835	579	565	1337	1003	1991
72	582	570	1443	1095	2179	631	617	1564	1186	2365
78	630	618	1685	1277	2554	683	669	1835	1384	2771
84	678	666	1947	1475	2958	735	721	2120	1597	3209
90	726	714	2226	1685	3391	788	774	2433	1825	3679
96	775	763	2525	1911	3855	840	826	2757	2070	4181
102	823	811	2842	2150	4348	892	878	3103	2329	4716
108	871	859	3178	2403	4870	944	930	3457	2603	5282
114	919	907	3533	2671	5422	996	982	3854	2893	5881
120	967	955	3856	2952	6004	1048	1034	4204	3198	6511
126	1015	1003	4243	3248	6616	1100	1086	4614	3518	7174
132	1063	1051	4655	3558	7257	1152	1138	5059	3854	7869
138	1111	1099	5082	3881	7928	1204	1190	5522	4205	8596
144	1159	1147	5650	4219	8628	1256	1242	6067	4571	9356

WEIGHT OF SHELLS & HEADS

DIAM. VESSEL	WALL THICKNESS 7/8"					15/16"				
	SHELL		HEAD			SHELL		HEAD		
	I.S.	O.S.	ELLIP	F.&D.	HEMIS	I.S.	O.S.	ELLIP	F.&D.	HEMIS
12	120	104	82	59	80	130	111	90	67	86
14	139	123	103	74	106	150	131	110	83	115
16	157	141	122	90	137	170	151	135	101	148
18	176	160	147	107	171	190	171	157	123	185
20	195	179	170	127	209	210	191	185	144	226
22	213	197	199	147	251	230	211	213	167	271
24	232	216	225	175	297	250	231	241	194	320
26	251	235	252	199	347	270	251	271	220	374
28	270	254	288	225	401	290	271	310	249	431
30	288	272	327	252	458	310	291	351	282	493
32	307	291	366	281	519	330	311	393	314	558
34	326	310	412	312	584	350	331	442	347	628
36	344	328	458	352	653	370	351	491	387	702
38	363	347	506	385	726	390	371	543	422	780
40	382	366	558	421	803	410	391	597	462	863
42	400	384	611	458	883	430	411	654	507	949
48	456	440	789	589	1148	491	471	836	643	1233
54	512	496	982	736	1447	551	531	1051	802	1554
60	568	552	1200	900	1780	611	591	1285	979	1911
66	624	608	1440	1080	2149	671	651	1543	1174	2306
72	680	664	1702	1278	2551	731	711	1823	1387	2738
78	736	720	1986	1491	2989	791	771	2128	1616	3207
84	792	776	2293	1720	3461	851	832	2456	1864	3714
90	849	833	2620	1966	3968	911	892	2807	2129	4257
96	905	889	2970	2229	4509	971	952	3182	2412	4837
102	961	945	3341	2508	5085	1031	1012	3580	2712	5454
108	1017	1001	3735	2804	5695	1091	1072	4002	3036	6109
114	1073	1057	4150	3115	6340	1151	1132	4447	3366	6800
120	1129	1113	4528	3444	7019	1212	1192	4852	3720	7529
126	1185	1169	4985	3789	7734	1272	1252	5341	4091	8294
132	1241	1225	5463	4150	8482	1332	1312	5853	4480	9097
138	1297	1281	5963	4528	9266	1392	1372	6389	4886	9937
144	1353	1337	6485	4923	10084	1452	1432	6948	5310	10813

WEIGHT OF SHELLS & HEADS

DIAM. VESSEL	WALL THICKNESS									
	1"					1-1/16"				
	SHELL		HEAD			SHELL		HEAD		
	I.S.	O.S.	ELLIP	F.&D.	HEMIS	I.S.	O.S.	ELLIP	F.&D.	HEMIS
12	139	117	98	76	93	148	124	104	83	100
14	160	138	118	93	124	171	147	125	102	132
16	182	160	144	113	159	193	169	153	122	170
18	203	181	168	139	198	216	192	178	150	212
20	224	202	200	162	242	239	215	212	175	259
22	246	223	228	187	290	262	238	242	202	310
24	267	245	257	214	343	284	260	277	231	366
26	289	266	288	242	400	307	283	311	261	427
28	310	287	330	273	462	330	306	350	294	493
30	331	308	374	313	528	352	328	397	338	563
32	353	330	421	347	598	375	351	448	373	638
34	374	351	471	383	673	398	374	500	412	717
36	396	372	523	421	752	420	396	562	452	801
38	417	393	579	460	835	443	419	614	495	890
40	438	415	637	502	923	466	442	677	539	984
42	459	436	698	556	1015	489	465	741	597	1082
48	523	500	897	698	1318	557	533	953	749	1404
54	587	564	1121	869	1661	625	601	1191	931	1769
60	651	628	1371	1059	2043	693	669	1457	1134	2175
66	715	692	1646	1268	2465	761	737	1749	1357	2624
72	779	756	1945	1496	2926	829	805	2067	1590	3114
78	844	821	2270	1743	3427	897	874	2412	1851	3647
84	908	885	2620	2008	3967	965	942	2783	2134	4221
90	972	949	2994	2292	4547	1033	1010	3181	2435	4838
96	1036	1013	3394	2596	5166	1101	1078	3606	2758	5496
102	1100	1077	3819	2917	5825	1169	1146	4057	3099	6197
108	1164	1141	4268	3258	6523	1237	1214	4535	3462	6939
114	1228	1205	4743	3617	7261	1306	1282	5038	3843	7724
120	1292	1269	5175	3996	8039	1374	1350	5498	4246	8550
126	1356	1333	5697	4393	8856	1442	1418	6053	4667	9419
132	1420	1397	6243	4809	9712	1510	1486	6633	5108	10329
138	1484	1461	6815	5243	10609	1578	1554	7241	5571	11282
144	1549	1526	7411	5697	11544	1646	1623	7874	6053	12276

WEIGHT OF SHELLS & HEADS

DIAM. VESSEL	WALL THICKNESS									
	1-1/8"					1-3/16"				
	SHELL		HEAD			SHELL		HEAD		
	I.S.	O.S.	ELLIP	F.&D.	HEMIS	I.S.	O.S.	ELLIP	F.&D.	HEMIS
12	158	131	110	90	106	167	137	116	97	113
14	182	155	133	110	141	192	162	143	120	150
16	206	179	163	132	181	218	188	172	143	193
18	230	203	189	162	226	243	213	203	171	240
20	254	227	225	189	276	268	238	237	200	293
22	278	251	256	217	330	294	264	279	230	351
24	302	275	298	248	390	319	289	318	266	414
26	326	299	333	281	454	345	315	352	301	482
28	350	323	371	315	524	370	340	391	337	555
30	374	347	421	362	598	395	365	444	382	634
32	398	371	474	400	678	421	391	500	423	718
34	422	395	530	442	762	466	416	560	466	807
36	446	419	601	484	851	471	441	634	517	902
38	470	443	651	530	946	497	467	687	565	1001
40	494	467	717	576	1045	522	492	756	615	1106
42	518	491	785	639	1149	548	518	828	674	1216
48	591	563	1009	800	1491	624	594	1065	852	1577
54	663	635	1261	994	1877	700	670	1331	1049	1986
60	735	707	1543	1209	2308	776	746	1628	1276	2441
66	807	779	1852	1446	2783	852	822	1954	1526	2943
72	879	852	2189	1684	3303	929	899	2310	1788	3492
78	951	924	2554	1960	3867	1005	975	2695	2082	4089
84	1023	996	2947	2260	4476	1081	1051	3108	2398	4732
90	1095	1068	3368	2579	5129	1157	1127	3555	2736	5422
96	1167	1140	3818	2920	5827	1233	1203	4030	3097	6159
102	1239	1212	4296	3282	6569	1309	1279	4535	3480	6942
108	1312	1284	4802	3666	7356	1385	1355	5069	7772	7773
114	1384	1356	5336	4070	8187	1461	1431	5632	4314	8651
120	1456	1428	5822	4496	9062	1537	1507	6145	4764	9576
126	1528	1500	6409	4942	9982	1613	1583	6765	5236	10547
132	1600	1573	7024	5410	10947	1690	1660	7414	5731	11566
138	1672	1645	7667	5899	11956	1766	1736	8093	6248	12632
144	1744	1717	8338	6408	13010	1842	1812	8801	6786	13744

WEIGHT OF SHELLS & HEADS

DIAM. VESSEL	WALL THICKNESS 1-1/4"					WALL THICKNESS 1-5/16"				
	SHELL		HEAD			SHELL		HEAD		
	I.S.	O.S.	ELLIP	F.&D.	HEMIS	I.S.	O.S.	ELLIP	F.&D.	HEMIS
12	177	144	122	105	120	187	150	129	112	127
14	204	171	154	129	160	215	178	161	138	169
16	230	197	181	154	204	243	206	193	165	216
18	257	224	217	181	254	271	234	228	193	269
20	284	251	250	210	310	299	262	267	225	327
22	311	278	292	242	371	327	290	307	258	392
24	337	304	331	284	438	355	318	347	303	462
26	364	331	371	322	510	383	346	390	343	538
28	391	358	412	360	587	411	374	439	384	619
30	417	384	467	402	670	439	402	497	428	707
32	444	411	526	446	759	467	430	559	474	800
34	471	438	589	490	853	495	458	625	521	899
36	497	464	667	551	952	523	486	700	585	1003
38	524	491	724	601	1057	552	515	768	638	1113
40	551	518	796	654	1168	580	543	844	694	1230
42	578	545	872	710	1284	608	571	924	753	1352
48	658	625	1121	904	1665	692	655	1187	958	1752
54	738	705	1401	1104	2095	776	739	1482	1169	2205
60	818	785	1714	1343	2575	860	823	1812	1421	2709
66	898	865	2057	1606	3104	944	907	2173	3374	3265
72	979	945	2432	1893	3683	1029	991	2567	1988	3873
78	1059	1025	2837	2204	4311	1113	1075	2994	2314	4533
84	1139	1105	3275	2537	4988	1197	1159	3455	2664	5245
90	1219	1185	3742	2894	5715	1281	1243	3947	3039	6009
96	1299	1265	4242	3274	6491	1365	1328	4473	3438	6824
102	1379	1346	4774	3678	7317	1449	1418	5032	3862	7692
108	1459	1426	5336	4106	8192	1533	1496	5623	4311	8611
114	1539	1506	5929	4558	9116	1617	1580	6248	4786	9582
120	1619	1586	6469	5032	10090	1701	1664	6815	5283	10606
126	1700	1666	7121	5530	11113	1786	1748	7501	5807	11681
132	1780	1746	7804	6051	12186	1870	1832	8220	6354	12808
138	1860	1826	8519	6596	13308	1954	1916	8971	6926	13986
144	1940	1906	9264	7165	14480	2038	2000	9755	7524	15217

WEIGHT OF SHELLS & HEADS

DIAM. VESSEL	WALL THICKNESS									
	1-3/8"					1-7/16"				
	SHELL		HEAD			SHELL		HEAD		
	I.S.	O.S.	ELLIP	F.&D.	HEMIS	I.S.	O.S.	ELLIP	F.&D.	HEMIS
12	196	156	142	119	135	206	162	151	126	143
14	225	185	169	148	178	237	193	180	155	188
16	255	215	206	176	228	267	223	220	184	240
18	284	244	239	206	283	298	254	255	220	298
20	313	273	285	239	345	329	285	303	253	363
22	343	303	322	275	412	360	316	342	292	434
24	372	332	364	323	486	390	346	386	337	511
26	402	362	408	364	566	421	377	432	380	594
28	431	391	466	408	651	452	408	493	426	684
30	460	421	527	454	743	482	438	558	481	780
32	490	450	593	502	841	513	469	627	532	882
34	519	479	662	553	945	544	500	699	585	991
36	548	508	734	620	1054	575	531	775	648	1106
38	578	538	812	676	1170	605	561	857	707	1228
40	607	567	892	734	1293	636	592	941	768	1355
42	637	597	977	796	1420	667	623	1030	840	1489
48	725	685	1253	1012	1841	759	715	1320	1057	1929
54	813	773	1563	1234	2315	851	807	1646	1301	2426
60	901	861	1910	1500	2844	943	899	2061	1568	2979
66	989	949	2289	1768	3427	1035	991	2407	1861	3590
72	1078	1038	2703	2083	4065	1128	1083	2841	2177	4257
78	1166	1126	3152	2424	4757	1220	1175	3312	2534	4981
84	1254	1214	3635	2791	5503	1312	1267	3819	2917	5761
90	1342	1302	4152	3184	6303	1404	1360	4360	3328	6599
96	1430	1390	4704	3602	7159	1496	1452	4938	3766	7493
102	1518	1478	5291	4046	8068	1588	1544	5553	4230	8445
108	1606	1566	5911	4517	9032	1680	1636	6203	4722	9453
114	1694	1654	6567	5014	10050	1772	1728	6890	5241	10518
120	1783	1743	7162	5535	11122	1865	1820	7513	5786	11640
126	1871	1831	7882	6084	12249	1957	1912	8267	6360	12818
132	1959	1919	8636	6656	13430	2049	2004	9113	6959	14054
138	2047	2007	9424	7256	14666	2141	2097	9881	7586	15346
144	2135	2095	10246	7882	15955	2233	2189	10742	8240	16695

DIAM. VESSEL	WALL THICKNESS 1-1/2" SHELL I.S.	O.S.	HEAD ELLIP	F.&D.	HEMIS	1-9/16" SHELL I.S.	O.S.	HEAD ELLIP	F.&D.	HEMIS
12	216	168	162	134	150	227	174	173	144	158
14	248	200	192	162	198	260	207	204	174	208
16	280	232	234	192	252	294	241	248	206	265
18	312	264	271	234	313	327	274	287	249	328
20	344	296	321	271	381	361	308	340	287	399
22	376	328	363	310	455	394	341	384	329	476
24	408	360	409	352	536	427	374	432	745	561
26	440	392	457	397	623	461	408	483	415	652
28	472	424	521	444	717	494	441	550	470	750
30	504	456	589	508	817	527	474	621	536	855
32	536	488	661	562	924	561	508	696	592	966
34	568	520	738	618	1038	594	541	777	652	1085
36	600	552	817	676	1158	628	575	860	712	1210
38	633	585	903	738	1285	661	608	950	777	1343
40	665	617	991	802	1418	694	641	1042	844	1482
42	697	649	1084	885	1558	728	675	1140	931	1628
48	793	745	1388	1103	2018	828	775	1457	1110	2107
54	889	841	1729	1368	2537	928	875	1815	1436	2649
60	985	937	2111	1636	3115	1028	975	2212	1716	3251
66	1082	1034	2526	1954	3753	1129	1075	2647	2049	3916
72	1178	1130	2980	2272	4449	1229	1175	3122	2382	4643
78	1274	1226	3472	2644	5205	1329	1275	3635	2770	5431
84	1370	1322	4003	3044	6021	1420	1376	4189	3171	6281
90	1466	1418	4569	3472	6895	1529	1476	4781	3617	7192
96	1562	1514	5173	3930	7829	1629	1576	5411	4093	8166
102	1658	1610	5815	4414	8823	1729	1676	6081	4598	9201
108	1754	1706	6496	4928	9875	1829	1776	6792	5133	10298
114	1851	1803	7213	5468	10987	1930	1876	7540	5696	11457
120	1947	1899	7864	6038	12158	2030	1976	8219	6290	12678
126	2043	1995	8652	6636	13389	2130	2076	9041	6913	13960
132	2139	2091	9590	7262	14678	2230	2176	10020	7564	15304
138	2235	2187	10339	7916	16027	2330	2276	10738	8246	16710
144	2331	2283	11239	8599	17436	2430	2376	11741	8957	18188

WEIGHT OF SHELLS & HEADS

DIAM. VESSEL	WALL THICKNESS 1-5/8"					1-11/16"				
	SHELL		HEAD			SHELL		HEAD		
	I.S.	O.S.	ELLIP	F.&D.	HEMIS	I.S.	O.S.	ELLIP	F.&D.	HEMIS
12	236	180	184	153	166	247	186	195	163	174
14	271	215	217	186	218	283	222	230	198	228
16	305	249	263	220	277	319	258	277	235	290
18	340	284	304	265	344	355	294	321	280	359
20	375	319	359	304	417	391	330	379	315	436
22	410	354	405	348	498	427	366	427	361	520
24	444	388	455	393	586	463	402	480	415	611
26	479	423	509	443	681	499	438	535	466	710
28	514	458	578	495	783	535	474	608	521	817
30	548	492	653	564	892	571	570	686	585	930
32	583	527	732	623	1009	608	547	770	647	1051
34	618	562	815	685	1132	644	583	856	711	1180
36	653	597	903	748	1263	680	619	948	785	1316
38	687	631	997	817	1401	716	655	1045	857	1459
40	722	666	1094	886	1546	752	691	1147	930	1610
42	757	701	1195	978	1698	788	727	1253	1015	1768
48	861	805	1527	1216	2197	896	835	1598	1275	2288
54	965	909	1900	1505	2761	1004	943	1987	1562	2873
60	1069	1013	2314	1797	3388	1112	1051	2418	1880	3526
66	1174	1117	2768	2144	4080	1221	1159	2891	2226	4245
72	1278	1221	3264	2492	4836	1329	1267	3408	2603	5031
78	1382	1325	3799	2897	5657	1437	1376	3965	3008	5884
84	1486	1430	4375	3298	6542	1545	1484	4565	3443	6803
90	1590	1534	4994	3762	7490	1653	1592	5207	3926	7789
96	1694	1638	5650	4257	8504	1761	1700	5892	4441	8842
102	1798	1742	6348	4782	9581	1869	1808	6618	4966	9961
108	1903	1846	7088	5338	10723	1978	1916	7388	5567	11148
114	2007	1950	7867	5924	11928	2086	2024	8198	6177	12401
120	2111	2054	8575	6541	13198	2194	2133	8935	6819	13720
126	2215	2159	9431	7190	14533	2302	2241	9825	7493	15107
132	2319	2263	10450	7867	15931	2410	2349	10851	8198	16560
138	2423	2367	11138	8576	17394	2518	2457	11669	8936	18079
144	2527	2471	12243	9316	18921	2626	2565	12749	9705	19666

WEIGHT OF SHELLS & HEADS

DIAM. VESSEL	WALL THICKNESS									
	1-3/4"					1-13/16"				
	SHELL		HEAD			SHELL		HEAD		
	I.S.	O.S.	ELLIP	F.&D.	HEMIS	I.S.	O.S.	ELLIP	F.&D.	HEMIS
12	257	192	206	172	182	267	197	218	182	190
14	294	229	243	211	238	306	236	257	223	249
16	332	267	294	249	303	344	274	314	264	316
18	369	304	338	296	375	383	313	356	311	391
20	407	342	399	327	455	422	352	420	345	473
22	444	379	450	374	542	461	391	473	394	564
24	481	416	504	437	637	499	429	530	460	663
26	519	454	562	490	740	538	468	590	515	770
28	556	491	639	547	850	577	507	670	575	885
30	593	528	719	607	969	615	545	754	638	1007
32	631	566	807	671	1094	654	584	845	704	1138
34	668	603	898	737	1228	693	623	940	772	1276
36	706	641	993	823	1369	732	662	1040	862	1423
38	743	678	1094	897	1518	770	700	1144	939	1577
40	780	715	1200	973	1675	809	739	1254	1018	1740
42	818	753	1311	1053	1839	848	778	1370	1101	1910
48	930	865	1670	1332	2378	964	894	1743	1392	2469
54	1042	977	2074	1620	2986	1080	1010	2163	1691	3100
60	1154	1089	2523	1963	3664	1196	1126	2630	2047	3802
66	1267	1201	3015	2308	4410	1313	1243	3141	2407	4576
72	1379	1313	3552	2715	5226	1429	1359	3700	2829	5422
78	1491	1426	4132	3119	6111	1545	1475	4301	3299	6339
84	1603	1538	4756	3588	7065	1661	1591	4948	3737	7328
90	1715	1650	5421	4091	8089	1777	1707	5639	4237	8389
96	1827	1762	6134	4626	9181	1893	1823	6379	4792	9521
102	1940	1874	6888	5150	10343	2010	1940	7162	5334	10725
108	2052	1986	7688	5796	11574	2126	2056	7991	6003	12001
114	2164	2099	8529	6430	12874	2242	2172	8865	6660	13348
120	2276	2211	9295	7098	14243	2358	2288	9659	7351	14767
126	2388	2323	10220	7797	15681	2474	2404	10618	8076	16257
132	2500	2435	11252	8530	17189	2590	2520	11650	8535	17820
138	2612	2547	12201	9296	18766	2707	2637	12673	9628	19453
144	2725	2659	13256	10094	20412	2823	2753	13768	10455	21159

WEIGHT OF SHELLS & HEADS

DIAM. VESSEL	WALL THICKNESS									
	1-7/8"					1-15/16"				
	SHELL		HEAD			SHELL		HEAD		
	I.S.	O.S.	ELLIP	F.&D.	HEMIS	I.S.	O.S.	ELLIP	F.&D.	HEMIS
12	278	203	231	191	198	288	208	243	201	206
14	318	243	271	235	259	329	249	285	247	270
16	358	283	326	278	329	371	291	343	293	342
18	398	323	375	327	407	412	332	394	342	423
20	438	363	441	363	493	454	374	462	382	512
22	478	403	497	414	587	495	415	521	435	610
24	518	443	556	482	689	536	456	583	498	716
26	558	483	619	540	800	578	498	648	558	830
28	598	523	701	602	929	619	539	737	622	953
30	638	563	789	668	1046	661	581	825	699	1085
32	679	604	883	736	1181	702	622	923	770	1225
34	719	644	981	808	1325	743	663	1025	845	1374
36	759	684	1086	902	1477	785	705	1134	932	1531
38	799	724	1194	981	1637	826	746	1246	1014	1697
40	839	764	1309	1063	1805	867	787	1365	1099	1871
42	879	804	1429	1150	1981	909	829	1489	1200	2054
48	999	924	1817	1452	2561	1033	953	1892	1501	2653
54	1119	1044	2253	1762	3214	1157	1077	2344	1835	3329
60	1239	1164	2737	2132	3941	1282	1202	2846	2203	4081
66	1360	1284	3268	2506	4743	1406	1326	3397	2607	4910
72	1480	1405	3846	2944	5618	1530	1450	3995	3040	5816
78	1600	1525	4470	3380	6568	1654	1574	4642	3512	6798
84	1720	1645	5141	3886	7592	1778	1698	5357	4015	7857
90	1840	1765	5858	4383	8690	1902	1822	6080	4552	8992
96	1960	1885	6624	4958	9862	2027	1947	6873	5123	10204
102	2081	2005	7436	5518	11108	2151	2071	7714	5722	11492
108	2201	2126	8295	6210	12429	2275	2195	8603	6417	12858
114	2321	2246	9201	6890	13823	2399	2319	9540	7120	14299
120	2441	2366	10024	7604	15292	2523	2443	10358	7858	15818
126	2561	2486	11017	8355	16834	2647	2567	11420	8633	17413
132	2681	2606	12058	9140	18451	2772	2692	12460	9444	19084
138	2802	2726	13146	9960	20142	2896	2816	13623	10291	20832
144	2922	2846	14280	10816	21907	3020	2940	14756	11176	22657

WEIGHT OF SHELLS & HEADS										
DIAM. VESSEL	WALL THICKNESS									
	2″					2 1/4″				
	SHELL		HEAD			SHELL		HEAD		
	I.S.	O.S.	ELLIP	F.&D.	HEMIS	I.S.	O.S.	ELLIP	F.&D.	HEMIS
12	299	214	256	210	215	342	216	307	248	251
14	342	257	300	259	281	391	282	358	296	326
16	384	299	361	307	356	439	330	362	349	411
18	427	342	414	358	439	487	379	425	406	506
20	470	385	484	400	531	535	427	495	467	612
22	513	428	546	456	633	583	475	578	533	726
24	555	470	610	514	742	631	523	648	603	851
26	598	513	678	576	861	679	571	723	678	986
28	641	556	767	642	988	727	619	801	757	1130
30	683	598	862	730	1124	775	667	904	840	1285
32	726	641	963	804	1269	823	715	1014	927	1449
34	769	684	1068	882	1423	871	763	1130	1019	1623
36	812	727	1181	962	1586	919	811	1277	1115	1834
38	854	769	1298	1047	1757	967	859	1380	1216	2001
40	897	812	1421	1134	1937	1015	907	1515	1321	2205
42	940	855	1550	1250	2126	1063	955	1655	1438	2419
48	1068	983	1968	1550	2745	1208	1100	2115	1802	3125
54	1196	1111	2436	1909	3444	1352	1244	2632	2181	3922
60	1325	1239	2956	2274	4221	1496	1388	3204	2632	4808
66	1453	1367	3526	2708	5078	1640	1532	3833	3085	5787
72	1581	1496	4145	3140	6013	1784	1676	4519	3618	6854
78	1709	1624	4814	3645	7028	1929	1821	5260	4146	8012
84	1837	1752	5573	4145	8122	2073	1965	6058	4760	9194
90	1965	1880	6302	4722	9295	2217	2109	6913	5364	10528
96	2094	2008	7122	5288	10546	2361	2253	7823	6058	11952
102	2222	2137	7992	5937	11877	2505	2397	8790	6737	13466
108	2350	2265	8911	6624	13287	2650	2542	9814	7513	15073
114	2478	2393	9880	7349	14776	2794	2686	10893	8332	16767
120	2606	2521	10692	8112	16345	2938	2830	11874	9193	18554
126	2734	2649	11824	8911	17992	3082	2974	13059	10096	20328
132	2863	2777	12862	9748	19718	3226	3118	14301	11041	22291
138	2991	2906	14100	10623	21523	3371	3263	15597	12029	24343
144	3119	3034	15232	11536	23408	3514	3407	16952	13059	26424

WEIGHT OF PIPES AND FITTINGS

NOM. PIPE SIZE	DESIGNATION	NOM. WALL THK.	PIPE 1 ft.	ELBOW			RETURN		TEE
				90° L.R.	90° S.R.	45° L.R.	180° L.R.	180° S.R.	
½	STD	.109	0.9	0.2		0.1	0.4		0.4
	X STG	.147	1.1	0.3		0.2	0.5		0.5
	SCH. 160	.187	1.3						0.4
	XX STG	.294	1.7						
¾	STD	.113	1.1	0.2		0.1	0.4		0.5
	X STG	.154	1.5	0.3		0.2	0.7		0.6
	SCH. 160	.218	1.9						0.6
	XX STG	.308	2.4						
1	STD	.133	1.7	0.4	0.3	0.3	0.8	0.5	0.8
	X STG	.179	2.2	0.5		0.3	1.0		0.9
	SCH. 160	.250	2.8	0.6	0.4	0.3	1.2	0.8	1.0
	XX STG	.358	3.7	0.8	0.5	0.4	1.5	1.0	1.3
1¼	STD	.140	2.3	0.6	0.4	0.4	1.3	0.8	1.3
	X STG	.191	3.0	0.9		0.5	1.8		1.6
	SCH. 160	.250	3.8	1.0	0.7	0.5	2.0	1.4	2.0
	XX STG	.382	5.2	1.4	0.9	0.8	2.7	1.8	2.5
1½	STD	.145	2.7	0.9	0.6	0.4	1.9	1.1	2.0
	X STG	.200	3.6	1.2	0.8	0.7	2.4	1.5	2.3
	SCH. 160	.281	4.9	1.4	1.2	1.0	3.3	2.4	3.0
	XX STG	.400	6.4	1.9	1.0	1.1	4.0	2.7	3.4
2	STD	.154	3.7	1.6	1.0	0.8	3.2	2.0	3.5
	X STG	.218	5.0	2.2	1.5	1.2	4.4	3.0	4.0
	SCH. 160	.343	7.5	3.3	2.2	1.6	6.0	4.0	5.0
	XX STG	.436	9.0	3.5	2.3	2.0	7.5	5.0	6.3
2½	STD	.203	5.8	3.3	2.1	1.8	6.5	4.3	6.0
	X STG	.276	7.7	4.0	2.8	2.1	8.0	5.6	7.0
	SCH. 160	.375	10.0	5.1	3.4	3.0	12.0	6.0	8.0
	XX STG	.552	13.7	7.0	5.0	3.8	14.0	9.7	10.5
3	STD	.216	7.6	5.0	3.0	2.6	10.2	6.0	7.0
	X STG	.300	10.3	6.5	4.3	3.5	13.0	8.5	8.5
	SCH. 160	.438	14.3	8.5	6.0	4.4	18.0	12.0	10.0
	XX STG	.600	18.6	11.0	7.3	5.8	22.0	14.6	13.5

WEIGHT OF PIPES AND FITTINGS

NOM. PIPE SIZE	DESIGNATION	NOM. WALL THK.	PIPE 1 Ft.	ELBOW			RETURN		TEE
				90° L.R.	90° S.R.	45° L.R.	180° L.R.	180° S.R.	
3½	STD	.226	9.1	6.8	4.5	3.5	13.0	9.0	9.0
	X STG	.318	12.5	8.4	6.0	4.5	16.8	12.0	12.0
	XX STG	.636	22.9	16.0	11.0	8.5	32.00	22.0	18.0
4	STD	.237	10.8	9.0	6.3	4.5	18.5	12.5	12.0
	X STG	.337	15.0	13.5	8.5	6.1	25.0	17.0	15.8
	SCH.120	.438	19.0	15.6	10.4	7.8	31.3	20.8	23.5
	SCH. 160	.531	22.5	18.0	12.0	8.8	40.0	24.0	25.0
	XX STG	.674	27.5	20.0	13.0	10.8	40.0	27.0	25.0
5	STD	.258	14.6	15.5	9.6	7.5	30.0	19.0	21.0
	X STG	.375	20.8	22.0	14.0	10.8	44.0	28.0	26.0
	SCH.120	.500	27.0	27.8	18.6	13.9	55.6	37.2	44.5
	SCH. 160	.625	33.0	32.0	22.0	16.0	65.0	44.0	55.0
	XX STG	.750	38.6	36.0	24.0	19.0	72.0	48.0	40.0
6	STD	.280	19.0	24.5	18.0	12.0	50.0	35.0	34.0
	X STG	.432	28.6	35.0	23.0	17.5	70.0	46.0	40.0
	SCH. 120	.562	36.4	45.2	30.0	22.6	90.3	60.0	64.0
	SCH. 160	.718	45.3	57.0	38.0	30.0	120.0	76.0	62.0
	XX STG.	.864	53.2	65.0	44.0	32.0	130.0	87.0	68.0
8	SCH. 20	.250	22.4	36.5	24.4	18.2	73.0	48.8	54.0
	SCH. 30	.277	24.7	40.9	27.0	20.4	81.9	54.0	57.0
	STD	.322	28.6	50.0	34.0	23.0	95.0	68.0	55.0
	SCH. 60	.406	35.6	58.0	39.1	29.4	117.0	78.0	76.0
	X. STG.	.500	43.4	71.0	47.5	35.0	142.0	100.0	75.0
	SCH. 100	.593	50.9	84.0	56.0	42.0	168.0	112.0	97.0
	SCH. 120	.718	60.6	100.8	66.0	50.4	202.0	133.0	115.0
	SCH. 140	.812	67.8	111.0	74.0	55.0	222.0	149.0	133.0
	SCH. 160	.906	74.7	120.0	80.0	62.0	230.0	160.0	152.0
	XX STG.	.875	72.4	118.0	79	60.0	236.0	158.0	148.0
10	SCH. 20	.250	28.0	56.8	38.2	28.4	114.0	76.4	73.0
	SCH. 30	.307	34.2	71.4	46.8	35.7	143.0	94.0	81.0
	STD.	.365	40.5	88.0	58.0	43.0	177.0	115.0	85.0
	X STG.	.500	54.7	107.0	70.0	53.0	215.0	140.0	105.0
(cont.)									

WEIGHT OF PIPES AND FITTINGS

NOM. PIPE SIZE	DESIGNATION	NOM. WALL THK.	PIPE 1 ft.	ELBOW 90° L.R.	ELBOW 90° S.R.	ELBOW 45° L.R.	RETURN 180° L.R.	RETURN 180° S.R.	TEE
(cont.)	SCH. 80	.592	64.4	133	88	67	267	177	161
	SCH. 100	.718	77.0	159	106	79	318	212	180
10	SCH. 120	.843	89.2	185	123	92	370	246	215
	SCH. 140	1.000	104.2	214	143	107	428	286	241
	SCH. 160	1.125	116.0	260	174	130	530	348	260
	SCH. 20	.250	33.4	82	55	41	164	109	120
	SCH. 30	.330	43.8	108	72	54	216	145	136
	STD.	.375	49.6	125	80	62	230	155	120
	SCH. 40	.406	53.6	132	88	66	264	176	147
	X STG	.500	65.4	160	104	84	320	218	160
12	SCH. 60	.562	73.2	182	121	91	364	242	226
	SCH. 80	.687	88.6	219	146	109	439	292	245
	SCH. 100	.843	108.0	268	177	134	535	354	304
	SCH. 120	1.000	125.5	311	207	155	622	414	353
	SCH. 140	1.125	140.0	347	231	174	694	462	404
	SCH. 160	1.312	161.0	450	300	225	910	600	480
	SCH. 10	.250	37.0	106	70	53	212	140	193
	SCH. 20	312	46.0	132	87	66	264	175	210
	STD.	.375	55.0	160	105	80	325	210	165
	SCH. 40	.438	63.0	183	122	91	366	244	252
	X STG	.500	72.0	205	140	100	400	275	230
14	SCH. 60	.593	85.0	245	163	123	490	326	311
	SCH. 80	.750	107.0	310	205	154	619	410	369
	SCH. 100	.937	131.0						
	SCH. 120	1.093	151.0	425		213	850		
	SCH. 140	1.250	171.0						
	SCH. 160	1.406	190.0	572	382	286	1092	764	
	SCH. 10	.250	42.0	139	92	69	277	184	201
	SCH. 20	.312	52.0	172	115	86	344	230	222
16	SCH. 30 STD	.375	63.0	206	132	100	412	260	195
	SCH.40XSTG	.500	83.0	276	174	135	550	340	280
	SCH. 60	.656	108.0	355	236	178	710	472	458
(cont.)									

WEIGHT OF PIPES AND FITTINGS

NOM. PIPE SIZE	DESIGNATION	NOM. WALL THK.	PIPE 1 ft.	ELBOW 90° L.R.	ELBOW 90° S.R.	ELBOW 45° L.R.	RETURN 180° L.R.	RETURN 180° S.R.	TEE
16 (cont.)	SCH. 80	.843	137	450	300	225	900	600	548
	SCH.100	1.031	165						
	SCH.120	1.218	193						
	SCH. 140	1.438	224						
	SCH. 160	1.593	245	809	540	405	1618	1080	
18	SCH. 10	.250	47	176	118	88	352	226	281
	SCH. 20	.312	59	219	146	110	438	292	307
	STD	.375	71	260	167	126	510	330	249
	SCH. 30	.438	82	308	205	154	616	410	399
	X STG	.500	93	340	219	167	690	430	332
	SCH. 40	.562	105	390	259	195	780	518	525
	SCH. 60	.750	138	494	340	247	989	680	612
	SCH. 80	.937	171	634	422	317	1268	844	710
	SCH. 100	1.156	208						
	SCH. 120	1.375	244						
	SCH. 140	1.562	275						
	SCH. 160	1.781	309						
20	SCH. 10	.250	53	217	144	109	434	288	439
	SCH. 20 STD	.375	79	320	210	160	640	410	342
	SCH.30XSTG	.500	105	420	275	206	830	550	480
	SCH. 40	.593	123	506	338	253	1012	676	706
	SCH. 60	.812	167	690	457	345	1380	914	834
	SCH. 80	1.031	209	861	573	431	1722	1146	1021
	SCH. 100	1.281	256						
	SCH. 120	1.500	297						
	SCH. 140	1.750	342						
	SCH. 160	1.968	379						
22		.250	58	262	174	131	524	348	477
		.312	72						
		.375	87	394		197	787		414
		.437	103						
(cont.)		.500	115	520		260	1040		550

WEIGHT OF PIPES AND FITTINGS

NOM. PIPE SIZE	DESIGNATION	NOM. WALL THK.	PIPE 1 FT	ELBOW 90° L.R.	ELBOW 90° S.R.	ELBOW 45° L.R.	RETURN 180° L.R.	RETURN 180° S.R.	TEE
22 (cont.)		.562	129						
		.625	143						
		.688	157						
		.750	170						
24	SCH. 10	.250	63	314	208	157	627	416	677
	SCH. 20 STD	.375	95	460	298	238	890	590	528
	X STG	.500	125	600	392	300	1200	780	610
	SCH. 30	.562	141	702	470	351	1404	940	977
	SCH. 40	.687	171	846	564	423	1692	1128	1257
	SCH. 60	.968	238	1188	783	594	2377	1566	1446
	SCH. 80	1.218	297	1470	977	735	2940	1954	1673
	SCH. 100	1.531	367						
	SCH. 120	1.812	429						
	SCH. 140	2.062	484						
	SCH. 160	2.343	542						
26		.250	67						
		.312	84						
		.375	103	550		275	1100		770
		.437	119						
		.500	136	729		365	1458		875
		.562	153						
		.625	169						
		.688	186						
		.750	202						
30		.312	99	612		306	1223		1058
		.375	119	734	464	367	1465	930	1060
		.500	158	975	618	488	1950	1235	1200

WEIGHT OF FLANGES

NOM. PIPE SIZE	150 lbs.					300 lbs.				
	SLIP ON	WELD NECK	LONG. WELD NECK	BLIND	STUDS	SLIP ON	WELD NECK	LONG. WELD NECK	BLIND	STUDS
½	1.0	2.0		2.0	1.0	1.5	2.0		2.0	1.0
¾	1.5	2.0		2.0	1.0	2.5	3.0		3.0	2.0
1	2.0	2.5	8.0	2.0	1.0	3.0	4.0	10.0	4.0	2.0
1¼	2.5	2.5	10.0	3.0	1.0	4.5	5.0	14.0	6.0	2.0
1½	3.0	4.0	12.0	3.0	1.0	6.5	7.0	17.0	7.0	3.5
2	5.0	6.0	16.0	4.0	1.5	7.0	8.0	19.0	8.0	4.0
2½	8.0	10.0	21.0	7.0	1.5	10.0	12.0	28.0	12.0	7.0
3	9.0	11.5	24.0	9.0	1.5	13.0	16.0	36.0	16.0	7.5
3½	11.0	12.0	31.0	13.0	3.5	16.0	20.0	45.0	21.0	7.5
4	12.0	16.0	47.0	17.0	4.0	21.0	25.0	54.0	27.0	7.5
5	13.0	20.0	57.0	20.0	6.0	26.0	34.0	86.0	35.0	8.0
6	18.0	24.0	77.0	26.0	6.0	35.0	45.0	108.0	50.0	11.5
8	28.0	42.0	103	45.0	6.5	54.0	70.0	150	81.0	18.0
10	37.0	55.0	150	70.0	15.0	77.0	99.0	218	127	38.0
12	60.0	85.0	215	110	15.0	110	142	289	184	49.0
14	77.0	114	221	131	22.0	164	186	342	236	62.0
16	93.0	142	254	170	31.0	220	246	426	307	83.0
18	120	155	278	209	41.0	280	305	493	390	101
20	155	170	324	272	52.0	325	378	575	492	105
22	159	224		333	69.0	433	429		594	157
24	210	260	439	411	71.0	490	545	823	754	174
26	248	270	470	498	93.6	552	615	870	950	239
30	319	375	600	681	112.0	779	858	1130	1403	307

WEIGHT OF FLANGES

NOM. PIPE SIZE	400 lbs.					600 lbs.				
	SLIP ON	WELD NECK	LONG. WELD NECK	BLIND	STUDS	SLIP ON	WELD NECK	LONG. WELD NECK	BLIND	STUDS
½	2.0	3.0		2.0	1.0	2.0	3.0		2.0	1.0
¾	3.0	3.5		3.0	2.0	3.0	3.5		3.0	2.0
1	3.5	4.0	11.0	4.0	2.0	3.5	4.0	11.0	4.0	2.0
1¼	4.5	5.5	14.0	6.0	2.0	4.5	5.5	14.0	6.0	2.0
1½	6.5	8.0	17.0	8.0	3.5	6.5	8.0	17.0	8.0	3.5
2	8.0	10.0	21.0	10.0	4.5	8.0	10.0	21.0	10.0	4.5
2½	12.0	14.0	29.0	15.0	7.5	12.0	14.0	29.0	15.0	8.0
3	15.0	18.0	38.0	20.0	7.7	15.0	18.0	38.0	20.0	8.0
3½	21.0	26.0	48.0	29.0	11.6	21.0	26.0	48.0	29.0	11.6
4	24.0	30.0	67.0	33.0	12.0	33.0	37.0	80.0	41.0	12.5
5	31.0	39.0	90.0	44.0	12.5	63.0	68.0	128	68.0	19.5
6	39.0	49.0	115.0	61.0	19.0	80.0	73.0	158	86.0	30.0
8	63.0	78.0	140	100	30.0	97.0	112.0	215	139	40.0
10	91.0	110.0	230	155	52.0	177	189	324	231	72.0
12	129	160	301	226	69.0	215	226	500	295	91.0
14	191	233	336	310	88.0	259	347	417	378	118
16	253	294	416	398	114	366	481	564	527	152
18	310	360	481	502	139	476	555	654	665	193
20	378	445	563	621	180	612	690	840	855	242
22	464	465		685	205	643	710		962	267
24	539	640	799	936	274	876	977	1100	1175	365
26	616	680	970	1111	307	898	960	1250	1490	398
30	859	940	1230	1596	453	1158	1230	1520	1972	574

WEIGHT OF FLANGES

NOM. PIPE SIZE	900 lbs.					1500 lbs.				
	SLIP ON	WELD NECK	LONG. WELD NECK	BLIND	STUDS	SLIP ON	WELD NECK	LONG. WELD NECK	BLIND	STUDS
½	6.0	7.0		4.0	3.2	6.0	7.0		4.0	3.2
¾	6.0	7.0		6.0	3.3	6.0	7.0		6.0	3.3
1	7.5	8.5	15.0	9.0		7.5	8.5	15.0	9.0	6.0
1¼	10.0	10.0	18.0	10.0		10.0	10.0	18.0	10.0	6.0
1½	14.0	14.0	23.0	14.0		14.0	14.0	23.0	14.0	9.0
2	25.0	24.0	44.0	25.0		25.0	24.0	44.0	25.0	12.5
2½	36.0	36.0	65.0	35.0	19.0	36.0	36.0	72.0	35.0	19.0
3	31.0	29.0	72.0	32.0	12.5	48.0	48.0	84.0	48.0	25.0
3½										
4	53.0	51.0	98.0	54.0	25.0	73.0	69.0	118	73.0	34.0
5	83.0	86.0	143	87.0	33.0	132.0	132.0	195	142	60.0
6	108.0	110.0	199	113	40.0	164	164	235	159	76.0
8	172	187	310	197	69.0	258	273	366	302	121
10	245	268	385	290	95.0	436	454	610	507	184
12	326	372	667	413	124	667	690	1028	775	306
14	380	562	558	494	159	WEIGHTS ON APPLICATION	940	1030	975	425
16	459	685	670	619	199		1250	1335	1300	570
18	647	924	949	880	299		1625	1750	1750	770
20	792	1164	1040	1107	361		2050	2130	2225	1010
22										
24	1480	2107	1775	2099	687		3325	3180	3625	1560
26	1450	1650	1650	2200	765	1525	1575		2200	
30	1990	2290	2200	3025	1074	2075	2150		3025	

WEIGHT OF FLANGES

NOM. PIPE SIZE	2500 lbs.									
	SLIP ON	WELD NECK	LONG. WELD NECK	BLIND	STUDS	SLIP ON	WELD NECK	LONG. WELD NECK	BLIND	STUDS
½	7.0	8.0		7.0	3.4					
¾	9.0	9.0		10.0	3.6					
1	12.0	13.0	20.0	12.0	6.0					
1¼	18.0	20.0	30.0	18.0	9.0					
1½	25.0	28.0	38.0	25.0	12.0					
2	38.0	42.0	55.0	39.0	21.0					
2½	55.0	52.0	85.0	56.0	27.0					
3	83.0	94.0	125.0	86.0	37.0					
3½										
4	127	146	185	133	61					
5	210	244	300	223	98					
6	323	378	450	345	145					
8	485	576	600	533	232					
10	925	1068	1150	1025	445					
12	1300	1608	1560	1464	622					
14										
16										
18										
20										
22										
24										
26										
30										

Manufacturers' Standard Gage for

SHEET STEEL

This gage system replaces U.S. Standard Gage for Steel Sheets.
It is based on weight 41.82 pounds per square foot per inch of thickness.
In ordering steel sheets, it is advisable to specify the inch equivalent of gage.

Mfrs. Std. Gage No.	Inch Equivalent	Lbs. Per Square Inch	Lbs. Per Square Foot	Mfrs. Std. Gage No.	Inch Equivalent	Lbs. Per Square Inch	Lbs. Per Square Foot
3	.2391	.069444	10.000	21	.0329	.0095486	1.3750
4	.2242	.065104	9.3750	22	.0299	.0086806	1.2500
5	.2092	.060764	8.7500	23	.0269	.0078125	1.1250
6	.1943	.056424	8.1250	24	.0239	.0069444	1.0000
7	.1793	.052083	7.5000	25	.0209	.0060764	.87500
8	.1644	.047743	6.8750	26	.0179	.0052083	.75000
9	.1495	.043403	6.2500	27	.0164	.0047743	.68750
10	.1345	.039062	5.6250	28	.0149	.0043403	.62500
11	.1196	.034722	5.0000	29	.0135	.0039062	.56250
12	.1046	.030382	4.3750	30	.0120	.0034722	.50000
13	.0897	.026042	3.7500	31	.0105	.0030382	.43750
14	.0747	.021701	3.1250	32	.0097	.0028212	.40625
15	.0673	.019531	2.8125	33	.0090	.0026042	.37500
16	.0598	.017361	2.5000	34	.0082	.0023872	.34375
17	.0538	.015625	2.2500	35	.0075	.0021701	.31250
18	.0478	.013889	2.0000	36	.0067	.0019531	.28125
19	.0418	.012153	1.7500	37	.0064	.0018446	.26562
20	.0359	.010417	1.5000	38	.0060	.0017361	.25000

GALVANIZED SHEET

Galv. Sheet Gage No.	Ounces Per Square Foot	Lbs. Per Square Foot	Lb. per Sq. In.	Thickness Equivalent for Galv. Sheet Gage No.	Galv. Sheet Gage No.	Ounces Per Square Foot	Lbs. Per Square Foot	Lb. per Sq. In.	Thickness Equivalent for Galv. Sheet Gage No.
8	112.5	7.03125	0.048828	0.1681	21	24.5	1.53125	.010634	.0366
9	102.5	6.40625	.044488	.1532	22	22.5	1.40625	.0097656	.0336
10	92.5	5.78125	.040148	.1382	23	20.5	1.28125	.0088976	.0306
11	82.5	5.15625	.035807	.1233	24	18.5	1.15625	.0080295	.0276
12	72.5	4.53125	.031467	.1084	25	16.5	1.03125	.0071615	.0247
13	62.5	3.90625	.027127	.0934	26	14.5	.90625	.0062934	.0217
14	52.5	3.28125	.022786	.0785	27	13.5	.84375	.0058594	.0202
15	47.5	2.96875	.020616	.0710	28	12.5	.78125	.0054253	.0187
16	42.5	2.65625	.018446	.0635	29	11.5	.71875	.0049913	.0172
17	38.5	2.40625	.016710	.0575	30	10.5	.65625	.0045573	.0157
18	34.5	2.15625	.014974	.0516	31	9.5	.59375	.0041233	.0142
19	30.5	1.90625	.013238	.0456	32	9.0	.56250	.0039062	.0134
20	26.5	1.65625	.011502	.0396					

WEIGHT OF PLATES

Pounds Per Linear Foot

Width In.	Thickness, Inches													
	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16	1
¼	.16	.21	.27	.32	.37	.43	.48	.53	.58	.64	.69	.74	.80	.85
½	.32	.43	.53	.64	.74	.85	.96	1.06	1.17	1.28	1.38	1.49	1.59	1.70
¾	.48	.64	.80	.96	1.12	1.28	1.43	1.59	1.75	1.91	2.07	2.23	2.39	2.55
1	.64	.85	1.06	1.28	1.49	1.70	1.91	2.13	2.34	2.55	2.76	2.98	3.19	3.40
1¼	.80	1.06	1.33	1.59	1.86	2.13	2.39	2.66	2.92	3.19	3.45	3.72	3.98	4.25
1½	.96	1.28	1.59	1.91	2.23	2.55	2.87	3.19	3.51	3.83	4.14	4.46	4.78	5.10
1¾	1.12	1.49	1.86	2.23	2.60	2.98	3.35	3.72	4.09	4.46	4.83	5.21	5.58	5.95
2	1.28	1.70	2.13	2.55	2.98	3.40	3.83	4.25	4.68	5.10	5.53	5.95	6.38	6.80
2¼	1.43	1.91	2.39	2.87	3.35	3.83	4.30	4.78	5.26	5.74	6.22	6.69	7.17	7.65
2½	1.59	2.13	2.66	3.19	3.72	4.25	4.78	5.31	5.84	6.38	6.91	7.44	7.97	8.50
2¾	1.75	2.34	2.92	3.51	4.09	4.68	5.26	5.84	6.43	7.01	7.60	8.18	8.77	9.35
3	1.91	2.55	3.19	3.83	4.46	5.10	5.74	6.38	7.01	7.65	8.29	8.93	9.56	10.2
3¼	2.07	2.76	3;45	4.14	4.83	5.53	6.22	6.91	7.60	8.29	8.98	9.67	10.4	11.1
3½	2.23	2.98	3.72	4.46	5.21	5.95	6.69	7.44	8.18	8.93	9.67	10.4	11.2	11.9
3¾	2.39	3.19	3.98	4.78	5.58	6.38	7.17	7.97	8.77	9.56	10.4	11.2	12.0	12.8
4	2.55	3.40	4.25	5.10	5.95	6.80	7.65	8.50	9.35	10.2	11.1	11.9	12.8	13.6
4¼	2.71	3.61	4.52	5.42	6.32	7.23	8.13	9.03	9.93	10.8	11.7	12.6	13.6	14.5
4½	2.87	3.83	4.78	5.74	6.69	7.65	8.61	9.56	10.5	11.5	12.4	13.4	14.3	15.3
4¾	3.03	4.04	5.05	6.06	7.07	8.08	9.08	10.1	11.1	12.1	13.1	14.1	15.1	16.2
5	3.19	4.25	5.31	6.38	7.44	8.50	9.56	10.6	11.7	12.8	13.8	14.9	15.9	17.0
5¼	3.35	4.46	5.58	6.69	7.81	8.93	10.0	11.2	12.3	13.4	14.5	15.6	16.7	17.9
5½	3.51	4.68	5.84	7.01	8.18	9.35	10.5	11.7	12.9	14.0	15.2	16.4	17.5	18.7
5¾	3.67	4.89	6.11	7.33	8.55	9.78	11.0	12.2	13.4	14.7	15.9	17.1	18.3	19.6
6	3.83	5.10	6.38	7.65	8.93	10.2	11.5	12.8	14.0	15.3	16.6	17.9	19.1	20.4
6¼	3.98	5.31	6.64	7.97	9.30	10.6	12.0	13.3	14.6	15.9	17.3	18.6	19.9	21.3
6½	4.14	5.53	6.91	8.29	9.67	11.1	12.4	13.8	15.2	16.6	18.0	19.3	20.7	22.1
6¾	4.30	5.74	7.17	8.61	10.0	11.5	12.9	14.3	15.8	17.2	18.7	20.1	21.5	23.0
7	4.46	5.95	7.44	8.93	10.4	11.9	13.4	14.9	16.4	17.9	19.3	20.8	22.3	23.8
7¼	4.62	6.16	7.70	9.24	10.8	12.3	13.9	15.4	17.0	18.5	20.0	21.6	23.1	24.7
7½	4.78	6.38	7.97	9.56	11.2	12.8	14.3	15.9	17.5	19.1	20.7	22.3	23.9	25.5
7¾	4.94	6.59	8.23	9.98	11.5	13.2	14.8	16.5	18.1	19.8	21.4	23.1	24.7	26.4
8	5.10	6.80	8.50	10.2	11.9	13.6	15.3	17.0	18.7	20.4	22.1	23.8	25.5	27.2
8¼	5.26	7.01	8.77	10.5	12.3	14.0	15.8	17.5	19.3	21.0	22.8	24.5	26.3	28.1
8½	5.42	7.23	9.03	10.8	12.6	14.5	16.3	18.1	19.9	21.7	23.5	25.3	27.1	28.9
8¾	5.58	7.44	9.30	11.2	13.0	14.9	16.7	18.6	20.5	22.3	24.2	26.0	27.9	29.8
9	5.74	7.65	9.56	11.5	13.4	15.3	17.2	19.1	21.0	23.0	24.9	26.8	28.7	30.6
9¼	5.90	7.86	9.83	11.8	13.8	15.7	17.7	19.7	21.6	23.6	5.6	27.5	29.5	31.5
9½	6.06	8.08	10.1	12.1	14.1	16.2	18.2	20.2	22.2	24.2	26.2	28.3	30.3	32.3
9¾	6.22	8.29	10.4	12.4	14.5	16.6	18.7	20.7	22.8	24.9	26.9	29.0	31.1	33.2
10	6.38	8.50	10.6	12.8	14.9	17.0	19.1	21.3	23.4	25.5	27.6	29.8	31.9	34.0

WEIGHT OF PLATES

Pounds Per Linear Foot

Width In.	Thickness, Inches													
	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16	1
10¼	6.53	8.71	10.9	13.1	15.3	17.4	19.6	21.8	24.0	26.1	28.3	30.5	32.7	34.9
10½	6.69	8.93	11.2	13.4	15.6	17.9	20.1	22.3	24.5	26.8	29.0	31.2	33.5	35.7
10¾	6.85	9.14	11.4	13.7	16.0	18.3	20.6	22.8	25.1	27.4	29.7	32.0	34.3	36.6
11	7.01	9.35	11.7	14.0	16.4	18.7	21.0	23.4	25.7	28.1	30.4	32.7	35.1	37.4
11¼	7.17	9.56	12.0	14.3	16.7	19.1	21.5	23.9	26.3	28.7	31.1	33.5	35.9	38.3
11½	7.33	9.78	12.2	14.7	17.1	19.6	22.0	24.4	26.9	29.3	31.8	34.2	36.7	39.1
11¾	7.49	9.99	12.5	15.0	17.5	20.0	22.5	25.0	27.5	30.0	32.5	35.0	37.5	40.0
12	7.65	10.2	12.8	15.3	17.9	20.4	23.0	25.5	28.1	30.6	33.2	35.7	38.3	40.8
12½	7.97	10.6	13.3	15.9	18.6	21.3	23.9	26.6	29.2	31.9	34.5	37.2	39.8	42.5
13	8.29	11.1	13.8	16.6	19.3	22.1	24.9	27.6	30.4	33.2	35.9	38.7	41.4	44.2
13½	8.61	11.5	14.3	17.2	20.1	23.0	25.8	28.7	32.6	34.4	37.3	40.2	43.0	45.9
14	8.93	11.9	14.9	17.9	20.8	23.8	26.8	29.8	32.7	35.7	38.7	41.7	44.6	47.6
14½	9.24	12.3	15.4	18.5	21.6	24.7	27.7	30.8	33.9	37.0	40.1	43.1	46.2	49.3
15	9.56	12.8	15.9	19.1	22.3	25.5	28.7	31.9	35.1	38.3	41.4	44.6	47.8	51.0
15½	9.88	13.2	16.5	19.8	23.1	26.4	29.6	32.9	36.2	39.5	42.8	46.1	49.4	52.7
16	10.2	13.6	17.0	20.4	23.8	27.2	30.6	34.0	37.4	40.8	44.2	47.6	51.0	54.4
16½	10.5	14.0	17.5	21.0	24.5	28.1	31.6	35.1	38.6	42.1	45.6	49.1	52.6	56.1
17	10.8	14.5	18.1	21.7	25.3	28.9	32.5	36.1	39.7	43.4	47.0	50.6	54.2	57.8
17½	11.2	14.9	18.6	22.3	26.0	29.8	33.5	37.2	40.9	44.6	48.3	52.1	55.8	59.5
18	11.5	15.3	19.1	23.0	26.8	30.6	34.4	38.3	42.1	45.9	49.7	53.6	57.4	61.2
18½	11.8	15.7	19.7	23.6	27.5	31.5	35.4	39.3	43.2	47.2	51.1	55.0	59.0	62.9
19	12.1	16.2	20.2	24.2	28.3	32.3	36.3	40.4	44.4	48.5	52.5	56.5	60.6	64.6
19½	12.4	16.6	20.7	24.9	29.0	33.2	37.3	41.4	45.6	49.7	53.9	58.0	62.2	66.3
20	12.8	17.0	21.3	25.5	29.8	34.0	38.3	42.5	46.8	51.0	55.3	59.5	63.8	68.0
20½	13.1	17.4	21.8	26.1	30.5	34.9	39.2	43.6	47.9	52.3	56.6	61.0	65.3	69.7
21	13.4	17.9	22.3	26.8	31.2	35.7	40.2	44.6	49.1	53.6	58.0	62.5	66.9	71.4
21½	13.7	18.3	22.8	27.4	32.0	36.6	41.1	45.7	50.3	54.8	59.4	64.0	68.5	73.1
22	14.0	18.7	23.4	28.1	32.7	37.4	42.1	46.8	51.4	56.1	60.8	65.5	70.1	74.8
22½	14.3	19.1	23.9	28.7	33.5	38.3	43.0	47.8	52.6	57.4	62.2	66.9	71.7	76.5
23	14.7	19.6	24.4	29.3	34.2	39.1	44.0	48.9	53.8	58.7	63.5	68.4	73.3	78.2
23½	15.0	20.0	25.0	30.0	35.0	40.0	44.9	49.9	54.9	59.9	64.9	69.9	74.9	79.9
24	15.3	20.4	25.5	30.6	35.7	40.8	45.9	51.0	56.1	61.2	66.3	71.4	76.5	81.6
25	15.9	21.3	26.6	31.9	37.2	42.5	47.8	53.1	58.4	63.8	69.1	74.4	79.7	85.0
26	16.6	22.1	27.6	33.2	38.7	44.2	49.7	55.3	60.8	66.3	71.8	77.4	82.9	88.4
27	17.2	23.0	28.7	34.4	40.2	45.9	51.6	57.4	63.1	68.9	74.6	80.3	86.1	91.8
28	17.9	23.8	29.8	35.7	41.7	47.6	53.6	59.5	65.5	71.4	77.4	83.3	89.3	95.2
29	18.5	24.7	30.8	37.0	43.1	49.3	55.5	61.6	67.8	74.0	80.1	86.3	92.4	98.6
30	19.1	25.5	31.9	38.3	44.6	51.0	57.4	63.8	70.1	76.5	82.9	89.3	95.6	102
31	19.8	26.4	32.9	39.5	46.1	52.7	59.3	65.9	72.5	79.1	85.6	92.2	98.8	105
32	20.4	27.2	34.0	40.8	47.6	54.4	61.2	68.0	74.8	81.6	88.4	95.2	102	109

WEIGHT OF PLATES

Pounds Per Linear Foot

Width In.	Thickness, Inches													
	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16	1
33	21.0	28.1	35.1	42.1	49.1	56.1	63.1	70.1	77.1	84.2	91.2	98.2	105	112
34	21.7	28.9	36.1	43.4	50.6	57.8	65.0	72.3	79.5	86.7	93.9	101	108	116
35	22.3	29.8	37.2	44.6	52.1	59.5	66.9	74.4	81.8	89.3	96.1	104	112	119
36	23.0	30.6	38.3	45.9	53.6	61.2	68.9	76.5	84.2	91.8	99.5	107	115	122
37	23.6	31.5	39.3	47.2	55.0	62.9	70.8	78.6	86.5	94.4	102	110	118	126
38	24.2	32.3	40.4	48.5	56.5	64.6	72.7	80.8	88.8	96.9	105	113	121	129
39	24.9	33.2	41.4	49.7	58.0	66.3	74.6	82.9	91.2	99.5	108	116	124	133
40	25.5	34.0	42.5	51.0	59.5	68.0	76.5	85.0	93.5	102	111	119	128	136
41	26.1	34.9	43.6	52.3	61.0	69.7	78.4	87.1	95.8	105	113	122	131	139
42	26.8	35.7	44.6	53.6	62.5	71.4	80.3	89.3	98.2	107	116	125	134	143
43	27.4	36.6	45.7	54.8	64.0	73.1	82.2	91.4	101	110	119	128	137	146
44	28.1	37.4	46.8	56.1	65.5	74.8	84.2	93.5	103	112	122	131	140	150
45	28.7	38.3	47.8	57.4	66.9	76.5	86.1	95.6	105	115	124	134	143	153
46	29.3	39.1	48.9	58.7	68.4	78.2	88.0	97.8	108	117	127	137	147	156
47	30.0	40.0	49.9	59.9	69.9	79.9	89.9	99.9	110	120	130	140	150	160
48	30.6	40.8	51.0	61.2	71.4	81.6	91.8	102	112	122	133	143	153	163
49	31.2	41.7	52.1	62.5	72.9	83.3	93.7	104	115	125	135	146	156	167
50	21.9	42.5	53.1	63.8	74.4	85.0	95.6	106	117	128	138	149	159	170
51	32.5	43.4	54.2	65.0	75.9	86.7	97.5	108	119	130	141	152	163	173
52	33.2	44.2	55.3	66.3	77.4	88.4	99.5	111	122	133	144	155	166	177
53	33.8	45.1	56.3	67.6	78.8	90.1	101	113	124	135	146	158	169	180
54	34.4	45.9	57.4	68.9	80.3	91.8	103	115	126	138	149	161	172	184
55	35.1	46.8	58.4	70.1	81.8	93.5	105	117	129	140	152	164	175	187
56	35.7	47.6	59.5	71.4	83.3	95.2	107	119	131	143	155	167	179	190
57	36.3	48.5	60.6	72.7	84.8	96.9	109	121	133	145	158	170	182	194
58	37.0	49.3	61.6	74.0	86.3	98.6	111	123	136	148	160	173	185	197
59	37.6	50.2	62.7	75.2	87.8	100	113	125	138	151	163	176	188	201
60	38.3	51.0	63.8	76.5	89.3	102	115	128	140	153	166	179	191	204
61	38.9	51.9	64.8	77.8	90.7	104	117	130	143	156	169	182	194	207
62	39.5	52.7	65.9	79.1	92.2	105	119	132	145	158	171	185	198	211
63	40.2	53.6	66.9	80.3	93.7	107	121	134	147	161	174	187	201	214
64	20.8	54.4	68.0	81.6	95.2	109	122	136	150	163	177	190	204	218
65	41.4	55.3	69.1	82.9	96.7	111	124	138	152	166	180	193	207	221
66	42.1	56.1	70.1	84.2	98.2	112	126	140	154	168	182	196	210	224
67	42.7	57.0	71.2	85.4	99.7	114	128	142	157	171	185	199	214	228
68	43.4	57.8	72.3	86.7	101	116	130	145	159	173	188	202	217	231
69	44.0	58.7	73.3	88.0	103	117	132	147	161	176	191	205	220	235
70	44.6	59.5	74.4	89.3	104	119	134	149	164	179	193	208	223	238
71	45.3	60.4	75.4	90.5	106	121	136	151	166	181	196	211	226	241
72	45.9	61.2	76.5	91.8	107	122	138	153	168	184	199	214	230	245

WEIGHTS OF PLATES

Pounds Per Linear Foot

Width In.	Thickness, Inches													
	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16	1
73	46.5	62.1	77.6	93.1	109	124	140	155	171	186	202	217	233	248
74	47.2	62.9	78.6	94.4	110	126	142	157	173	189	204	220	236	252
75	47.8	63.8	79.7	95.6	112	128	143	159	175	191	207	223	239	255
76	48.5	64.6	80.8	96.9	113	129	145	162	178	194	210	226	242	258
77	49.1	65.5	81.8	98.2	115	131	147	164	180	196	213	229	245	262
78	49.7	66.3	82.9	99.5	116	133	149	166	182	199	216	232	249	265
79	50.4	67.2	83.9	101	118	134	151	168	185	202	218	235	252	269
80	51.0	68.0	85.0	102	119	136	153	170	187	204	221	238	255	272
81	51.6	68.9	86.1	103	121	138	155	172	189	207	224	241	258	275
82	52.3	69.7	87.1	105	122	139	157	174	192	209	227	244	261	279
83	52.9	70.6	88.2	106	124	141	159	176	194	212	229	247	265	282
84	53.6	71.4	89.3	107	125	143	161	179	196	214	232	250	268	286
85	54.2	72.3	90.3	108	126	145	163	181	199	217	235	253	271	289
86	54.8	73.1	91.4	110	128	146	165	183	201	219	238	256	274	292
87	55.5	74.0	92.4	111	129	148	166	185	203	222	240	259	277	296
88	56.1	74.8	93.5	112	131	150	168	187	206	224	243	262	281	299
89	56.7	75.7	94.6	114	132	151	170	189	208	227	246	265	284	303
90	57.4	76.5	95.6	115	134	153	172	191	210	230	249	268	287	306
91		77.4	96.7	116	135	155	174	193	213	232	251	271	290	309
92		78.2	97.8	117	137	156	176	196	215	235	254	274	293	313
93		79.1	98.8	119	138	158	178	198	217	237	257	277	296	316
94		79.9	99.9	120	140	160	180	200	220	240	260	280	300	320
95		80.8	101	121	141	162	182	202	222	242	262	283	303	323
96		81.6	102	122	143	163	184	204	224	245	265	286	306	326
98		83.3	104	125	146	167	187	208	229	250	271	292	312	333
100		85.0	106	128	149	170	191	213	234	255	276	298	319	340
102		86.7	108	130	152	173	195	217	238	260	282	304	325	347
104		88.4	111	133	155	177	199	221	243	265	287	309	332	354
106		90.1	113	135	158	180	203	225	248	270	293	315	338	360
108		91.8	115	138	161	184	207	230	253	275	298	321	344	367
110		93.5	117	140	164	187	210	234	257	281	304	327	351	374
112		95.2	119	143	167	190	214	238	262	286	309	333	357	381
114		96.9	121	145	170	194	218	242	267	291	315	339	363	388
116		98.6	123	148	173	197	222	247	271	296	321	345	370	394
118		100	125	151	176	201	226	251	276	301	326	351	376	401
120		102	128	153	179	204	230	255	281	306	332	357	383	408
122		104	130	156	182	207	233	259	285	311	337	363	389	415
124		105	132	158	185	211	237	264	290	316	343	369	395	422
126		107	134	161	187	214	241	268	295	321	348	375	402	428
128		109	136	163	190	218	245	272	299	326	354	381	408	435

WEIGHT OF CIRCULAR PLATES

ALL DIMENSIONS IN INCHES — WEIGHTS IN POUNDS

DIA	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16	1
1.00	.042	.056	.070	.083	.097	.111	.125	.139	.153	.167	.181	.195	.209	.223
1.25	.065	.087	.109	.130	.152	.174	.196	.217	.239	.261	.282	.304	.326	.348
1.50	.094	.125	.156	.188	.219	.250	.282	.313	.344	.375	.407	.438	.469	.501
1.75	.128	.170	.213	.256	.298	.341	.383	.426	.468	.511	.554	.596	.639	.681
2.00	.167	.223	.278	.334	.389	.445	.501	.556	.612	.668	.723	.779	.834	.890
2.25	.211	.282	.352	.422	.493	.563	.634	.704	.774	.845	.915	.986	1.056	1.126
2.50	.261	.348	.435	.521	.608	.695	.782	.869	.956	1.043	1.130	1.217	1.304	1.391
2.75	.315	.421	.526	.631	.736	.841	.946	1.052	1.157	1.262	1.367	1.472	1.577	1.683
3.00	.375	.501	.626	.751	.876	1.001	1.126	1.252	1.377	1.502	1.627	1.752	1.877	2.003
3.25	.441	.588	.734	.881	1.028	1.175	1.322	1.469	1.616	1.763	1.910	2.056	2.203	2.350
3.50	.511	.681	.852	1.022	1.192	1.363	1.533	1.704	1.874	2.044	2.215	2.385	2.555	2.726
3.75	.587	.782	.978	1.173	1.369	1.564	1.760	1.956	2.151	2.347	2.542	2.738	2.933	3.129
4.00	.668	.890	1.113	1.335	1.558	1.780	2.003	2.225	2.448	2.670	2.893	3.115	3.338	3.560
4.25	.754	1.005	1.256	1.507	1.758	2.009	2.261	2.512	2.763	3.014	3.265	3.517	3.768	4.019
4.50	.845	1.126	1.408	1.690	1.971	2.253	2.534	2.816	3.098	3.379	3.661	3.942	4.224	4.506
4.75	.941	1.255	1.569	1.883	2.196	2.510	2.824	3.138	3.451	3.765	4.079	4.393	4.706	5.020
5.00	1.043	1.391	1.738	2.086	2.434	2.781	3.129	3.477	3.824	4.172	4.520	4.867	5.215	5.563
5.25	1.150	1.533	1.916	2.300	2.683	3.066	3.450	3.833	4.216	4.600	4.983	5.366	5.749	6.133
5.50	1.262	1.683	2.103	2.524	2.945	3.365	3.786	4.207	4.627	5.048	5.469	5.889	6.310	6.731
5.75	1.379	1.839	2.299	2.759	3.218	3.678	4.138	4.598	5.058	5.517	5.977	6.437	6.897	7.356
6.00	1.502	2.003	2.503	3.004	3.504	4.005	4.506	5.006	5.507	6.008	6.508	7.009	7.509	8.010
6.50	1.763	2.350	2.938	3.525	4.113	4.700	5.288	5.875	6.463	7.051	7.638	8.226	8.813	9.401
7.00	2.044	2.726	3.407	4.088	4.770	5.451	6.133	6.814	7.496	8.177	8.858	9.540	10.22	10.90
7.50	2.347	3.129	3.911	4.693	5.476	6.258	7.040	7.822	8.605	9.387	10.16	10.95	11.73	12.51
8.00	2.670	3.560	4.450	5.340	6.230	7.120	8.010	8.900	9.790	10.68	11.57	12.46	13.35	14.24
8.50	3.014	4.019	5.024	6.028	7.033	8.038	9.043	10.04	11.05	12.05	13.06	14.06	15.07	16.07
9.00	3.379	4.506	5.632	6.758	7.885	9.011	10.13	11.26	12.39	13.51	14.64	15.77	16.89	18.02
9.50	3.765	5.020	6.275	7.530	8.785	10.04	11.29	12.55	13.80	15.06	16.31	17.57	18.82	20.08
10.00	4.172	5.563	6.953	8.344	9.734	11.12	12.51	13.90	15.29	16.68	18.07	19.46	20.85	22.25
10.50	4.600	6.133	7.666	9.199	10.73	12.26	13.79	15.33	16.86	18.39	19.93	21.46	22.99	24.53
11.00	5.048	6.731	8.413	10.09	11.77	13.46	15.14	16.82	18.50	20.19	21.87	23.55	25.24	26.92
11.50	5.517	7.356	9.196	11.03	12.87	14.71	16.55	18.39	20.23	22.06	23.90	25.74	27.58	29.42
12.00	6.008	8.010	10.01	12.01	14.01	16.02	18.02	20.02	22.02	24.03	26.03	28.03	30.03	32.04
12.50	6.519	8.691	10.86	13.03	15.21	17.38	19.55	21.72	23.90	26.07	28.24	30.42	32.59	34.76
13.00	7.051	9.401	11.75	14.10	16.45	18.80	21.15	23.50	25.85	28.20	30.55	32.90	35.25	37.60
13.50	7.603	10.13	12.67	15.20	17.74	20.27	22.81	25.34	27.87	30.41	32.94	35.48	38.01	40.55
14.00	8.177	10.90	13.62	16.35	19.07	21.80	24.53	27.25	29.98	32.70	35.43	38.15	40.88	43.61
14.50	8.771	11.69	14.61	17.54	20.46	23.39	26.31	29.23	32.16	35.08	38.00	40.93	43.85	46.78
15.00	9.387	12.51	15.64	18.77	21.90	25.03	28.16	31.28	34.41	37.54	40.67	43.80	46.93	50.06
15.50	10.02	13.36	16.70	20.04	23.38	26.72	30.06	33.41	36.75	40.09	43.43	46.77	50.11	53.45
16.00	10.68	14.24	17.80	21.36	24.92	28.48	32.04	35.60	39.16	42.72	46.28	49.84	53.40	56.96
16.50	11.35	15.14	18.93	22.71	26.50	30.28	34.07	37.86	41.64	45.43	49.21	53.00	56.79	60.57
17.00	12.05	16.07	20.09	24.11	28.13	32.15	36.17	40.18	44.20	48.22	52.24	56.26	60.28	64.30
17.50	12.77	17.03	21.29	25.55	29.81	34.07	38.32	42.58	46.84	51.10	55.36	59.62	63.88	68.14
18.00	13.51	18.02	22.52	27.03	31.54	36.04	40.55	45.05	49.56	54.06	58.57	63.07	67.58	72.09
18.50	14.27	19.03	23.79	28.55	33.31	38.07	42.83	47.59	52.35	57.11	61.87	66.63	71.39	76.15
19.00	15.06	20.08	25.10	30.12	35.14	40.16	45.18	50.20	55.22	60.24	65.26	70.28	75.30	80.32
19.50	15.86	21.15	26.43	31.72	37.01	42.30	47.59	52.87	58.16	63.45	68.74	74.03	79.31	84.60
20.00	16.68	22.25	27.81	33.37	38.93	44.50	50.06	55.62	61.18	66.75	72.31	77.87	83.43	89.00
20.50	17.53	23.37	29.22	35.06	40.90	46.75	52.59	58.44	64.28	70.13	75.97	81.81	87.66	93.50
21.00	18.39	24.53	30.66	36.79	42.92	49.06	55.19	61.32	67.46	73.59	79.72	85.85	91.99	98.12
21.50	19.28	25.71	32.14	38.56	44.99	51.42	57.85	64.28	70.71	77.13	83.56	89.99	96.42	102.85

WEIGHT OF CIRCULAR PLATES

ALL DIMENSIONS IN INCHES — WEIGHTS IN POUNDS

DIA	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16	1
22	20	27	34	40	47	54	61	67	74	81	87	94	101	108
22½	21	28	35	42	49	56	63	70	77	84	92	99	106	113
23	22	29	37	44	51	59	66	74	81	88	96	103	110	118
23½	23	31	38	46	54	61	69	77	84	92	100	108	115	123
24	24	32	40	48	56	64	72	80	88	96	104	112	120	128
24½	25	33	42	50	58	67	75	83	92	100	109	117	125	134
25	26	35	43	52	61	70	78	87	96	104	113	122	130	139
25½	27	36	45	54	63	72	81	90	99	109	118	127	136	145
26	28	38	47	56	66	75	85	94	103	113	122	132	141	150
26½	29	39	49	59	68	78	88	98	107	117	127	137	146	156
27	30	41	51	61	71	81	91	101	112	122	132	142	152	162
27½	32	42	53	63	74	84	95	105	116	126	137	147	158	168
28	33	44	55	65	76	87	98	109	120	131	142	153	164	174
28½	34	45	56	68	79	90	102	113	124	136	147	158	169	181
29	35	47	58	70	82	94	105	117	129	140	152	164	175	187
29½	36	48	61	73	85	97	109	121	133	145	157	169	182	194
30	38	50	63	75	88	100	113	125	138	150	163	175	188	200
30½	39	52	65	78	91	103	116	129	142	155	168	181	194	207
31	40	53	67	80	94	107	120	134	147	160	174	187	200	214
31½	41	55	69	83	97	110	124	138	152	166	179	193	207	221
32	43	57	71	85	100	114	128	142	157	171	185	199	214	228
32½	44	59	73	88	103	118	132	147	162	176	191	206	220	235
33	45	61	76	91	106	121	136	151	167	182	197	212	227	242
33½	47	62	78	94	109	125	140	156	172	187	203	218	234	250
34	48	64	80	96	113	129	145	161	177	193	209	225	241	257
34½	50	66	83	99	116	132	149	166	182	199	215	232	248	265
35	51	68	85	102	119	136	153	170	187	204	221	238	256	273
35½	53	70	88	105	123	140	158	175	193	210	228	245	263	280
36	54	72	90	108	126	144	162	180	198	216	234	252	270	288
36½	56	74	93	111	130	148	167	185	204	222	241	259	278	296
37	57	76	95	114	133	152	171	190	209	228	247	267	286	305
37½	59	78	98	117	137	156	176	196	215	235	254	274	293	313
38	60	80	100	120	141	161	181	201	221	241	261	281	301	321
38½	62	82	103	124	144	165	186	206	227	247	268	289	309	330
39	63	85	106	127	148	169	190	212	233	254	275	296	317	338
39½	65	87	108	130	152	174	195	217	239	260	282	304	325	347
40	67	89	111	134	156	178	200	223	245	267	289	312	334	356
40½	68	91	114	137	160	182	205	228	251	274	297	319	342	365
41	70	94	117	140	164	187	210	234	257	281	304	327	351	374
41½	72	96	120	144	168	192	216	240	263	287	311	335	359	383
42	74	98	123	147	172	196	221	245	270	294	319	343	368	392
42½	75	100	126	151	176	201	226	251	276	301	327	352	377	402
43	77	103	129	154	180	206	231	257	283	309	334	360	386	411
43½	79	105	132	158	184	211	237	263	289	316	342	368	395	421
44	81	108	135	162	188	215	242	269	296	323	350	377	404	431
44½	83	110	138	165	193	220	248	275	303	330	358	386	413	441
45	84	113	141	169	197	225	253	282	310	338	366	394	422	451
45½	86	115	144	173	202	230	259	288	317	345	374	403	432	461
46	88	118	147	177	206	235	265	294	324	353	383	412	441	471
46½	90	120	150	180	210	241	271	301	331	361	391	421	451	481
47	92	123	154	184	215	246	276	307	338	369	399	430	461	492
47½	94	126	157	188	220	251	282	314	345	377	408	439	471	502
48	96	128	160	192	224	256	288	320	352	384	417	449	481	513
48½	98	131	164	196	229	262	294	327	360	393	425	458	491	523
49	100	134	167	200	234	267	301	334	367	401	434	467	501	534
49½	102	136	170	204	239	273	307	341	375	409	443	477	511	545

WEIGHT OF CIRCULAR PLATES

ALL DIMENSIONS IN INCHES — WEIGHTS IN POUNDS

DIA	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16	1
50	104	139	174	209	243	278	313	348	382	417	452	487	521	556
50½	106	142	177	213	248	284	319	355	390	426	461	497	532	567
51	109	145	181	217	253	289	326	362	398	434	470	506	543	579
51½	111	148	184	221	258	295	332	369	406	443	479	516	553	590
52	113	150	188	226	263	301	338	376	414	451	489	526	564	602
52½	115	153	192	230	268	307	345	383	422	460	498	537	575	613
53	117	156	195	234	273	313	352	391	430	469	508	547	586	625
53½	119	159	199	239	279	318	358	398	438	478	517	557	597	637
54	122	162	203	243	284	324	365	406	446	487	527	568	608	649
54½	124	165	207	248	289	330	372	413	454	496	537	578	620	661
55	126	168	210	252	294	337	379	421	463	505	547	589	631	673
55½	129	171	214	257	300	343	386	428	471	514	557	600	643	685
56	131	1/4	218	262	305	349	392	436	480	523	567	611	654	698
56½	133	178	222	266	311	355	400	444	488	533	577	622	666	710
57	136	181	226	271	316	361	407	452	497	542	587	633	678	723
57½	138	184	230	276	322	368	414	460	506	552	598	644	690	736
58	140	187	234	281	327	374	421	468	515	561	608	655	702	749
58½	143	190	238	286	333	381	428	476	524	571	619	666	714	761
59	145	194	242	290	339	387	436	484	532	581	629	678	726	775
59½	148	197	246	295	345	394	443	492	542	591	640	689	738	788
60	150	200	250	300	350	401	451	501	551	601	651	701	751	801
60½	153	204	255	305	356	407	458	509	560	611	662	713	764	814
61	155	207	259	310	362	414	466	517	569	621	673	724	776	828
61½	158	210	263	316	368	421	473	526	579	631	684	736	789	842
62	160	214	267	321	374	428	481	535	588	641	695	748	802	855
62½	163	217	272	326	380	435	489	543	598	652	706	761	815	869
63	166	221	276	331	386	442	497	552	607	662	718	773	828	883
63½	168	224	280	336	393	449	505	561	617	673	729	785	841	897
64	171	228	285	342	399	456	513	570	627	684	740	797	854	911
64½	174	231	289	347	405	463	521	579	636	694	752	810	868	926
65	176	235	294	353	411	470	529	588	646	705	764	823	881	940
65½	179	239	298	358	418	477	537	597	656	716	776	835	895	955
66	182	242	303	363	424	485	545	606	666	727	787	848	909	969
66½	184	246	307	369	430	492	553	615	676	738	799	861	922	984
67	187	250	312	375	437	499	562	624	687	749	812	874	936	999
67½	190	253	317	380	444	507	570	634	697	760	824	887	950	1014
68	193	257	322	386	450	514	579	643	707	772	836	900	965	1029
68½	196	261	326	392	457	522	587	653	718	783	848	914	979	1044
69	199	265	331	397	463	530	596	662	728	795	861	927	993	1059
69½	202	269	336	403	470	537	605	672	739	806	873	940	1008	1075
70	204	273	341	409	477	545	613	681	750	818	886	954	1022	1090
70½	207	276	346	415	484	553	622	691	760	829	899	968	1037	1106
71	210	280	351	421	491	561	631	701	771	841	911	981	1052	1122
71½	213	284	355	427	498	569	640	711	782	853	924	995	1066	1137
72	216	288	360	433	505	577	649	721	793	865	937	1009	1081	1153
72½	219	292	365	439	512	585	658	731	804	877	950	1023	1096	1170
73	222	296	371	445	519	593	667	741	815	889	963	1038	1112	1186
73½	225	301	376	451	526	601	676	751	826	902	977	1052	1127	1202
74	228	305	381	457	533	609	685	762	838	914	990	1066	1142	1218
74½	232	309	386	463	540	617	695	772	849	926	1003	1081	1158	1235
75	235	313	391	469	548	626	704	782	860	939	1017	1095	1173	1252
75½	238	317	396	476	555	634	713	793	872	951	1031	1110	1189	1268
76	241	321	402	482	562	643	723	803	884	964	1044	1125	1205	1285
76½	244	326	407	488	570	651	732	814	895	977	1058	1139	1221	1302
77	247	330	412	495	577	660	742	825	907	989	1072	1154	1237	1319
77½	251	334	418	501	585	668	752	835	919	1002	1086	1169	1253	1336

WEIGHT OF CIRCULAR PLATES

ALL DIMENSIONS IN INCHES — WEIGHTS IN POUNDS

DIA	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16	1
78	254	338	423	508	592	677	761	846	931	1015	1100	1184	1269	1354
78½	257	343	428	514	600	686	771	857	943	1028	1114	1200	1285	1371
79	260	347	434	521	608	694	781	868	955	1041	1128	1215	1302	1389
79½	264	352	439	527	615	703	791	879	967	1055	1143	1230	1318	1406
80	267	356	445	534	623	712	801	890	979	1068	1157	1246	1335	1424
80½	270	360	451	541	631	721	811	901	991	1081	1172	1262	1352	1442
81	274	365	456	547	639	730	821	912	1004	1095	1186	1277	1369	1460
81½	277	369	462	554	647	739	831	924	1016	1108	1201	1293	1386	1478
82	281	374	468	561	655	748	842	935	1029	1122	1216	1309	1403	1496
82½	284	379	473	568	663	757	852	947	1041	1136	1230	1325	1420	1514
83	287	383	479	575	671	766	862	958	1054	1150	1245	1341	1437	1533
83½	291	388	485	582	679	776	873	970	1067	1164	1260	1357	1454	1551
84	294	392	491	589	687	785	883	981	1079	1177	1276	1374	1472	1570
84½	298	397	496	596	695	794	894	993	1092	1192	1291	1390	1489	1589
85	301	402	502	603	703	804	904	1005	1105	1206	1306	1407	1507	1608
85½	305	407	508	610	712	813	915	1017	1118	1220	1322	1423	1525	1627
86	309	411	514	617	720	823	926	1029	1131	1234	1337	1440	1543	1646
86½	312	416	520	624	728	832	936	1041	1145	1249	1353	1457	1561	1665
87	316	421	526	632	737	842	947	1053	1158	1263	1368	1474	1579	1684
87½	319	426	532	639	745	852	958	1065	1171	1278	1384	1491	1597	1704
88	323	431	538	646	754	862	969	1077	1185	1292	1400	1508	1615	1723
88½	327	436	545	654	762	871	980	1089	1198	1307	1416	1525	1634	1743
89	330	441	551	661	771	881	991	1102	1212	1322	1432	1542	1652	1762
89½	334	446	557	668	780	891	1003	1114	1225	1337	1448	1560	1671	1782
90	338	451	563	676	788	901	1014	1126	1239	1352	1464	1577	1690	1802
90½	342	456	569	683	797	911	1025	1139	1253	1367	1481	1595	1708	1822
91	345	461	576	691	806	921	1036	1152	1267	1382	1497	1612	1727	1843
91½	349	466	582	699	815	931	1048	1164	1281	1397	1514	1630	1746	1863
92	353	471	589	706	824	942	1059	1177	1295	1412	1530	1648	1766	1883
92½	357	476	595	714	833	952	1071	1190	1309	1428	1547	1666	1785	1904
93	361	481	601	722	842	962	1082	1203	1323	1443	1564	1684	1804	1924
93½	365	486	608	729	851	973	1094	1216	1337	1459	1580	1702	1824	1945
94	369	492	614	737	860	983	1106	1229	1352	1475	1597	1720	1843	1966
94½	373	497	621	745	869	994	1118	1242	1366	1490	1614	1739	1863	1987
95	377	502	628	753	879	1004	1130	1255	1381	1506	1632	1757	1883	2008
95½	380	507	634	761	888	1015	1141	1268	1395	1522	1649	1776	1902	2029
96	384	513	641	769	897	1025	1153	1282	1410	1538	1666	1794	1922	2051
96½	389	518	648	777	907	1036	1166	1295	1425	1554	1684	1813	1943	2072
97	393	523	654	785	916	1047	1178	1308	1439	1570	1701	1832	1963	2094
97½	397	529	661	793	925	1058	1190	1322	1454	1586	1719	1851	1983	2115
98	401	534	668	801	935	1068	1202	1336	1469	1603	1736	1870	2003	2137
98½	405	540	675	810	944	1079	1214	1349	1484	1619	1754	1889	2024	2159
99	409	545	681	818	954	1090	1227	1363	1499	1636	1772	1908	2044	2181
99½	413	551	688	826	964	1101	1239	1377	1514	1652	1790	1927	2065	2203
100	417	556	695	834	973	1113	1252	1391	1530	1669	1808	1947	2086	2225
100½	421	562	702	843	983	1124	1264	1405	1545	1686	1826	1966	2107	2247
101	426	567	709	851	993	1135	1277	1419	1560	1702	1844	1986	2128	2270
101½	430	573	716	860	1003	1146	1289	1433	1576	1719	1862	2006	2149	2292
102	434	579	723	868	1013	1157	1302	1447	1592	1736	1881	2026	2170	2315
102½	438	584	731	877	1023	1169	1315	1461	1607	1753	1899	2045	2192	2338
103	443	590	738	885	1033	1180	1328	1475	1623	1770	1918	2065	2213	2361
103½	447	596	745	894	1043	1192	1341	1490	1639	1788	1937	2086	2235	2384
104	451	602	752	902	1053	1203	1354	1504	1655	1805	1955	2106	2256	2407
104½	456	607	759	911	1063	1215	1367	1519	1670	1822	1974	2126	2278	2430
105	460	613	767	920	1073	1227	1380	1533	1687	1840	1993	2146	2300	2453
105½	464	619	774	929	1083	1238	1393	1548	1703	1857	2012	2167	2322	2477

WEIGHT OF CIRCULAR PLATES

ALL DIMENSIONS IN INCHES — WEIGHTS IN POUNDS

DIA	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16	1
106	469	625	781	938	1094	1250	1406	1563	1719	1875	2031	2188	2344	2500
106½	473	631	789	946	1104	1262	1420	1577	1735	1893	2050	2208	2366	2524
107	478	637	796	955	1115	1274	1433	1592	1751	1911	2070	2229	2388	2547
107½	482	643	804	964	1125	1286	1446	1607	1768	1928	2089	2250	2411	2571
108	487	649	811	973	1135	1298	1460	1622	1784	1946	2109	2271	2433	2595
108½	491	655	819	982	1146	1310	1473	1637	1801	1965	2128	2292	2456	2619
109	496	661	826	991	1157	1322	1487	1652	1817	1983	2148	2313	2478	2644
109½	500	667	834	1000	1167	1334	1501	1667	1834	2001	2168	2334	2501	2668
110	505	673	841	1010	1178	1346	1514	1683	1851	2019	2187	2356	2524	2692
110½	509	679	849	1019	1189	1358	1528	1698	1868	2038	2207	2377	2547	2717
111	514	685	857	1028	1199	1371	1542	1713	1885	2056	2227	2399	2570	2741
111½	519	692	864	1037	1210	1383	1556	1729	1902	2075	2248	2420	2593	2766
112	523	698	872	1047	1221	1396	1570	1744	1919	2093	2268	2442	2617	2791
112½	528	704	880	1056	1232	1408	1584	1760	1936	2112	2288	2464	2640	2816
113	533	710	888	1065	1243	1421	1598	1776	1953	2131	2308	2486	2664	2841
113½	537	717	896	1075	1254	1433	1612	1791	1971	2150	2329	2508	2687	2866
114	542	723	904	1084	1265	1446	1627	1807	1988	2169	2349	2530	2711	2892
114½	547	729	912	1094	1276	1459	1641	1823	2005	2188	2370	2552	2735	2917
115	552	736	920	1103	1287	1471	1655	1839	2023	2207	2391	2575	2759	2943
115½	557	742	928	1113	1299	1484	1670	1855	2041	2226	2412	2597	2783	2968
116	561	749	936	1123	1310	1497	1684	1871	2058	2246	2433	2620	2807	2994
116½	566	755	944	1132	1321	1510	1699	1887	2076	2265	2454	2642	2831	3020
117	571	761	952	1142	1333	1523	1713	1904	2094	2284	2475	2665	2855	3046
117½	576	768	960	1152	1344	1536	1728	1920	2112	2304	2496	2688	2880	3072
118	581	775	968	1162	1355	1549	1743	1936	2130	2324	2517	2711	2905	3098
118½	586	781	976	1172	1367	1562	1758	1953	2148	2343	2539	2734	2929	3124
119	591	788	985	1182	1379	1575	1772	1969	2166	2363	2560	2757	2954	3151
119½	596	794	993	1192	1390	1589	1787	1986	2184	2383	2582	2780	2979	3177
120	601	801	1001	1202	1402	1602	1802	2003	2203	2403	2603	2804	3004	3204
120½	606	808	1010	1212	1413	1615	1817	2019	2221	2423	2625	2827	3029	3231
121	611	814	1018	1222	1425	1629	1832	2036	2240	2443	2647	2850	3054	3258
121½	616	821	1026	1232	1437	1642	1848	2053	2258	2463	2669	2874	3079	3285
122	621	828	1035	1242	1449	1656	1863	2070	2277	2484	2691	2898	3105	3312
122½	626	835	1043	1252	1461	1669	1878	2087	2296	2504	2713	2922	3130	3339
123	631	842	1052	1262	1473	1683	1894	2104	2314	2525	2735	2945	3156	3366
123½	636	848	1061	1273	1485	1697	1909	2121	2333	2545	2757	2969	3182	3394
124	641	855	1069	1283	1497	1711	1924	2138	2352	2566	2780	2994	3207	3421
124½	647	862	1078	1293	1509	1724	1940	2156	2371	2587	2802	3018	3233	3449
125	652	869	1086	1304	1521	1738	1956	2173	2390	2607	2825	3042	3259	3477
125½	657	876	1095	1314	1533	1752	1971	2190	2409	2628	2847	3066	3285	3504
126	662	883	1104	1325	1545	1766	1987	2208	2429	2649	2870	3091	3312	3532
126½	668	890	1113	1335	1558	1780	2003	2225	2448	2670	2893	3115	3338	3561
127	673	897	1121	1346	1570	1794	2019	2243	2467	2692	2916	3140	3364	3589
127½	678	904	1130	1356	1582	1809	2035	2261	2487	2713	2939	3165	3391	3617
128	684	911	1139	1367	1595	1823	2051	2278	2506	2734	2962	3190	3418	3645
128½	689	919	1148	1378	1607	1837	2067	2296	2526	2756	2985	3215	3444	3674
129	694	926	1157	1389	1620	1851	2083	2314	2546	2777	3008	3240	3471	3703
129½	700	933	1166	1399	1633	1866	2099	2332	2565	2799	3032	3265	3498	3731
130	705	940	1175	1410	1645	1880	2115	2350	2585	2820	3055	3290	3525	3760
130½	710	947	1184	1421	1658	1895	2131	2368	2605	2842	3079	3316	3552	3789
131	716	955	1193	1432	1671	1909	2148	2386	2625	2864	3102	3341	3580	3818
131½	721	962	1202	1443	1683	1924	2164	2405	2645	2886	3126	3367	3607	3848
132	727	969	1212	1454	1696	1938	2181	2423	2665	2908	3150	3392	3635	3877
132½	732	977	1221	1465	1709	1953	2197	2441	2686	2930	3174	3418	3662	3906
133	738	984	1230	1476	1722	1968	2214	2460	2706	2952	3198	3444	3690	3936
133½	744	991	1239	1487	1735	1983	2231	2478	2726	2974	3222	3470	3718	3966

WEIGHT OF CIRCULAR PLATES

ALL DIMENSIONS IN INCHES — WEIGHTS IN POUNDS

DIA	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16	1
134	749	999	1249	1498	1748	1998	2247	2497	2747	2996	3246	3496	3746	3995
134½	755	1006	1258	1509	1761	2013	2264	2516	2767	3019	3270	3522	3774	4025
135	760	1014	1267	1521	1774	2028	2281	2534	2788	3041	3295	3548	3802	4055
135½	766	1021	1277	1532	1787	2043	2298	2553	2809	3064	3319	3575	3830	4085
136	772	1029	1286	1543	1800	2058	2315	2572	2829	3087	3344	3601	3858	4115
136½	777	1036	1296	1555	1814	2073	2332	2591	2850	3109	3368	3628	3887	4146
137	783	1044	1305	1566	1827	2088	2349	2610	2871	3132	3393	3654	3915	4176
137½	789	1052	1315	1578	1840	2103	2366	2629	2892	3155	3418	3681	3944	4207
138	795	1059	1324	1589	1854	2119	2384	2648	2913	3178	3443	3708	3973	4237
138½	800	1067	1334	1601	1867	2134	2401	2668	2934	3201	3468	3735	4001	4268
139	806	1075	1343	1612	1881	2149	2418	2687	2956	3224	3493	3762	4030	4299
139½	812	1082	1353	1624	1894	2165	2436	2706	2977	3247	3518	3789	4059	4330
140	818	1090	1363	1635	1908	2181	2453	2726	2998	3271	3543	3816	4088	4361
140½	824	1098	1373	1647	1922	2196	2471	2745	3020	3294	3569	3843	4118	4392
141	829	1106	1382	1659	1935	2212	2488	2765	3041	3318	3594	3871	4147	4424
141½	835	1114	1392	1671	1949	2228	2506	2784	3063	3341	3620	3898	4177	4455
142	841	1122	1402	1682	1963	2243	2524	2804	3085	3365	3645	3926	4206	4487
142½	847	1130	1412	1694	1977	2259	2541	2824	3106	3389	3671	3953	4236	4518
143	853	1137	1422	1706	1991	2275	2559	2844	3128	3412	3697	3981	4266	4550
143½	859	1145	1432	1718	2005	2291	2577	2864	3150	3436	3723	4009	4295	4582
144	865	1153	1442	1730	2019	2307	2595	2884	3172	3460	3749	4037	4325	4614
144½	871	1161	1452	1742	2033	2323	2613	2904	3194	3484	3775	4065	4356	4646
145	877	1170	1462	1754	2047	2339	2631	2924	3216	3509	3801	4093	4386	4678
145½	883	1178	1472	1766	2061	2355	2650	2944	3238	3533	3827	4122	4416	4710
146	889	1186	1482	1779	2075	2371	2668	2964	3261	3557	3854	4150	4446	4743
146½	895	1194	1492	1791	2089	2388	2686	2985	3283	3582	3880	4178	4477	4775
147	902	1202	1503	1803	2104	2404	2705	3005	3306	3606	3907	4207	4508	4808
147½	908	1210	1513	1815	2118	2420	2723	3026	3328	3631	3933	4236	4538	4841
148	914	1218	1523	1828	2132	2437	2741	3046	3351	3655	3960	4264	4569	4874
148½	920	1227	1533	1840	2147	2453	2760	3067	3373	3680	3987	4293	4600	4907
149	926	1235	1544	1852	2161	2470	2779	3087	3396	3705	4014	4322	4631	4940
149½	932	1243	1554	1865	2176	2487	2797	3108	3419	3730	4041	4351	4662	4973
150	939	1252	1564	1877	2190	2503	2816	3129	3442	3755	4068	4381	4693	5006
150½	945	1260	1575	1890	2205	2520	2835	3150	3465	3780	4095	4410	4725	5040
151	951	1268	1585	1902	2220	2537	2854	3171	3488	3805	4122	4439	4756	5073
151½	958	1277	1596	1915	2234	2553	2873	3192	3511	3830	4149	4469	4788	5107
152	964	1285	1606	1928	2249	2570	2892	3213	3534	3856	4177	4498	4819	5141
152½	970	1294	1617	1940	2264	2587	2911	3234	3558	3881	4204	4528	4851	5175
153	977	1302	1628	1953	2279	2604	2930	3255	3581	3906	4232	4558	4883	5209
153½	983	1311	1638	1966	2294	2621	2949	3277	3604	3932	4260	4587	4915	5243
154	989	1319	1649	1979	2309	2638	2968	3298	3628	3958	4287	4617	4947	5277
154½	996	1328	1660	1992	2324	2656	2988	3320	3651	3983	4315	4647	4979	5311
155	1002	1336	1671	2005	2339	2673	3007	3341	3675	4009	4343	4677	5012	5346
155½	1009	1345	1681	2018	2354	2690	3026	3363	3699	4035	4371	4708	5044	5380
156	1015	1354	1692	2031	2369	2707	3046	3384	3723	4061	4400	4738	5076	5415
156½	1022	1362	1703	2044	2384	2725	3065	3406	3747	4087	4428	4768	5109	5450
157	1028	1371	1714	2057	2399	2742	3085	3428	3771	4113	4456	4799	5142	5484
157½	1035	1380	1725	2070	2415	2760	3105	3450	3795	4140	4485	4830	5175	5519
158	1041	1389	1736	2083	2430	2777	3124	3472	3819	4166	4513	4860	5207	5555
158½	1048	1397	1747	2096	2446	2795	3144	3494	3843	4192	4542	4891	5240	5590
159	1055	1406	1758	2109	2461	2813	3164	3516	3867	4219	4570	4922	5274	5625
159½	1061	1415	1769	2123	2476	2830	3184	3538	3892	4245	4599	4953	5307	5661
160	1068	1424	1780	2136	2492	2848	3204	3560	3916	4272	4628	4984	5340	5696
160½	1075	1433	1791	2149	2508	2866	3224	3582	3941	4299	4657	5015	5374	5732
161	1081	1442	1802	2163	2523	2884	3244	3605	3965	4326	4686	5047	5407	5768
161½	1088	1451	1814	2176	2539	2902	3264	3627	3990	4353	4715	5078	5441	5803

WEIGHT OF CIRCULAR PLATES

ALL DIMENSIONS IN INCHES WEIGHTS IN POUNDS

DIA	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16	1
162	1095	1460	1825	2190	2555	2920	3285	3650	4015	4380	4744	5109	5474	5839
162½	1102	1469	1836	2203	2571	2938	3305	3672	4039	4407	4774	5141	5508	5875
163	1108	1478	1847	2217	2586	2956	3325	3695	4064	4434	4803	5173	5542	5912
163½	1115	1487	1859	2231	2602	2974	3346	3718	4089	4461	4833	5205	5576	5948
164	1122	1496	1870	2244	2618	2992	3366	3740	4114	4488	4862	5236	5610	5984
164½	1129	1505	1882	2258	2634	3010	3387	3763	4139	4516	4892	5268	5645	6021
165	1136	1514	1893	2272	2650	3029	3407	3786	4165	4543	4922	5300	5679	6058
165½	1143	1524	1905	2285	2666	3047	3428	3809	4190	4571	4952	5333	5714	6094
166	1150	1533	1916	2299	2682	3066	3449	3832	4215	4598	4982	5365	5748	6131
166½	1157	1542	1928	2313	2699	3084	3470	3855	4241	4626	5012	5397	5783	6168
167	1164	1551	1939	2327	2715	3103	3491	3878	4266	4654	5042	5430	5818	6205
167½	1170	1561	1951	2341	2731	3121	3511	3902	4292	4682	5072	5462	5852	6243
168	1177	1570	1962	2355	2747	3140	3532	3925	4317	4710	5102	5495	5887	6280
168½	1185	1579	1974	2369	2764	3159	3554	3948	4343	4738	5133	5528	5923	6317
169	1192	1589	1986	2383	2780	3177	3575	3972	4369	4766	5163	5561	5958	6355
169½	1199	1598	1998	2397	2797	3196	3596	3995	4395	4794	5194	5594	5993	6393
170	1206	1608	2009	2411	2813	3215	3617	4019	4421	4823	5225	5627	6028	6430
170½	1213	1617	2021	2426	2830	3234	3638	4043	4447	4851	5255	5660	6064	6468
171	1220	1627	2033	2440	2846	3253	3660	4066	4473	4880	5286	5693	6100	6506
171½	1227	1636	2045	2454	2863	3272	3681	4090	4499	4908	5317	5726	6135	6544
172	1234	1646	2057	2468	2880	3291	3703	4114	4525	4937	5348	5760	6171	6583
172½	1241	1655	2069	2483	2897	3310	3724	4138	4552	4966	5379	5793	6207	6621
173	1249	1665	2081	2497	2913	3330	3746	4162	4578	4994	5411	5827	6243	6659
173½	1256	1674	2093	2512	2930	3349	3768	4186	4605	5023	5442	5861	6279	6698
174	1263	1684	2105	2526	2947	3368	3789	4210	4631	5052	5473	5894	6315	6737
174½	1270	1694	2117	2541	2964	3388	3811	4235	4658	5081	5505	5928	6352	6775
175	1278	1704	2129	2555	2981	3407	3833	4259	4685	5111	5537	5962	6388	6814
175½	1285	1713	2142	2570	2998	3427	3855	4283	4712	5140	5568	5997	6425	6853
176	1292	1723	2154	2585	3015	3446	3877	4308	4738	5169	5600	6031	6461	6892
176½	1300	1733	2166	2599	3033	3466	3899	4332	4765	5199	5632	6065	6498	6931
177	1307	1743	2178	2614	3050	3485	3921	4357	4792	5228	5664	6099	6535	6971
177½	1314	1753	2191	2629	3067	3505	3943	4381	4820	5258	5696	6134	6572	7010
178	1322	1762	2203	2644	3084	3525	3966	4406	4847	5287	5728	6169	6609	7050
178½	1329	1772	2215	2659	3102	3545	3988	4431	4874	5317	5760	6203	6646	7089
179	1337	1782	2228	2673	3119	3565	4010	4456	4901	5347	5792	6238	6684	7129
179½	1344	1792	2240	2688	3136	3585	4033	4481	4929	5377	5825	6273	6721	7169
180	1352	1802	2253	2703	3154	3605	4055	4506	4956	5407	5857	6308	6759	7209
180½	1359	1812	2265	2718	3172	3625	4078	4531	4984	5437	5890	6343	6796	7249
181	1367	1822	2278	2734	3189	3645	4100	4556	5011	5467	5923	6378	6834	7289
181½	1374	1832	2291	2749	3207	3665	4123	4581	5039	5497	5955	6414	6872	7330
182	1382	1843	2303	2764	3224	3685	4146	4606	5067	5528	5988	6449	6910	7370
182½	1390	1853	2316	2779	3242	3705	4169	4632	5095	5558	6021	6484	6948	7411
183	1397	1863	2329	2794	3260	3726	4191	4657	5123	5589	6054	6520	6986	7451
183½	1405	1873	2341	2810	3278	3746	4214	4683	5151	5619	6087	6556	7024	7492
184	1412	1883	2354	2825	3296	3767	4237	4708	5179	5650	6121	6591	7062	7533
184½	1420	1894	2367	2840	3314	3787	4260	4734	5207	5681	6154	6627	7101	7574
185	1428	1904	2380	2856	3332	3808	4284	4759	5235	5711	6187	6663	7139	7615
185½	1436	1914	2393	2871	3350	3828	4307	4785	5264	5742	6221	6699	7178	7656
186	1443	1924	2406	2887	3368	3849	4330	4811	5292	5773	6254	6736	7217	7698
186½	1451	1935	2418	2902	3386	3870	4353	4837	5321	5804	6288	6772	7255	7739
187	1459	1945	2431	2918	3404	3890	4377	4863	5349	5836	6322	6808	7294	7781
187½	1467	1956	2444	2933	3422	3911	4400	4889	5378	5867	6356	6845	7333	7822
188	1475	1966	2458	2949	3441	3932	4424	4915	5407	5898	6390	6881	7373	7864
188½	1482	1977	2471	2965	3459	3953	4447	4941	5435	5930	6424	6918	7412	7906
189	1490	1987	2484	2981	3477	3974	4471	4968	5464	5961	6458	6955	7451	7948
189½	1498	1998	2497	2996	3496	3995	4494	4994	5493	5993	6492	6991	7491	7990

WEIGHT OF CIRCULAR PLATES

ALL DIMENSIONS IN INCHES

WEIGHTS IN POUNDS

DIA	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16	1
190	1506	2008	2510	3012	3514	4016	4518	5020	5522	6024	6526	7028	7530	8032
190½	1514	2019	2523	3028	3533	4037	4542	5047	5551	6056	6561	7065	7570	8075
191	1522	2029	2537	3044	3551	4059	4566	5073	5581	6088	6595	7102	7610	8117
191½	1530	2040	2550	3060	3570	4080	4590	5100	5610	6120	6630	7140	7650	8160
192	1538	2051	2563	3076	3589	4101	4614	5126	5639	6152	6664	7177	7690	8202
192½	1546	2061	2577	3092	3607	4123	4638	5153	5669	6184	6699	7214	7730	8245
193	1554	2072	2590	3108	3626	4144	4662	5180	5698	6216	6734	7252	7770	8288
193½	1562	2083	2603	3124	3645	4166	4686	5207	5728	6248	6769	7290	7810	8331
194	1570	2094	2617	3140	3664	4187	4710	5234	5757	6281	6804	7327	7851	8374
194½	1578	2104	2630	3157	3683	4209	4735	5261	5787	6313	6839	7365	7891	8417
195	1586	2115	2644	3173	3702	4230	4759	5288	5817	6346	6874	7403	7932	8461
195½	1595	2126	2658	3189	3721	4252	4784	5315	5847	6378	6910	7441	7973	8504
196	1603	2137	2671	3205	3740	4274	4808	5342	5877	6411	6945	7479	8013	8548
196½	1611	2148	2685	3222	3759	4296	4833	5370	5907	6444	6980	7517	8054	8591
197	1619	2159	2698	3238	3778	4318	4857	5397	5937	6476	7016	7556	8095	8635
197½	1627	2170	2712	3255	3797	4340	4882	5424	5967	6509	7052	7594	8137	8679
198	1636	2181	2726	3271	3816	4362	4907	5452	5997	6542	7087	7633	8178	8723
198½	1644	2192	2740	3288	3836	4384	4932	5479	6027	6575	7123	7671	8219	8767
199	1652	2203	2754	3304	3855	4406	4956	5507	6058	6609	7159	7710	8261	8811
199½	1660	2214	2767	3321	3874	4428	4981	5535	6088	6642	7195	7749	8302	8856
200	1669	2225	2781	3338	3894	4450	5006	5563	6119	6675	7231	7788	8344	8900

WEIGHT OF BOLTS

With square heads and hexagon nuts in pounds per 100

Length Under Head Inches	Diameter of Bolt in Inches								
	1/4	3/8	1/2	5/8	3/4	7/8	1	1 1/8	1 1/4
1	2.38	6.11	13.0	24.1	38.9				
1 1/4	2.71	6.71	14.0	25.8	41.5				
1 1/2	3.05	7.47	15.1	27.6	44.0	67.3	95.1		
1 3/4	3.39	8.23	16.5	29.3	46.5	70.8	99.7		
2	3.73	8.99	17.8	31.4	49.1	74.4	104	143	
2 1/4	4.06	9.75	19.1	33.5	52.1	77.9	109	149	
2 1/2	4.40	10.5	20.5	35.6	55.1	82.0	114	155	206
2 3/4	4.74	11.3	21.8	37.7	58.2	86.1	119	161	213
3	5.07	12.0	23.2	39.8	61.2	90.2	124	168	221
3 1/4	5.41	12.8	24.5	41.9	64.2	94.4	129	174	229
3 1/2	5.75	13.5	25.9	44.0	67.2	98.5	135	181	237
3 3/4	6.09	14.3	27.2	46.1	70.2	103	140	188	246
4	6.42	15.1	28.6	48.2	73.3	107	145	195	254
4 1/4	6.76	15.8	29.9	50.3	76.3	111	151	202	262
4 1/2	7.10	16.6	31.3	52.3	79.3	115	156	208	271
4 3/4	7.43	17.3	32.6	54.4	82.3	119	162	215	279
5	7.77	18.1	33.9	56.5	85.3	123	167	222	288
5 1/4	8.11	18.9	35.3	58.6	88.4	127	172	229	296
5 1/2	8.44	19.6	36.6	60.7	91.4	131	178	236	304
5 3/4	8.78	20.4	38.0	62.8	94.4	136	183	242	313
6	9.12	21.1	39.3	64.9	97.4	140	188	249	321
6 1/4	9.37	21.7	40.4	66.7	100	143	193	255	329
6 1/2	9.71	22.5	41.8	68.7	103	147	198	262	337
6 3/4	10.1	23.3	43.1	70.8	106	151	204	269	345
7	10.4	24.0	44.4	72.9	109	156	209	275	354
7 1/4	10.7	24.8	45.8	75.0	112	160	214	282	362
7 1/2	11.0	25.5	47.1	77.1	115	164	220	289	371
7 3/4	11.4	26.3	48.5	79.2	118	168	225	296	379
8	11.7	27.0	49.8	81.3	121	172	231	303	387
8 1/2		28.6	52.5	85.5	127	180	241	316	404
9		30.1	55.2	89.7	133	189	252	330	421
9 1/2		31.6	57.9	93.9	139	197	263	343	438
10		33.1	60.6	98.1	145	205	274	357	454
10 1/2		34.6	63.3	102	151	213	284	371	471
11		36.2	66.0	106	157	221	295	384	488
11 1/2		37.7	68.7	110	163	230	306	398	505
12		39.2	71.3	115	170	238	316	411	522
12 1/2			74.0	119	176	246	327	425	538
13			76.7	123	182	254	338	439	556
13 1/2			79.4	127	188	263	349	452	572
14			82.1	131	194	271	359	466	589
14 1/2			84.8	135	200	279	370	479	605
15			87.5	140	206	287	381	493	622
15 1/2			90.2	144	212	296	392	507	639
16			92.9	148	218	304	402	520	656
Per Inch Additional	1.3	3.0	5.4	8.4	12.1	16.5	21.4	27.2	33.6

Notes: Bolt is Regular Square Bolt, ASA B18.2 and nut is finished Hexagon Nut, ASA B18.2. This table conforms to weight standards adopted by the Industrial Fasteners Institute.

WEIGHTS OF OPENINGS

NOZZLES

With ANSI Welding Neck Flange and Reinforcing Pad
(Table for Quick Reference)

SIZE	CLASS				
	150	300	600	900	1500
1½	6	11	13	17	18
2	9	12	15	28	30
3	16	25	40	45	70
4	25	40	60	75	105
6	45	70	120	155	225
8	65	110	175	260	380
10	95	145	285	375	620
12	135	220	365	550	920
14	165	285	515	775	
16	215	370	695	965	
18	331	610	935	1379	
20	428	708	1245	1693	
24	589	1131	1815	3041	

NOZZLES

With ASA Welding Neck Flange, Reinforcing Pad, Blind Flange
Studs and Gasket (Table for Quick Reference)

SIZE	CLASS				
	150	300	600	900	1500
3	25	41	60	77	118
4	42	67	101	129	178
6	71	120	206	268	384
8	110	191	314	457	682
10	165	272	516	665	1127
12	245	404	660	963	1695
14	296	521	893	1269	
16	440	800	1300	1600	3510
18	540	1000	1600	2250	4460
20	700	1200	2100	2800	5700
24	1000	1885	2990	5140	9350

SCREWED COUPLINGS

	NOMINAL PIPE SIZE						
	½	¾	1	1½	2	2½	3
3000 lb	0.25	0.44	0.63	2.19	3.13	4.00	6.75
6000 lb	0.50	1.00	2.13	4.38	7.75	10.75	13.50

WEIGHTS OF PACKING
Pounds Per Cubic Foot

SIZE	RASCHIG RING			PALL RING		INTALOX
	CERAMIC	CARBON STEEL	CARBON	CARBON STEEL	PLASTIC	
1/4	60	133	46			54
3/8	61	94				50
1/2	55	75	27			45
1/2		132				
5/8	56	62		37	7.25	
3/4	50	52	34			44
3/4		94				
1	42	39	27	30	5.50	44
1		71				
1 1/4	46	62	31			
1 1/2	43	49	34	26	4.75	42
1 1/2	46					
2	41	37	27	24	4.50	42
3	37	25	23			37
3 1/2					4.25	
4	36					

The data condensed from the technical literature of the U. S. Stoneware Co.

The weights of carbon steel in percentage of other metals: Stainless Steel 105%, Copper 120%, Aluminum 37%, Monel or Nickel 115%

WEIGHTS OF INSULATION
POUNDS PER CUBIC FOOT

CALCIUM SILICATE	12.5
FOAMGLASS	9.0
MINERAL WOOL	8.0
GLASS FIBER	4-8
FOAMGLASS	8-10

For mechanical design of vessel add 80% to these weights which covers the weight of seal, jacketing and the absorbed moisture.

SPECIFIC GRAVITIES

METALS 62°F.

Aluminum	2.70
Antimony	6.618
Barium	3.78
Bismuth	9.781
Boron	2.535
Brass: 80 C., 2 OZ.	8.60
70 C., 3 OZ.	8.44
60 C., 4 OZ.	8.36
50 C., 5 OZ.	8.20
Bronze: 90 C., 10 T.	8.78
Cadmium	8.648
Calcium	1.54
Chromium	6.93
Cobalt	8.71
Copper	8.89
Gold	19.3
Iridium	22.42
Iron - cast	7.03 - 7.73
Iron - wrought	7.80 - 7.90
Lead	11.342
Magnesium	1.741
Manganese	7.3
Mercury (68° F.)	13.546
Molybdenum	10.2
Nickel	8.8
Platinum	21.37
Potassium	0.870
Silver	10.42 - 10.53
Sodium	0.9712
Steel	7.85
Tantalum	16.6
Tellurium	6.25
Tin	7.29
Titanium	4.5
Tungsten	18.6 - 19.1
Uranium	18.7
Vanadium	5.6
Zinc	7.04 - 7.16

HYDROCARBONS 60/60° F.

Ethane	0.3564
Propane	0.5077
N-butane	0.5844
Iso-butane	0.5631
N-pentane	0.6310
Iso-pentane	0.6247
N-hexane	0.6640
2-methylpentane	0.6579
3-methylpentane	0.6689
2, 2-dimethylbutane (neohexane)	0.6540
2, 3-dimethylbutane	0.6664
N-heptane	0.6882
2-methylhexane	0.6830
3-methylhexane	0.6917
2, 2-dimethylpentane	0.6782
2, 4-dimethylpentane	0.6773
1, 1-dimethylcyclopentane	0.7592
N-octane	0.7068
Cyclopentane	0.7504
Methylcyclopentane	0.7536
Cyclohexane	0.7834
Methylcyclohexane	0.7740
Benzene	0.8844
Toulene	0.8718

LIQUIDS 62° F.

Acetic Acid	1.06
Alcohol, commercial	0.83
Alcohol, pure	0.79
Ammonia	0.89
Benzine	0.69
Bromine	2.97
Carbolic acid	0.96
Carbon disulphide	1.26
Cotton-seed oil	0.93
Ether, sulphuric	0.72
Fluoric acid	1.50
Gasoline	0.70
Kerosene	0.80
Linseed oil	0.94
Mineral oil	0.92
Muriatic acid	1.20
Naphtha	0.76
Nitric Acid	1.50
Olive oil	0.92
Palm oil	0.97
Petroleum oil	0.82
Phosphoric acid	1.78
Rape oil	0.92
Sulphuric acid	1.84
Tar	1.00
Turpentine oil	0.87
Vinegar	1.08
Water	1.00
Water, sea	1.03
Whale oil	0.92

GASSES 32°F.

Air	1.000
Acetylene	0.920
Alcohol vapor	1.601
Ammonia	0.592
Carbon dioxide	1.520
Carbon monoxide	0.967
Chlorine	2.423
Ether vapor	2.586
Ethylene	0.967
Hydrofluoric acid	1.261
Hydrogen	0.069
Illuminating gas	0.400
Mercury vapor	6.940
Marsh gas	0.555
Nitrogen	0.971
Nitric oxide	1.039
Nitrous oxide	1.527
Oxygen	1.106
Sulphur dioxide	2.250
Water vapor	0.623

MISCELLANEOUS SOLIDS 62° F.

Asbestos	2.4
Asphaltum	1.4
Borax	1.8
Brick, common	1.8
Brick, fire	2.3
Brick, hard	2.0
Brick, pressed	2.2
Brickwork, in mortar	1.6
Brickwork, in cement	1.8
Cement, Portland (set)	3.1
Chalk	2.3
Charcoal	0.4
Coal, anthracite	1.5
Coal, bituminous	1.3
Concrete	2.2
Earth, dry	1.2
Earth, wet	1.7
Emery	4.0
Glass	2.6
Granite	2.7
Gypsum	2.4
Ice	0.9
Iron slag	2.7
Limestone	2.6
Marble	2.7
Masonry	2.4
Mica	2.8
Mortar	1.5
Phosphorus	1.8
Plaster of Paris	1.8
Quartz	2.6
Sand, dry	1.6
Sand, wet	2.0
Sandstone	2.3
Slate	2.8
Soapstone	2.7
Sulphur	2.0
Tar, bituminous	1.2
Tile	1.8
Tap rock	3.0

Specific gravity of **solids and liquids** is the ratio of their density to the density of water at a specified temperature.

Specific gravity of **gases** is the ratio of their density to the density of air at standard conditions of pressure and temperature.

To find the weight per cubic foot of a material, multiply the specific gravity by 62.36.

EXAMPLE: The weight of a cubic foot of gasoline 62.36 × 0.7 = 43.65 lbs.

VOLUME OF SHELLS AND HEADS

I.D. of Vessel in.	Cylindrical SHELL/LIN. FT.				2:1 ELLIP. HEAD*			
	Cu.Ft.	Gal.	Bbl.	Wt. of Water lb.	Cu.Ft.	Gal.	Bbl.	Wt. of Water lb.
12	0.8	5.9	0.14	49	0.1	0.98	0.02	8.17
14	1.1	8.0	0.19	67	0.2	1.55	0.04	12.98
16	1.4	10.4	0.25	87	0.3	2.32	0.06	19.37
18	1.8	13.2	0.31	110	0.4	3.30	0.08	27.58
20	2.2	16.3	0.39	136	0.6	4.53	0.11	37.83
22	2.6	19.7	0.47	165	0.8	6.03	0.14	50.35
24	3.1	23.5	0.56	196	1.0	7.83	0.19	65.37
26	3.7	27.6	0.66	230	1.3	9.96	0.24	83.11
28	4.3	32.0	0.76	267	1.7	12.44	0.30	103.8
30	4.9	36.7	0.87	306	2.0	15.30	0.36	127.7
32	5.6	41.8	0.99	349	2.5	18.57	0.44	155.0
34	6.3	47.2	1.12	394	3.0	22.27	0.53	185.9
36	7.1	52.9	1.26	441	3.5	26.47	0.63	220.1
38	7.9	58.9	1.40	492	4.2	31.09	0.74	259.5
40	8.7	65.3	1.55	545	4.8	36.27	0.86	302.6
42	9.6	72.0	1.71	601	5.6	41.98	1.00	350.4
48	12.6	94.0	2.24	784	8.4	62.67	1.49	523.0
54	15.9	119.0	2.83	993	11.9	89.23	2.12	744.6
60	19.6	146.9	3.50	1226	16.3	122.4	2.91	1021
66	23.8	177.7	4.23	1483	21.8	162.9	3.88	1360
72	28.3	211.5	5.04	1765	28.3	211.5	5.04	1765
78	33.2	248.2	5.91	2071	35.9	268.9	6.40	2244
84	38.5	287.9	6.85	2402	44.9	335.9	8.00	2802
90	44.2	330.5	7.87	2758	55.2	413.1	9.84	3447
96	50.3	376.0	8.95	3138	67.0	501.3	11.94	4184
102	56.7	424.4	10.11	3542	80.3	601.4	14.32	5018
108	63.6	475.9	11.33	3971	95.4	713.8	17.00	5957
114	70.9	530.2	12.62	4425	112.2	839.5	20.00	7006
120	78.5	587.5	13.99	4903	130.9	979.2	23.31	8171
126	86.6	647.7	15.42	5405	151.5	1134	27.00	9459
132	95.0	710.9	16.93	5932	174.2	1303	31.03	10876
138	103.9	777.0	18.50	6484	190.1	1489	35.46	12428
144	113.1	846.0	20.14	7060	226.2	1692	40.29	14120

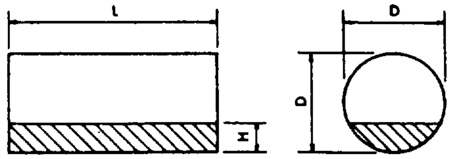
*Volume within the straight flange is not included

VOLUME OF SHELLS AND HEADS

I.D. of Vessel in.	ASME F & D. HEAD*				HEMIS. HEAD*			
	Cu.Ft.	Gal.	Bbl.	Wt. of Water lb.	Cu.Ft.	Gal.	Bbl.	Wt. of Water lb.
12	0.08	0.58	0.01	4.83	0.26	1.96	0.05	16.34
14	0.12	0.94	0.02	7.83	0.42	3.11	0.07	25.95
16	0.19	1.45	0.03	12.08	0.62	4.64	0.11	38.74
18	0.27	2.04	0.05	17.00	0.88	6.61	0.16	55.16
20	0.37	2.80	0.07	28.33	1.21	9.07	0.22	75.66
22	0.50	3.78	0.09	31.49	1.61	12.07	0.29	100.7
24	0.65	4.86	0.12	40.49	2.09	15.67	0.37	130.7
26	0.82	6.14	0.15	51.15	2.66	19.92	0.47	166.2
28	1.10	8.21	0.20	68.40	3.33	24.88	0.59	207.6
30	1.30	9.70	0.23	80.81	4.09	30.60	0.73	255.4
32	1.64	12.30	0.29	102.5	4.96	37.14	0.88	309.9
34	1.88	14.10	0.34	117.5	5.95	44.54	1.06	371.7
36	2.15	16.10	0.38	134.1	7.07	52.88	1.26	441.2
38	2.75	20.60	0.49	171.6	8.31	62.19	1.48	519.0
40	3.07	23.00	0.55	191.6	9.70	72.53	1.73	605.3
42	3.68	27.50	0.65	229.1	11.22	83.97	2.00	700.7
48	5.12	38.30	0.91	319.1	16.76	125.3	2.98	1046
54	7.30	54.60	1.30	454.9	23.86	178.5	4.25	1489
60	10.08	75.40	1.80	628.2	32.73	244.8	5.83	2043
66	13.54	101	2.41	843.9	43.56	325.8	7.76	2719
72	17.65	132	3.14	1100	56.55	423.0	10.07	3530
78	22.32	167	3.98	1391	71.90	537.8	12.80	4488
84	28.47	213	5.07	1775	89.80	671.7	16.00	5606
90	35.56	266	6.33	2216	110.4	826.2	19.67	6895
96	42.51	318	7.57	2649	134.0	1003	23.87	8368
102	52.14	390	9.29	3249	160.8	1203	28.63	10037
108	60.96	456	10.86	3799	190.9	1428	34.00	11914
114	73.66	551	13.12	4590	224.5	1679	39.98	14012
120	84.35	631	15.02	5257	261.8	1958	46.63	16343
126	97.32	728	17.33	6065	303.1	2267	53.98	18919
132	108.7	813	19.36	6773	348.5	2607	62.06	21752
138	127.0	950	22.62	7915	398.2	2978	70.91	24856
144	147.9	1106	26.33	9214	452.4	3384	80.57	28241

*Volume within the straight flange is not included

PARTIAL VOLUMES IN HORIZONTAL CYLINDERS



Partial volumes of horizontal cylinder equals total volume x coefficient (found from table below)

EXAMPLE

HORIZONTAL CYLINDER D = 10 ft., 0 in. H = 2.75 ft. L = 60 ft., 0 in.

TOTAL VOLUME: $0.7854 \times D^2 \times L$ Find the partial volume of the cylindrical shell

Total volume: $0.7854 \times 10^2 \times 60 = 4712.4$ cu. ft.

Coefficient from table:
H/D = 2.75/10 = .275

Refer to the first two figures (.27) in the column headed (H/D) in the table below. Proceed to the right until the coefficient is found under the column headed (5) which is the third digit. The coefficient of 0.275 is found to be .223507

Total volume x coefficient = partial volume
4712.4 x .223507 = 1053.25 cu. ft.
cu. ft. multiplied by 7.480519 = U. S. Gallon
cu. ft. multiplied by 28.317016 = Liter

COEFFICIENTS

H/D	0	1	2	3	4	5	6	7	8	9
.00	.000000	.000053	.000151	.000279	.000429	.000600	.000788	.000992	.001212	.001445
.01	.001692	.001952	.002223	.002507	.002800	.003104	.003419	.003743	.004077	.004421
.02	.004773	.005134	.005503	.005881	.006267	.006660	.007061	.007470	.007886	.008310
.03	.008742	.009179	.009625	.010076	.010534	.010999	.011470	.011947	.012432	.012920
.04	.013417	.013919	.014427	.014940	.015459	.015985	.016515	.017052	.017593	.018141
.05	.018692	.019250	.019813	.020382	.020955	.021533	.022115	.022703	.023296	.023894
.06	.024496	.025103	.025715	.026331	.026952	.027578	.028208	.028842	.029481	.030124
.07	.030772	.031424	.032081	.032740	.033405	.034073	.034747	.035423	.036104	.036789
.08	.037478	.038171	.038867	.039569	.040273	.040981	.041694	.042410	.043129	.043852
.09	.044579	.045310	.046043	.046782	.047523	.048268	.049017	.049768	.050524	.051283
.10	.052044	.052810	.053579	.054351	.055126	.055905	.056688	.057474	.058262	.059054
.11	.059850	.060648	.061449	.062253	.063062	.063872	.064687	.065503	.066323	.067147
.12	.067972	.068802	.069633	.070469	.071307	.072147	.072991	.073836	.074686	.075539
.13	.076393	.077251	.078112	.078975	.079841	.080709	.081581	.082456	.083332	.084212
.14	.085094	.085979	.086866	.087756	.088650	.089545	.090443	.091343	.092246	.093153
.15	.094061	.094971	.095884	.096799	.097717	.098638	.099560	.100486	.101414	.102343
.16	.103275	.104211	.105147	.106087	.107029	.107973	.108920	.109869	.110820	.111773
.17	.112728	.113686	.114646	.115607	.116572	.117538	.118506	.119477	.120450	.121425
.18	.122403	.123382	.124364	.125347	.126333	.127321	.128310	.129302	.130296	.131292
.19	.132290	.133291	.134292	.135296	.136302	.137310	.138320	.139332	.140345	.141361
.20	.142378	.143398	.144419	.145443	.146468	.147494	.148524	.149554	.150587	.151622
.21	.152659	.153697	.154737	.155779	.156822	.157867	.158915	.159963	.161013	.162066
.22	.163120	.164176	.165233	.166292	.167353	.168416	.169480	.170546	.171613	.172682
.23	.173753	.174825	.175900	.176976	.178053	179131	.180212	.181294	.182378	.183463
.24	.184550	.185639	.186729	.187820	.188912	190007	.191102	.192200	.193299	.194400
.25	.195501	.196604	.197709	.198814	.199922	.201031	.202141	.203253	.204368	.205483
.26	.206600	.207718	.208837	.209957	.211079	.212202	.213326	.214453	.215580	.216708
.27	.217839	.218970	.220102	.221235	.222371	.223507	.224645	.225783	.226924	.228065
.28	.229209	.230352	.231498	.232644	.233791	.234941	.236091	.237242	.238395	.239548
.29	.240703	.241859	.243016	.244173	.245333	.246494	.247655	.248819	.249983	.251148
.30	.252315	.253483	.254652	.255822	.256992	.258165	.259338	.260512	.261687	.262863
.31	.264039	.265218	.266397	.267578	.268760	.269942	.271126	.272310	.273495	.274682

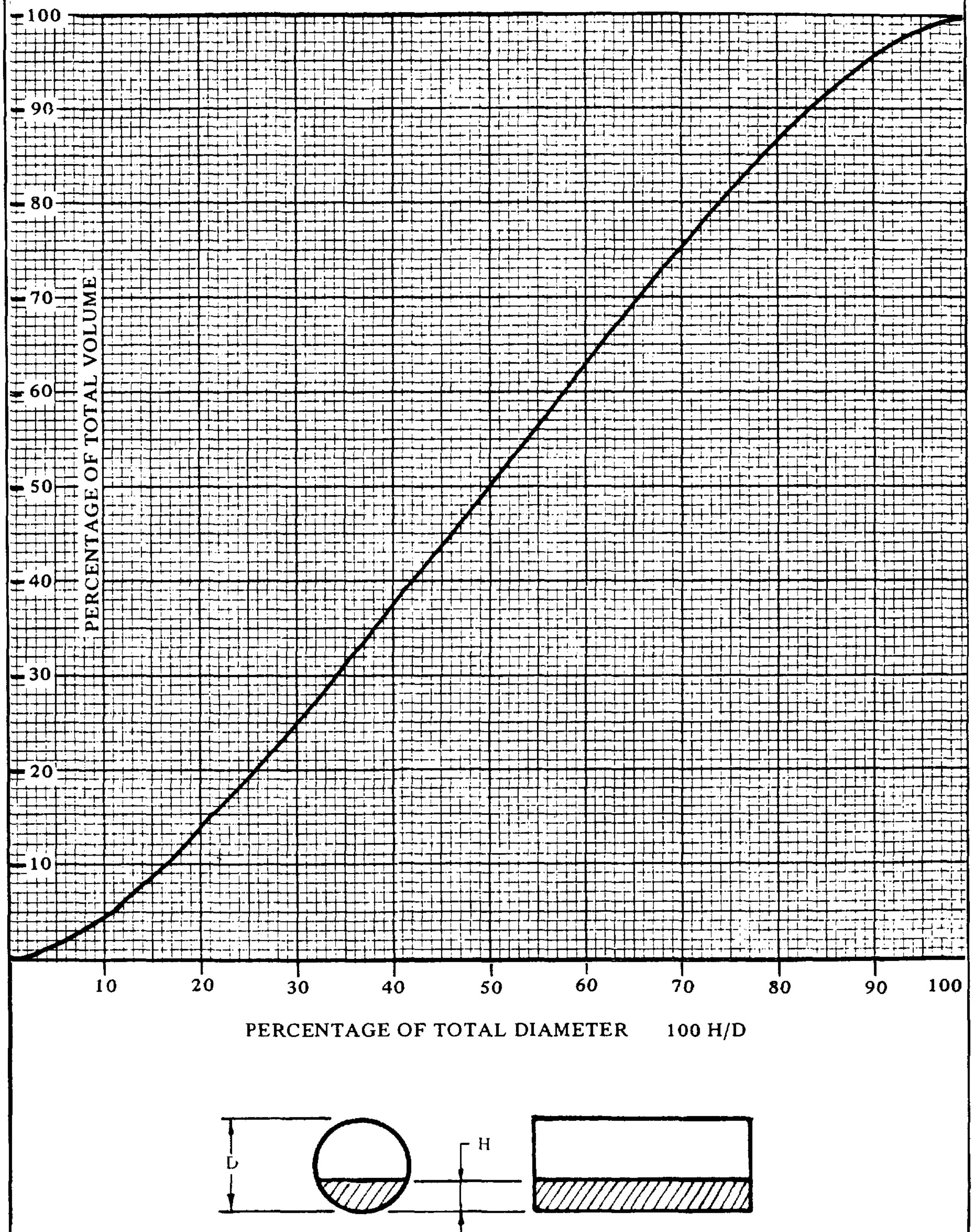
PARTIAL VOLUMES IN HORIZONTAL CYLINDERS COEFFICIENTS (Cont.)

H/D	0	1	2	3	4	5	6	7	8	9
.32	.275869	.277058	.278247	.279437	.280627	.281820	.283013	.284207	.285401	.286598
.33	.287795	.288992	.290191	.291390	.292591	.293793	.294995	.296198	.297403	.298605
.34	.299814	.301021	.302228	.303438	.304646	.305857	.307068	.308280	.309492	.310705
.35	.311918	.313134	.314350	.315566	.316783	.318001	.319219	.320439	.321660	.322881
.36	.324104	.325326	.326550	.327774	.328999	.330225	.331451	.332678	.333905	.335134
.37	.336363	.337593	.338823	.340054	.341286	.342519	.343751	.344985	.346220	.347455
.38	.348690	.349926	.351164	.352402	.353640	.354879	.356119	.357359	.358599	.359840
.39	.361082	.362325	.363568	.364811	.366056	.367300	.368545	.369790	.371036	.372282
.40	.373530	.374778	.376026	.377275	.378524	.379774	.381024	.382274	.383526	.384778
.41	.386030	.387283	.388537	.389790	.391044	.392298	.393553	.394808	.396063	.397320
.42	.398577	.399834	.401092	.402350	.403608	.404866	.406125	.407384	.408645	.409904
.43	.411165	.412426	.413687	.414949	.416211	.417473	.418736	.419998	.421261	.422525
.44	.423788	.425052	.426316	.427582	.428846	.430112	.431378	.432645	.433911	.435178
.45	.436445	.437712	.438979	.440246	.441514	.442782	.444050	.445318	.446587	.447857
.46	.449125	.450394	.451663	.452932	.454201	.455472	.456741	.458012	.459283	.460554
.47	.461825	.463096	.464367	.465638	.466910	.468182	.469453	.470725	.471997	.473269
.48	.474541	.475814	.477086	.478358	.479631	.480903	.482176	.483449	.484722	.485995
.49	.487269	.488542	.489814	.491087	.492360	.493633	.494906	.496179	.497452	.498726
.50	.500000	.501274	.502548	.503821	.505094	.506367	.507640	.508913	.510186	.511458
.51	.512731	.514005	.515278	.516551	.517824	.519097	.520369	.521642	.522914	.524186
.52	.525459	.526731	.528003	.529275	.530547	.531818	.533090	.534362	.535633	.536904
.53	.538175	.539446	.540717	.541988	.543259	.544528	.545799	.547068	.548337	.549606
.54	.550875	.552143	.553413	.554682	.555950	.557218	.558486	.559754	.561021	.562288
.55	.563555	.564822	.566089	.567355	.568622	.569888	.571154	.572418	.573684	.574948
.56	.576212	.577475	.578739	.580002	.581264	.582527	.583789	.585051	.586313	.587574
.57	.588835	.590096	.591355	.592616	.593875	.595134	.596392	.597650	.598908	.600166
.58	.601423	.602680	.603937	.605192	.606447	.607702	.608956	.610210	.611463	.612717
.59	.613970	.615222	.616474	.617726	.618976	.620226	.621476	.622725	.623974	.625222
.60	.626470	.627718	.628964	.630210	.631455	.632700	.633944	.635189	.636432	.637675
.61	.638918	.640160	.641401	.642641	.643881	.645121	.646360	.647598	.648836	.650074
.62	.651310	.652545	.653780	.655015	.656249	.657481	.658714	.659946	.661177	.662407
.63	.663637	.664866	.666095	.667322	.668549	.669775	.671001	.672226	.673450	.674674
.64	.675896	.677119	.678340	.679561	.680781	.681999	.683217	.684434	.685650	.686866
.65	.688082	.689295	.690508	.691720	.692932	.694143	.695354	.696562	.697772	.698979
.66	.700186	.701392	.702597	.703802	.705005	.706207	.707409	.708610	.709809	.711008
.67	.712205	.713402	.714599	.715793	.716987	.718180	.719373	.720563	.721753	.722942
.68	.724131	.725318	.726505	.727690	.728874	.730058	.731240	.732422	.733603	.734782
.69	.735961	.737137	.738313	.739488	.740662	.741835	.743008	.744178	.745348	.746517
.70	.747685	.748852	.750017	.751181	.752345	.753506	.754667	.755827	.756984	.758141
.71	.759297	.760452	.761605	.762758	.763909	.765059	.766209	.767356	.768502	.769648
.72	.770791	.771935	.773076	.774217	.775355	.776493	.777629	.778765	.779898	.781030
.73	.782161	.783292	.784420	.785547	.786674	.787798	.788921	.790043	.791163	.792282
.74	.793400	.794517	.795632	.796747	.797859	.798969	.800078	.801186	.802291	.803396
.75	.804499	.805600	.806701	.807800	.808898	.809993	.811088	.812180	.813271	.814361
.76	.815450	.816537	.817622	.818706	.819788	.820869	.821947	.823024	.824100	.825175
.77	.826247	.827318	.828387	.829454	.830520	.831584	.832647	.833708	.834767	.835824
.78	.836880	.837934	.838987	.840037	.841085	.842133	.843178	.844221	.845263	.846303
.79	.847341	.848378	.849413	.850446	.851476	.852506	.853532	.854557	.855581	.856602
.80	.857622	.858639	.859655	.860668	.861680	.862690	.863698	.864704	.865708	.866709
.81	.867710	.868708	.869704	.870698	.871690	.872679	.873667	.874653	.875636	.876618
.82	.877597	.878575	.879550	.880523	.881494	.882462	.883428	.884393	.885354	.886314
.83	.887272	.888227	.889180	.890131	.891080	.892027	.892971	.893913	.894853	.895789
.84	.896725	.897657	.898586	.899514	.900440	.901362	.902283	.903201	.904116	.905029
.85	.905939	.906847	.907754	.908657	.909557	.910455	.911350	.912244	.913134	.914021
.86	.914906	.915788	.916668	.917544	.918419	.919291	.920159	.921025	.921888	.922749
.87	.923607	.924461	.925314	.926164	.927009	.927853	.928693	.929531	.930367	.931198
.88	.932028	.932853	.933677	.934497	.935313	.936128	.936938	.937747	.938551	.939352
.89	.940150	.940946	.941738	.942526	.943312	.944095	.944874	.945649	.946421	.947190
.90	.947956	.948717	.949476	.950232	.950983	.951732	.952477	.953218	.953957	.954690
.91	.955421	.956148	.956871	.957590	.958306	.959019	.959727	.960431	.961133	.961829
.92	.962522	.963211	.963896	.964577	.965253	.965927	.966595	.967260	.967919	.968576

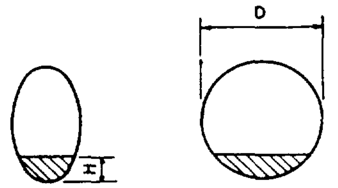
PARTIAL VOLUMES IN HORIZONTAL CYLINDERS COEFFICIENTS (cont.)

H/D	0	1	2	3	4	5	6	7	8	9
.93	.969228	.969876	.970519	.971158	.971792	.972422	.973048	.973669	.974285	.974897
.94	.975504	.976106	.976704	.977297	.977885	.978467	.979045	.979618	.980187	.980750
.95	.981308	.981859	.982407	.982948	.983485	.984015	.984541	.985060	.985573	.986081
.96	.986583	.987080	.987568	.988053	.988530	.989001	.989466	.989924	.990375	.990821
.97	.991258	.991690	.992114	.992530	.992939	.993340	.993733	.994119	.994497	.994866
.98	.995227	.995579	.995923	.996257	.996581	.996896	.997200	.997493	.997777	.998048
.99	.998308	.998555	.998788	.999008	.999212	.999400	.999571	.999721	.999849	.999947
1.00	1.000000									

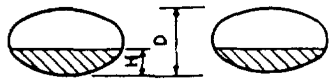
PARTIAL VOLUMES IN HORIZONTAL CYLINDERS
(Percentage Relation of Diameter to Volume)



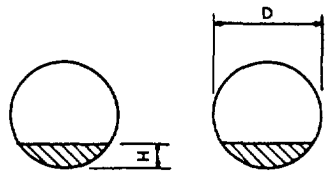
PARTIAL VOLUMES IN ELLIPSOIDAL HEADS AND SPHERES



Two 2:1 Ellipsoidal Heads on Horizontal Vessel
Total Volume: $0.2618\ D^3$



Two 2:1 Ellipsoidal Heads on Vertical Vessel
Total Volume = $2.0944\ D^3$



Sphere
Total Volume = $0.5236\ D^3$

Partial volumes of ellipsoidal heads and spheres = total volume x coefficient (in the table below)

EXAMPLE:
D = 10 ft., 0 in.   H = 2.75 ft.

Find the partial volume of (2) 2:1 ellipsoidal heads of a horizontal vessel. The total volume of the two heads:

$0.2618 \times D^3 = 0.2618 \times 10^3 = 261.8$ cu. ft.

Coefficient from table

H/D = 2.75/10 = .275

Refer to the first two figures (.27) in the column headed (H/D) in the table below. Proceed to the right until the coefficient is found under the column headed (5) which is the third digit. The coefficient of .275 is found to be .185281

Total volume x coefficient = partial volume
261.8 x .185281 = 48.506 cu. ft.
cu. ft. multiplied by 7.480519 = U.S. Gallon
cu. ft. multiplied by 28.317016 = Liter

COEFFICIENTS

H/D	0	1	2	3	4	5	6	7	8	9
.00	.000000	.000003	.000012	.000027	.000048	.000075	.000108	.000146	.000191	.000242
.01	.000298	.000360	.000429	.000503	.000583	.000668	.000760	.000857	.000960	.001069
.02	.001184	.001304	.001431	.001563	.001700	.001844	.001993	.002148	.002308	.002474
.03	.002646	.002823	.003006	.003195	.003389	.003589	.003795	.004006	.004222	.004444
.04	.004672	.004905	.005144	.005388	.005638	.005893	.006153	.006419	.006691	.006968
.05	.007250	.007538	.007831	.008129	.008433	.008742	.009057	.009377	.009702	.010032
.06	.010368	.010709	.011055	.011407	.011764	.012126	.012493	.012865	.013243	.013626
.07	.014014	.014407	.014806	.015209	.015618	.016031	.016450	.016874	.017303	.017737
.08	.018176	.018620	.019069	.019523	.019983	.020447	.020916	.021390	.021869	.022353
.09	.022842	.023336	.023835	.024338	.024847	.025360	.025879	.026402	.026930	.027462
.10	.028000	.028542	.029090	.029642	.030198	.030760	.031326	.031897	.032473	.033053
.11	.033638	.034228	.034822	.035421	.036025	.036633	.037246	.037864	.038486	.039113
.12	.039744	.040380	.041020	.041665	.042315	.042969	.043627	.044290	.044958	.045630
.13	.046306	.046987	.047672	.048362	.049056	.049754	.050457	.051164	.051876	.052592
.14	.053312	.054037	.054765	.055499	.056236	.056978	.057724	.058474	.059228	.059987
.15	.060750	.061517	.062288	.063064	.063843	.064627	.065415	.066207	.067003	.067804
.16	.068608	.069416	.070229	.071046	.071866	.072691	.073519	.074352	.075189	.076029
.17	.076874	.077723	.078575	.079432	.080292	.081156	.082024	.082897	.083772	.084652
.18	.085536	.086424	.087315	.088210	.089109	.090012	.090918	.091829	.092743	.093660
.19	.094582	.095507	.096436	.097369	.098305	.099245	.100189	.101136	.102087	.103042
.20	.104000	.104962	.105927	.106896	.107869	.108845	.109824	.110808	.111794	.112784
.21	.113778	.114775	.115776	.116780	.117787	.118798	.119813	.120830	.121852	.122876
.22	.123904	.124935	.125970	.127008	.128049	.129094	.130142	.131193	.132247	.133305
.23	.134366	.135430	.136498	.137568	.138642	.139719	.140799	.141883	.142969	.144059
.24	.145152	.146248	.147347	.148449	.149554	.150663	.151774	.152889	.154006	.155127

PARTIAL VOLUMES IN ELLIPSOIDAL HEADS AND SPHERES COEFFICIENTS (Cont.)

H/D	0	1	2	3	4	5	6	7	8	9
.25	.156250	.157376	.158506	.159638	.160774	.161912	.163054	.164198	.165345	.166495
.26	.167648	.168804	.169963	.171124	.172289	.173456	.174626	.175799	.176974	.178153
.27	.179334	.180518	.181705	.182894	.184086	.185281	.186479	.187679	.188882	.190088
.28	.191296	.192507	.193720	.194937	.196155	.197377	.198601	.199827	.201056	.202288
.29	.203522	.204759	.205998	.207239	.208484	.209730	.210979	.212231	.213485	.214741
.30	.216000	.217261	.218526	.219792	.221060	.222331	.223604	.224879	.226157	.227437
.31	.228718	.230003	.231289	.232578	.233870	.235163	.236459	.237757	.239057	.240359
.32	.241664	.242971	.244280	.245590	.246904	.248219	.249536	.250855	.252177	.253500
.33	.254826	.256154	.257483	.258815	.260149	.261484	.262822	.264161	.265503	.266847
.34	.268192	.269539	.270889	.272240	.273593	.274948	.276305	.277663	.279024	.280386
.35	.281750	.283116	.284484	.285853	.287224	.288597	.289972	.291348	.292727	.294106
.36	.295488	.296871	.298256	.299643	.201031	.302421	.303812	.305205	.306600	.307996
.37	.309394	.310793	.312194	.313597	.315001	.316406	.317813	.319222	.320632	.322043
.38	.323456	.324870	.326286	.327703	.329122	.330542	.331963	.333386	.334810	.336235
.39	.337662	.339090	.340519	.341950	.343382	.344815	.346250	.347685	.349122	.350561
.40	.352000	.353441	.354882	.356325	.357769	.359215	.360661	.362109	.363557	.365007
.41	.366458	.367910	.369363	.370817	.372272	.373728	.375185	.376644	.378103	.379563
.42	.381024	.382486	.383949	.395413	.386878	.388344	.389810	.391278	.392746	.394216
.43	.395686	.397157	.398629	.400102	.401575	.403049	.404524	.406000	.407477	.408954
.44	.410432	.411911	.413390	.414870	.416351	.417833	.419315	.420798	.422281	.423765
.45	.425250	.426735	.428221	.429708	.431195	.432682	.434170	.435659	.437148	.438638
.46	.440128	.441619	.443110	.444601	.446093	.447586	.449079	.450572	.452066	.453560
.47	.455054	.456549	.458044	.459539	.461035	.462531	.464028	.465524	.467021	.468519
.48	.470016	.471514	.473012	.474510	.476008	.477507	.479005	.480504	.482003	.483503
.49	.485002	.486501	.488001	.489501	.491000	.492500	.494000	.495500	.497000	.498500
.50	.500000	.501500	.503000	.504500	.506000	.507500	.509000	.510499	.511999	.513499
.51	.514998	.516497	.517997	.519496	.520995	.522493	.523992	.525490	.526988	.528486
.52	.529984	.531481	.532979	.534476	.535972	.537469	.538965	.540461	.541956	.543451
.53	.544946	.546440	.547934	.549428	.550921	.552414	.553907	.555399	.556890	.558381
.54	.559872	.561362	.562852	.564341	.565830	.567318	.568805	.570292	.571779	.573265
.55	.574750	.576235	.577719	.579202	.580685	.582167	.583649	.585130	.586610	.588089
.56	.589568	.591046	.592523	.594000	.595476	.596951	.598425	.599898	.601371	.602843
.57	.604314	.605784	.607254	.608722	.610190	.611656	.613122	.614587	.616051	.617514
.58	.618976	.620437	.621897	.623356	.624815	.626272	.627728	.629183	.630637	.632090
.59	.633542	.634993	.636443	.637891	.639339	.640785	.642231	.643675	.645118	.646559
.60	.648000	.649439	.650878	.652315	.653750	.655185	.656618	.658050	.659481	.660910
.61	.662338	.663765	.665190	.666614	.668037	.669458	.670878	.672297	.673714	.675130
.62	.676544	.677957	.679368	.680778	.682187	.683594	.684999	.686403	.687806	.689207
.63	.690606	.692004	.693400	.694795	.696188	.697579	.698969	.700357	.701744	.703129
.64	.704512	.705894	.707273	.708652	.710028	.711403	.712776	.714147	.715516	.716884
.65	.718250	.719614	.720976	.722337	.723695	.725052	.726407	.727760	.729111	.730461
.66	.731808	.733153	.734497	.735839	.737178	.738516	.739851	.741185	.742517	.743846
.67	.745174	.746500	.747823	.749145	.750464	.751781	.753096	.754410	.755720	.757029
.68	.758336	.759641	.760943	.762243	.763541	.764837	.766130	.767422	.768711	.769997
.69	.771282	.772563	.773843	.775121	.776396	.777669	778940	.780208	.781474	.782739
.70	.784000	.785259	.786515	.787769	.789021	.790270	.791516	.792761	.794002	.795241
.71	796478	.797712	.798944	.800173	.801399	.802623	.803845	.805063	.806280	.807493
.72	.808704	.809912	.811118	.812321	.813521	.814719	.815914	.817106	.818295	.819482
.73	.820666	.821847	.823026	.824201	.825374	.826544	.827711	.828876	.830037	.831196
.74	.832352	.833505	.834655	.835802	.836946	.838088	.839226	.840362	.841494	.842624
.75	.843750	.844873	.845994	.847111	.848226	.849337	.850446	.851551	.852653	.853752
.76	.854848	.855941	.857031	.858117	.859201	.860281	.861358	.862432	.863502	.864570
.77	.865634	.866695	.867753	.868807	.869858	.870906	.871951	.872992	.874030	.875065
.78	.876096	.877124	.878148	.879170	.880187	.881202	.882213	.883220	.884224	.885225
.79	.886222	.887216	.888206	.889192	.890176	.891155	.892131	.893104	.894073	.895038
.80	.896000	.896958	.897913	.898864	.899811	.900755	.901695	.902631	.903564	.904493
.81	.905418	.906340	.907257	.908171	.909082	.909988	.910891	.911790	.912685	.913576
.82	.914464	.915348	.916228	.917103	.917976	.918844	.919708	.920568	.921425	.922277
.83	.923126	.923971	.924811	.925648	.926481	.927309	.928134	.928954	.929771	.930584
.84	.931392	.932196	.932997	.933793	.934585	.935373	.936157	.936936	.937712	.938483

PARTIAL VOLUMES IN ELLIPSOIDAL HEADS AND SPHERES COEFFICIENTS (Cont.)

H/D	0	1	2	3	4	5	6	7	8	9
.85	.939250	.940013	.940772	.941526	.942276	.943022	.943764	.944501	.945235	.945963
.86	.946688	.947408	.948124	.948836	.949543	.950246	.950944	.951638	.952328	.953013
.87	.953694	.954370	.955042	.955710	.956373	.957031	.957685	.958335	.958980	.959620
.88	.960256	.960887	.961514	.962136	.962754	.963367	.963975	.964579	.965178	.965772
.89	.966362	.966947	.967527	.968103	.968674	.969240	.969802	.970358	.970910	.971458
.90	972000	.972538	.973070	.973598	.974121	.974640	.975153	.975662	.976165	.976664
.91	.977158	.977647	.978131	.978610	.979084	.979553	.980017	.980477	.980931	.981380
.92	.981824	.982263	.982697	.983126	.983550	.983969	.984382	.984791	.985194	.985593
.93	.985986	.986374	.986757	.987135	.987507	.987874	.988236	.988593	.988945	.989291
.94	.989632	.989968	.990298	.990623	.990943	.991258	.991567	.991871	.992169	.992462
.95	.992750	.993032	.993309	.993581	.993847	.994107	.994362	.994612	.994856	.995095
.96	.995328	.995556	.995778	.995994	.996205	.996411	.996611	.996805	.996994	.997177
.97	.997354	.997526	.997692	.997852	.998007	.998156	.998300	.998437	.998569	.998696
.98	.998816	.998931	.999040	.999143	.999240	.999332	.999417	.999497	.999571	.999640
.99	.999702	.999758	.999809	.999854	.999892	.999925	.999952	.999973	.999988	.999997
1.00	1.000000									

AREA OF SURFACES

(In Square Feet)

* The area of straight flanges is not included in the figures of the table.

Outside Diameter of Vessel D inches	Cylindrical Shell per Lineal Foot (π x D)	2:1 Ellipsoidal Head* (1.09 x D^2)	ASME* Flanged and Dished Head (0.918 x D^2)	Hemispherical Head* (1.5708 x D^2)	Flat Head* (0.7854 x D^2)
12	3.14	1.09	0.92	1.57	0.79
14	3.66	1.48	1.25	2.14	1.07
16	4.19	1.94	1.64	2.79	1.40
18	4.71	2.45	2.07	3.53	1.77
20	5.23	3.02	2.56	4.36	2.18
22	5.76	3.66	3.10	5.28	2.64
24	6.28	4.36	3.68	6.28	3.14
26	6.81	5.12	4.32	7.08	3.69
28	7.32	5.92	5.00	8.55	4.28
30	7.85	6.81	5.76	9.82	4.91
32	8.37	7.76	6.53	11.17	5.58
34	8.90	8.75	7.39	12.11	6.31
36	9.43	9.82	8.29	14.14	7.07
38	9.94	10.93	9.21	15.75	7.88
40	10.47	12.11	10.20	17.44	8.72
42	11.00	13.35	11.25	19.23	9.62
48	12.57	17.47	14.70	25.13	12.57
54	14.14	22.09	18.60	31.81	15.90
60	15.71	27.30	23.60	39.27	19.64
66	17.28	33.10	27.80	47.52	23.76
72	18.85	39.20	33.00	56.55	28.27
78	20.42	46.00	38.85	66.37	33.18
84	21.99	53.40	45.00	76.97	38.49
90	23.56	61.20	51.60	88.37	44.16
96	25.20	69.80	58.90	100.54	50.27
102	26.70	78.80	66.25	113.43	56.25
108	28.27	88.25	74.35	127.25	63.62
114	29.85	98.25	83.00	141.78	70.88
120	31.50	109.00	92.00	157.08	78.87
126	32.99	120.11	100.85	173.20	86.59
132	34.56	132.00	111.50	190.09	95.03
138	36.20	144.00	121.50	207.76	102.00
144	37.70	157.00	132.20	226.22	113.50

DECIMALS OF AN INCH

WITH MILLIMETER EQUIVALENTS

	Decimal	Millimeter		Decimal	Millimeter		Decimal	Millimeter		Decimal	Millimeter
1/32	.03125	.794	9/32	.28125	7.144	17/32	.53125	13.494	25/32	.78125	19.844
1/16	.0625	1.587	5/16	.3125	7.937	9/16	.5625	14.287	13/16	.8125	20.637
3/32	.09375	2.381	11/32	.34375	8.731	19/32	.59375	15.081	27/32	.84375	21.431
1/8	.125	3.175	3/8	.375	9.525	5/8	.625	15.875	7/8	.875	22.225
5/32	.15625	3.969	13/32	.40625	10.319	21/32	.65625	16.669	29/32	.90625	23.019
3/16	.1875	4.762	7/16	.4375	11.113	11/16	.6875	17.462	15/16	.9375	23.812
7/32	.21875	5.556	15/32	.46875	11.906	23/32	.71875	18.256	31/32	.96875	24.606
1/4	.25	6.350	1/2	.5	12.700	3/4	.75	19.050	1	1.	25.400

DECIMALS OF A FOOT

	INCHES											
In.	0	1	2	3	4	5	6	7	8	9	10	11
0	.0000	.0833	.1667	.2500	.3333	.4167	.5000	.5833	.6667	.7500	.8333	.9167
1/16	.0052	.0885	.1719	.2552	.3385	.4219	.5052	.5885	.6719	.7552	.8385	.9219
1/8	.0104	.0937	.1771	.2604	.3437	.4271	.5104	.5937	.6771	.7604	.8437	.9271
3/16	.0156	.0989	.1823	.2656	.3489	.4323	.5156	.5989	.6823	.7656	.8489	.9323
1/4	.0208	.1041	.1875	.2708	.3541	.4375	.5208	.6041	.6875	.7708	.8541	.9375
5/16	.0260	.1093	.1927	.2760	.3593	.4427	.5260	.6093	.6927	.7760	.8593	.9427
3/8	.0313	.1146	.1980	.2813	.3646	.4480	.5313	.6146	.6980	.7813	.8646	.9480
7/16	.0365	.1198	.2032	.2865	.3698	4532	.5365	.6198	.7032	.7865	.8698	.9532
1/2	.0417	.1250	.2084	.2917	.3750	.4584	.5417	.6250	.7084	.7917	.8750	.9584
9/16	.0469	.1302	.2136	.2969	.3802	.4636	.5469	.6302	.7136	.7969	.8802	.9336
5/8	.0521	.1354	.2188	.3021	.3854	.4688	.5521	.6354	.7188	.8021	.8854	.9688
11/16	.0573	.1406	.2240	.3073	.3906	.4740	.5573	.6406	.7240	.8073	.8906	.9740
3/4	.0625	.1458	.2292	.3125	.3958	.4792	.5625	.6458	.7292	.8125	.8958	.9792
13/16	.0677	.1510	.2344	.3177	.4010	.4844	.5677	.6510	.7344	.8177	.9010	.9844
7/8	.0729	.1562	.2396	.3229	.4062	.4896	.5729	.6562	.7396	.8229	.9062	.9896
15/16	.0781	.1614	.2448	.3281	.4114	.4948	.5781	.6614	.7448	.8281	.9114	.9948

METRIC SYSTEM OF MEASUREMENT

This system has the advantage that it is a coherent system. Each quantity has only one unit and all base units are related to each other. The fractions and multiples of the units are made in the decimal system.

UNITS OF METRIC MEASURES

	unit	symbol	equivalent of
Length	meter	m	39.37 in
Area	meter^2	m^2	1.196 sq.yard
Volume	meter^3	m^3	1.310 cu.yard
Weight /mass/	gram	g	0.035 oz
Time	second	s	second
Temperature	degree Celsius	°C	0°C = 32°F 100°C = + 212°F

MULTIPLES AND FRACTIONS OF UNITS

Symbol	Prefix	Unit Multiplied by	Name
μ	mikro	10^{-6}	millionth
m	milli	10^{-3}	thousendth
c	centi	10^{-2}	hundredth
d	deci	10^{-1}	tenth
D	deka	10	ten
h	hekto	10^2	hundred
k	kilo	10^3	thousand
M	mega	10^6	million

EXAMPLE: Unit of weight is gram; _1000_ gram is one _kilo_gram, 1 kg

1,000m = 1 kilometer, km

MULTIPLES OF UNIT

MEASURES OF LENGTH
UNIT: METER, m

FRACTIONS OF UNIT

*1 decimeter, dm = 0.1m
1 centimeter, cm = 0.01 m
1 millimeter, mm = 0.001 m

*not used in practice

METRIC SYSTEM OF MEASUREMENT

MULTIPLES OF UNIT

1,000,000 m^2 = 1 sq. kilometer, km^2
10,000 m^2 = 1 sq. hectare, ha
100 m^2 = 1 sq. are, a *

MEASURES OF AREA
UNIT: SQUARE METER, m^2

FRACTIONS OF UNIT

*1 sq. decimeter, dm^2 = 0.01m^2
1 sq. centimeter, cm^2 = 0.0001m^2
1 sq. millimeter, mm^2 = 0.000,001m^2

*not used in practice

MULTIPLES OF UNIT

not used in practice

MEASURES OF VOLUME
UNIT: CUBIC METER, m^3

FRACTIONS OF UNIT

1 hectoliter, hl = 0.1m^3
1 liter, l = 0.001m^3
1 cu. centimeter = 0.000,001m^3
1 cu. millimeter = 0.000,000,001m^3

MULTIPLES OF UNIT

1,000,000 g = 1 ton, t
100,000 g = 1 quintal, q
1,000 g = 1 kilogram, kg
10 g = 1 dekagram, dg

MEASURES OF WEIGHT
UNIT: GRAM, *g*

FRACTIONS OF UNIT

centigram, cg = 0.01 g
milligram, mg = 0.001 g

METRIC SYSTEM OF MEASUREMENT

MEASURES OF LENGTH

	km	m	dm	cm	mm	μ	mμ
1 km	1	10^{3}	10^{4}	10^{5}	10^{6}	10^{9}	10^{12}
1 m	10^{-3}	1	10	10^{2}	10^{3}	10^{6}	10^{9}
1 dm*	10^{-4}	10^{-1}	1	10	10^{2}	10^{5}	10^{8}
1 cm	10^{-5}	10^{-2}	10^{-1}	1	10	10^{4}	10^{7}
1 mm	10^{-6}	10^{-3}	10^{-2}	10^{-1}	1	10^{3}	10^{6}
1 μ	10^{-9}	10^{-6}	10^{-5}	10^{-4}	10^{-3}	1	10^{3}
1 mμ	10^{-12}	10^{-9}	10^{-8}	10^{-7}	10^{-6}	10^{-3}	1

MEASURES OF AREA

	km^2	ha	a	m^2	dm^2	cm^2	mm^2
1 km^2	1	10^{2}	10^{4}	10^{6}	10^{8}	10^{10}	10^{12}
1 ha	10^{-2}	1	10^{2}	10^{4}	10^{6}	10^{8}	10^{10}
1 a	10^{-4}	10^{-2}	1	10^{2}	10^{4}	10^{6}	10^{8}
1 m^2	10^{-6}	10^{-4}	10^{-2}	1	10^{2}	10^{4}	10^{6}
1 dm^2	10^{-8}	10^{-6}	10^{-4}	10^{-2}	1	10^{2}	10^{4}
1 cm^2	10^{-10}	10^{-8}	10^{-6}	10^{-4}	10^{-2}	1	10^{2}
1 mm^2	10^{-12}	10^{-10}	10^{-8}	10^{-6}	10^{-4}	10^{-2}	1

MEASURES OF VOLUME

	m^3	hl	l	dm^3	cm^3	mm^3
1 m^3	1	10	10^{3}	10^{3}	10^{6}	10^{9}
1 hl	10^{-1}	1	10^{2}	10^{2}	10^{5}	10^{8}
1 l	10^{-3}	10^{-2}	1	1	10^{3}	10^{6}
1 dm^3	10^{-3}	10^{-2}	1	1	10^{3}	10^{6}
1 cm^3	10^{-6}	10^{-5}	10^{-3}	10^{-3}	1	10^{3}
1 mm^3	10^{-9}	10^{-8}	10^{-6}	10^{-6}	10^{-3}	1

MEASURES OF WEIGHT

	t	q	kg	dg	g	cg	mg
1 t	1	10	10^{3}	10^{5}	10^{6}	10^{8}	10^{9}
1 q	10^{-1}	1	10^{2}	10^{4}	10^{5}	10^{7}	10^{8}
1 kg	10^{-3}	10^{-2}	1	10^{2}	10^{3}	10^{5}	10^{6}
1 dg	10^{-5}	10^{-4}	10^{-2}	1	10	10^{3}	10^{4}
1 g	10^{-6}	10^{-5}	10^{-3}	10^{-1}	1	10^{2}	10^{3}
1 cg	10^{-8}	10^{-7}	10^{-5}	10^{-3}	10^{-2}	1	10
1 mg	10^{-9}	10^{-8}	10^{-6}	10^{-4}	10^{-3}	10^{-1}	1

EXAMPLE CALCULATION

Weight of the water in a cylindrical vessel of 2,000 mm inside diameter and 10,000 mm length: $3.1416 \times 1{,}000^2 \times 10{,}000 = 31{,}416{,}000{,}000$ mm^3

31,416 liter, 1

31.416 cu. meter, m

31416 kilogram, kg

(The weight of one liter of pure water at the maximum density (4°C) equals one kilogram.)

METRIC SYSTEM OF MEASUREMENT

RECOMMENDED PRESSURE VESSEL DIAMETERS

Diameter in inches	Diameter in millimeters	Diameter in inches	Diameter in millimeters
24-30	630	66-72	1,600
36	800	78-90	2,000
42-48	1,000	96-120	2,500
54-60	1,250	126-156	3,150

RECOMMENDED TANK DIAMETERS

Diameters in API feet	Diameters in meters	Diameters in API feet	Diameters in meters
10	3.15	70-80	20.00
15	4.00	90-100	25.00
20	5.00	120	31.50
25	6.30	140-163	40.00
30	8.00	180-200	50.00
35-40	10.00	220-240	63.00
45-50	12.50	260-300	80.00
60	16.00		

The recommended diameters are based on a geometric progression, called Renard Series (R10) of Preferred Numbers.*

Dimensions on drawings shall be expressed in millimeters. The symbol for millimeters, *mm* (no period) need not be shown on the drawings. However, the following note shall be shown on the darawings: ALL DIMENSIONS ARE IN MILLIMETERS.

Dimensions above 5 digits in millimeters may be expressed in meters(e.g. 110.75 m)

Scales of Metric Drawings: enlarging the object, 2, 5, 10, 20 times reducing the object in proportion of 1:2.5, 1:5, 1:10, 1:20, 1:50, 1:100, 1:200, 1:500, 1:1000

*Reference: *Making it with Metric*, The National Board of Boiler and Pressure Vessel Inspectors.

CONVERSION TABLE – LENGTH
INCHES TO MILLIMETERS
(1 Inch = 25.4 Millimeters)

IN.	0	1/16	1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16
0	0.0	1.6	3.2	4.8	6.4	7.9	9.5	11.1	12.7	14.3	15.9	17.5	19.1	20.6	22.2	23.8
1	25.4	27.0	28.6	30.2	31.8	33.3	34.9	36.5	38.1	39.7	41.3	42.9	44.5	46.0	47.6	49.2
2	50.8	52.4	54.0	55.6	57.2	58.7	60.3	61.9	63.5	65.1	66.7	68.3	69.9	71.4	73.0	74.6
3	76.2	77.8	79.4	81.0	82.6	84.1	85.7	87.3	88.9	90.5	92.1	93.7	95.3	96.8	98.4	100.0
4	101.6	103.2	104.8	106.4	108.0	109.5	111.1	112.7	114.3	115.9	117.5	119.1	120.7	122.2	123.8	125.4
5	127.0	128.6	130.2	131.8	133.4	134.9	136.5	138.1	139.7	141.3	142.9	144.5	146.1	147.6	149.2	150.8
6	152.4	154.0	155.6	157.2	158.8	160.3	161.9	163.5	165.1	166.7	168.3	169.9	171.5	173.0	174.6	176.2
7	177.8	179.4	181.0	182.6	184.2	185.7	187.3	188.9	190.5	192.1	193.7	195.3	196.9	198.4	200.0	201.6
8	203.2	204.8	206.4	208.0	209.6	211.1	212.7	214.3	215.9	217.5	219.1	220.7	222.3	223.8	225.4	227.0
9	228.6	230.2	231.8	233.4	235.0	236.5	238.1	239.7	241.3	242.9	244.5	246.1	247.7	249.2	250.8	252.4
10	254.0	255.6	257.2	258.8	260.4	261.9	263.5	265.1	266.7	268.3	269.9	271.5	273.1	274.6	276.2	277.8
11	279.4	281.0	282.6	284.2	285.8	287.3	288.9	290.5	292.1	293.7	295.3	296.9	298.5	300.0	301.6	303.2
12	304.8	306.4	308.0	309.6	311.2	312.7	314.3	315.9	317.5	319.1	320.7	322.3	323.9	325.4	327.0	328.6
13	330.2	331.8	333.4	335.0	336.6	338.1	339.7	341.3	342.9	344.5	346.1	347.7	349.3	350.8	352.4	354.0
14	355.6	357.2	358.8	360.4	362.0	363.5	365.1	366.7	368.3	369.9	371.5	373.1	374.7	376.2	377.8	379.4
15	381.0	382.6	384.2	385.8	387.4	388.9	390.5	392.1	393.7	395.3	396.9	398.5	400.1	401.6	403.2	404.8
16	406.4	408.0	409.6	411.2	412.8	414.3	415.9	417.5	419.1	420.7	422.3	423.9	425.5	427.0	428.6	430.2
17	431.8	433.4	435.0	436.6	438.2	439.7	441.3	442.9	444.5	446.1	447.7	449.3	450.9	452.4	454.0	455.6
18	457.2	458.8	460.4	462.0	463.6	465.1	466.7	468.3	469.9	471.5	473.1	474.7	476.3	477.8	479.4	481.0
19	482.6	484.2	485.8	487.4	489.0	490.5	492.1	493.7	495.3	496.9	498.5	500.1	501.7	503.2	504.8	506.4
20	508.0	509.6	511.2	512.8	514.4	515.9	517.5	519.1	520.7	522.3	523.9	525.5	527.1	528.6	530.2	531.8
21	533.4	535.0	536.6	538.2	539.8	541.3	542.9	544.5	546.1	547.7	549.3	550.9	552.5	554.0	555.6	557.2
22	558.8	560.4	562.0	563.6	565.2	566.7	568.3	569.9	571.5	573.1	574.7	576.3	577.9	579.4	581.0	582.6
23	584.2	585.8	587.4	589.0	590.6	592.1	593.7	595.3	596.9	598.5	600.1	601.7	603.3	604.8	606.4	608.0
24	609.6	611.2	612.8	614.4	616.0	617.5	619.1	620.7	622.3	623.9	625.5	627.1	628.7	630.2	631.8	633.4

INCHES TO MILLIMETERS (con't.)

IN.	0	1/16	1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16
25	635.0	636.6	638.2	639.8	641.4	642.9	644.5	646.1	647.7	649.3	650.9	652.5	654.1	655.6	657.2	658.8
26	660.4	662.0	663.6	665.2	666.8	668.3	669.9	671.5	673.1	674.7	676.3	677.9	679.5	681.0	682.6	684.2
27	685.8	687.4	689.0	690.6	692.2	693.7	695.3	696.9	698.5	700.1	701.7	703.3	704.9	706.4	708.0	709.6
28	711.2	712.8	714.4	716.0	717.6	719.1	720.7	722.3	723.9	725.5	727.1	728.7	730.3	731.8	733.4	735.0
29	736.6	738.2	739.8	714.4	743.0	744.5	746.1	747.7	749.3	750.9	752.5	754.1	755.7	757.2	758.8	760.4
30	762.0	763.6	765.2	766.8	768.4	769.9	771.5	773.1	774.7	776.3	777.9	779.5	781.1	782.6	784.2	785.8
31	787.4	789.0	790.6	792.2	793.8	795.3	796.9	798.5	800.1	801.7	803.3	804.9	806.5	808.0	809.6	811.2
32	812.8	814.4	816.0	817.6	819.2	820.7	822.3	823.9	825.5	827.1	828.7	830.3	831.9	833.4	835.0	836.6
33	838.2	839.8	841.4	843.0	844.6	846.1	847.7	849.3	850.9	852.5	854.1	855.7	857.3	858.8	860.4	862.0
34	863.6	865.2	866.8	868.4	870.0	871.5	873.1	874.7	876.3	877.9	879.5	881.1	882.7	884.2	885.8	887.4
35	889.0	890.6	892.2	893.8	895.4	896.9	898.5	900.1	901.7	903.3	904.9	906.5	908.1	909.6	911.2	912.8
36	914.4	916.0	917.6	919.2	920.8	922.3	923.9	925.5	927.1	928.7	930.3	931.9	933.5	935.0	936.6	938.2
37	939.8	941.4	943.0	944.6	946.2	947.7	949.3	950.9	952.5	954.1	955.7	957.3	958.9	960.4	962.0	963.6
38	965.2	966.8	968.4	970.0	971.6	973.1	974.7	976.3	977.9	979.5	981.1	982.7	984.3	985.8	987.4	989.0
39	990.6	992.2	993.8	995.4	997.0	998.5	1000.1	1001.7	1003.3	1004.9	1006.5	1008.1	1009.7	1011.2	1012.8	1014.4
40	1016.0	1017.6	1019.2	1020.8	1022.4	1023.9	1025.5	1027.1	1028.7	1030.3	1031.9	1033.5	1035.1	1036.6	1038.2	1039.8
41	1041.4	1043.0	1044.6	1046.2	1047.8	1049.3	1050.9	1052.5	1054.1	1055.7	1057.3	1058.9	1060.5	1062.0	1063.6	1065.2
42	1066.8	1068.4	1070.0	1071.6	1073.2	1074.7	1076.3	1077.9	1079.5	1081.1	1082.7	1084.3	1085.9	1087.4	1089.0	1090.6
43	1092.2	1093.8	1095.4	1097.0	1098.6	1100.1	1101.7	1103.3	1104.9	1106.5	1108.1	1109.7	1111.3	1112.8	1114.4	1116.0
44	1117.6	1119.2	1120.8	1122.4	1124.0	1125.5	1127.1	1128.7	1130.3	1131.9	1133.5	1135.1	1136.7	1138.2	1139.8	1141.4
45	1143.0	1144.6	1146.2	1147.8	1149.4	1150.9	1152.5	1154.1	1155.7	1157.3	1158.9	1160.5	1162.1	1163.6	1165.2	1166.8
46	1168.4	1170.0	1171.6	1173.2	1174.8	1176.3	1177.9	1179.5	1181.1	1182.7	1184.3	1185.9	1187.5	1189.0	1190.6	1192.2
47	1193.8	1195.4	1197.0	1198.6	1200.2	1201.7	1203.3	1204.9	1206.5	1208.1	1209.7	1211.3	1212.9	1214.4	1216.0	1217.6
48	1219.2	1220.8	1222.4	1224.0	1225.6	1227.1	1228.7	1230.3	1231.9	1233.5	1235.1	1236.7	1238.3	1239.8	1241.4	1243.0
49	1244.6	1246.2	1247.8	1249.4	1251.0	1252.5	1254.1	1255.7	1257.3	1258.9	1260.5	1262.1	1263.7	1265.2	1266.8	1268.4
50	1270.0	1271.6	1273.2	1274.8	1276.4	1277.9	1279.5	1281.1	1282.7	1284.3	1285.9	1287.5	1289.1	1290.6	1292.2	1293.8

CONVERSION TABLE – LENGTH
MILLIMETERS TO INCHES
(1 Millimeter = 0.0394 Inch)

Millimeters	0	1	2	3	4	5	6	7	8	9	Millimeters
0	0.00	0.039	0.079	0.118	0.157	0.197	0.236	0.276	0.315	0.354	0
10	0.39	0.43	0.47	0.51	0.55	0.59	0.63	0.67	0.71	0.75	10
20	0.79	0.83	0.87	0.91	0.94	0.98	1.02	1.06	1.10	1.14	20
30	1.18	1.22	1.26	1.30	1.34	1.38	1.42	1.46	1.50	1.54	30
40	1.57	1.61	1.65	1.69	1.73	1.77	1.81	1.85	1.89	1.93	40
50	1.97	2.01	2.05	2.09	2.13	2.17	2.20	2.24	2.28	2.32	50
60	2.36	2.40	2.44	2.48	2.52	2.56	2.60	2.64	2.68	2.72	60
70	2.76	2.80	2.83	2.87	2.91	2.95	2.99	3.03	3.07	3.11	70
80	3.15	3.19	3.23	3.27	3.31	3.35	3.39	3.43	3.46	3.50	80
90	3.54	3.58	3.62	3.66	3.70	3.74	3.78	3.82	3.86	3.90	90
100	3.94	3.98	4.02	4.06	4.09	4.13	4.17	4.21	4.25	4.29	100
110	4.33	4.37	4.41	4.45	4.49	4.53	4.57	4.61	4.65	4.69	110
120	4.72	4.76	4.80	4.84	4.88	4.92	4.96	5.00	5.04	5.08	120
130	5.12	5.16	5.20	5.24	5.28	5.31	5.35	5.39	5.43	5.47	130
140	5.51	5.55	5.59	5.63	5.67	5.71	5.75	5.79	5.83	5.87	140
150	5.91	5.94	5.98	6.02	6.06	6.10	6.14	6.18	6.22	6.26	150
160	6.30	6.34	6.38	6.42	6.46	6.50	6.54	6.57	6.61	6.65	160
170	6.69	6.73	6.77	6.81	6.85	6.89	6.93	6.97	7.01	7.05	170
180	7.09	7.13	7.17	7.20	7.24	7.28	7.32	7.36	7.40	7.44	180
190	7.48	7.52	7.56	7.60	7.64	7.68	7.72	7.76	7.80	7.83	190
200	7.87	7.91	7.95	7.99	8.03	8.07	8.11	8.15	8.19	8.23	200
210	8.27	8.31	8.35	8.39	8.43	8.46	8.50	8.54	8.58	8.62	210
220	8.66	8.70	8.74	8.78	8.82	8.86	8.90	8.94	8.98	9.02	220
230	9.06	9.09	9.13	9.17	9.21	9.25	9.29	9.33	9.37	9.41	230
240	9.45	9.49	9.53	9.57	9.61	9.65	9.69	9.72	9.76	9.80	240
250	9.84	9.88	9.92	9.96	10.00	10.04	10.08	10.12	10.16	10.20	250
260	10.24	10.28	10.31	10.35	10.39	10.43	10.47	10.51	10.55	10.59	260
270	10.63	10.67	10.71	10.75	10.79	10.83	10.87	10.91	10.94	10.98	270
280	11.02	11.06	11.10	11.14	11.18	11.22	11.26	11.30	11.34	11.38	280
290	11.42	11.46	11.50	11.54	11.57	11.61	11.65	11.69	11.73	11.77	290

MILLIMETERS TO INCHES (con't.)

Millimeters	0	1	2	3	4	5	6	7	8	9	Millimeters
300	11.81	11.85	11.89	11.93	11.97	12.01	12.05	12.09	12.13	12.17	300
310	12.20	12.24	12.28	12.32	12.36	12.40	12.44	12.48	12.52	12.56	310
320	12.60	12.64	12.68	12.72	12.76	12.80	12.83	12.87	12.91	12.95	320
330	12.99	13.03	13.07	13.11	13.15	13.19	13.23	13.27	13.31	13.35	330
340	13.39	13.43	13.46	13.50	13.54	13.58	13.62	13.66	13.70	13.74	340
350	13.78	13.82	13.86	13.90	13.94	13.98	14.02	14.06	14.09	14.13	350
360	14.17	14.21	14.25	14.29	14.33	14.37	14.41	14.45	14.49	14.53	360
370	14.57	14.61	14.65	14.69	14.72	14.76	14.80	14.84	14.88	14.92	370
380	14.96	15.00	15.04	15.08	15.12	15.16	15.20	15.24	15.28	15.31	380
390	15.35	15.39	15.43	15.47	15.51	15.55	15.59	15.63	15.67	15.71	390
400	15.75	15.79	15.83	15.87	15.91	15.94	15.98	16.02	16.06	16.10	400
410	16.14	16.18	16.22	16.26	16.30	16.34	16.38	16.42	16.46	16.50	410
420	16.54	16.57	16.61	16.65	16.69	16.73	16.77	16.81	16.85	16.89	420
430	16.93	16.97	17.01	17.05	17.09	17.13	17.17	17.20	17.24	17.28	430
440	17.32	17.36	17.40	17.44	17.48	17.52	17.56	17.60	17.64	17.68	440
450	17.72	17.76	17.80	17.83	17.87	17.91	17.95	17.99	18.03	18.07	450
460	18.11	18.15	18.19	18.23	18.27	18.31	18.35	18.39	18.43	18.46	460
470	18.50	18.54	18.58	18.62	18.66	18.70	18.74	18.78	18.82	18.86	470
480	18.90	18.94	18.98	19.02	19.06	19.09	19.13	19.17	19.21	19.25	480
490	19.29	19.33	19.37	19.41	19.45	19.49	19.53	19.57	19.61	19.65	490
500	19.69	19.72	19.76	19.80	19.84	19.88	19.92	19.96	20.00	20.04	500
510	20.08	20.12	20.16	20.20	20.24	20.28	20.31	20.35	20.39	20.43	510
520	20.47	20.51	20.55	20.59	20.63	20.67	20.71	20.75	20.79	20.83	520
530	20.87	20.91	20.94	20.98	21.02	21.06	21.10	21.14	21.18	21.22	530
540	21.26	21.30	21.34	21.38	21.42	21.46	21.50	21.54	21.58	21.61	540
550	21.65	21.69	21.73	21.77	21.81	21.85	21.89	21.93	21.97	22.01	550
560	22.05	22.09	22.13	22.17	22.20	22.24	22.28	22.32	22.36	22.40	560
570	22.44	22.48	22.52	22.56	22.60	22.64	22.68	22.72	22.76	22.80	570
580	22.83	22.87	22.91	22.95	22.99	23.03	23.07	23.11	23.15	23.19	580
590	23.23	23.27	23.31	23.35	23.39	23.43	23.46	23.50	23.54	23.58	590

MILLIMETERS TO INCHES (con't.)

Millimeters	0	1	2	3	4	5	6	7	8	9	Millimeters
600	23.62	23.66	23.70	23.74	23.78	23.82	23.86	23.90	23.94	23.98	600
610	24.02	24.06	24.09	24.13	24.17	24.21	24.25	24.29	24.33	24.37	610
620	24.41	24.45	24.49	24.53	24.57	24.61	24.65	24.68	24.72	24.76	620
630	24.80	24.84	24.88	24.92	24.96	25.00	25.04	25.08	25.12	25.16	630
640	25.20	25.24	25.28	25.31	25.35	25.39	25.43	25.47	25.51	25.55	640
650	25.59	25.63	25.67	25.71	25.75	25.79	25.83	25.87	25.91	25.94	650
660	25.98	26.02	26.06	26.10	26.14	26.18	26.22	26.26	26.30	26.34	660
670	26.38	26.42	26.46	26.50	26.54	26.57	26.61	26.65	26.69	26.73	670
680	26.77	26.81	26.85	26.89	26.93	26.97	27.01	27.05	27.09	27.13	680
690	27.17	27.20	27.24	27.28	27.32	27.36	27.40	27.44	27.48	27.52	690
700	27.56	27.60	27.64	27.68	27.72	27.76	27.80	27.83	27.87	27.91	700
710	27.95	27.99	28.03	28.07	28.11	28.15	28.19	28.23	28.27	28.31	710
720	28.35	28.39	28.43	28.46	28.50	28.54	28.58	28.62	28.66	28.70	720
730	28.74	28.78	28.82	28.86	28.90	28.94	28.98	29.02	29.06	29.09	730
740	29.13	29.17	29.21	29.25	29.29	29.33	29.37	29.41	29.45	29.49	740
750	29.53	29.57	29.61	29.65	29.68	29.72	29.76	29.80	29.84	29.88	750
760	29.92	29.96	30.00	30.04	30.08	30.12	30.16	30.20	30.24	30.28	760
770	30.31	30.35	30.39	30.43	30.47	30.51	30.55	30.59	30.63	30.67	770
780	30.71	30.75	30.79	30.83	30.87	30.91	30.94	30.98	31.02	31.06	780
790	31.10	31.14	31.18	31.22	31.26	31.30	31.34	31.38	31.42	31.46	790
800	31.50	31.54	31.57	31.61	31.65	31.69	31.73	31.77	31.81	31.85	800
810	31.89	31.93	31.97	32.01	32.05	32.09	32.13	32.17	32.20	32.24	810
820	32.28	32.32	32.36	32.40	32.44	32.48	32.52	32.56	32.60	32.64	820
830	32.68	32.72	32.76	32.80	32.83	32.87	32.91	32.95	32.99	33.03	830
840	33.07	33.11	33.15	33.19	33.23	33.27	33.31	33.35	33.39	33.43	840
850	33.46	33.50	33.54	33.58	33.62	33.66	33.70	33.74	33.78	33.82	850
860	33.86	33.90	33.94	33.98	34.02	34.06	34.09	34.13	34.17	34.21	860
870	34.25	34.29	34.33	34.37	34.41	34.45	34.49	34.53	34.57	34.61	870
880	34.65	34.68	34.72	34.76	34.80	34.84	34.88	34.92	34.96	35.00	880
890	35.04	35.08	35.12	35.16	35.20	35.24	35.28	35.31	35.35	35.39	890

MILLIMETERS TO INCHES (con't.)

Millimeters	0	1	2	3	4	5	6	7	8	9	Millimeters
900	35.43	35.47	35.51	35.55	35.59	35.63	35.67	35.71	35.75	35.79	900
910	35.83	35.87	35.91	35.94	35.98	36.02	36.06	36.10	36.14	36.18	910
920	36.22	36.26	36.30	36.34	36.38	36.42	36.46	36.50	36.54	36.57	920
930	36.61	36.65	36.69	36.73	36.77	36.81	36.85	36.89	36.93	36.97	930
940	37.01	37.05	37.09	37.13	37.17	37.20	37.24	37.28	37.32	37.36	940
950	37.40	37.44	37.48	37.52	37.56	37.60	37.64	37.68	37.72	37.76	950
960	37.80	37.83	37.87	37.91	37.95	37.99	38.03	38.07	38.11	38.15	960
970	38.19	38.23	38.27	38.31	38.35	38.39	38.43	38.46	38.50	38.54	970
980	38.58	38.62	38.66	38.70	38.74	38.78	38.82	38.86	38.90	38.94	980
990	38.98	39.02	39.06	39.09	39.13	39.17	39.21	39.25	39.29	39.33	990
1000	39.37	39.41	39.45	39.49	39.53	39.57	39.61	39.65	39.68	39.72	1000

SQUARE FEET TO SQUARE METERS

1 Sq. Ft. = 0.0929034 Square Meters

Square Feet	0	1	2	3	4	5	6	7	8	9
0	0.000	0.093	0.186	0.279	0.372	0.465	0.557	0.650	0.743	0.836
10	0.929	1.022	1.115	1.208	1.301	1.394	1.486	1.579	1.672	1.765
20	1.858	1.951	2.044	2.137	2.230	2.323	2.415	2.508	2.601	2.694
30	2.787	2.880	2.973	3.066	3.159	3.252	3.345	3.437	3.530	3.623
40	3.716	3.809	3.902	3.995	4.088	4.181	4.274	4.366	4.459	4.552
50	4.645	4.738	4.831	4.924	5.017	5.110	5.203	5.295	5.388	5.481
60	5.574	5.667	5.760	5.853	5.946	6.039	6.132	6.225	6.317	6.410
70	6.503	6.596	6.689	6.782	6.875	6.968	7.061	7.154	7.246	7.339
80	7.432	7.525	7.618	7.711	7.804	7.897	7.990	8.083	8.175	8.268
90	8.361	8.454	8.547	8.640	8.733	8.826	8.919	9.012	9.105	9.197

SQUARE METERS TO SQUARE FEET

1 Sq. M = 10.76387 Square Feet

Square Meters	0	1	2	3	4	5	6	7	8	9
0	0.00	10.76	21.53	32.29	43.06	53.82	64.58	75.35	86.11	96.87
10	107.64	118.40	129.17	139.93	150.69	161.46	172.22	182.99	193.75	204.51
20	215.28	226.04	236.81	247.57	258.33	269.10	279.86	290.62	301.39	312.15
30	322.92	333.68	344.44	355.21	365.97	376.74	387.50	398.26	409.03	419.79
40	430.56	441.32	452.08	462.85	473.61	484.37	495.14	505.90	516.67	527.43
50	538.19	548.96	559.72	570.49	581.25	592.01	602.78	613.54	624.30	635.07
60	645.83	656.60	667.36	678.12	688.89	699.65	710.42	721.18	731.94	742.71
70	753.47	764.23	775.00	785.76	796.53	807.29	818.05	828.82	839.58	850.35
80	861.11	871.87	882.64	893.40	904.17	914.93	925.69	936.46	947.22	957.98
90	968.75	979.51	990.28	1001.04	1011.80	1022.57	1033.33	1044.10	1054.86	1065.62

CONVERSION TABLE – WEIGHTS

POUNDS TO KILOGRAMS
(1 pound = 0.4536 kilogram)

Pounds	0	1	2	3	4	5	6	7	8	9
0	0.00	0.45	0.91	1.36	1.81	2.27	2.72	3.18	3.63	4.08
10	4.54	4.99	5.44	5.90	6.35	6.80	7.26	7.71	8.16	8.62
20	9.07	9.53	9.98	10.43	10.89	11.34	11.79	12.25	12.70	13.15
30	13.61	14.06	14.52	14.97	15.42	15.88	16.33	16.78	17.24	17.69
40	18.14	18.60	19.05	19.50	19.96	20.41	20.87	21.32	21.77	22.23
50	22.68	23.13	23.59	24.04	24.49	24.95	25.40	25.86	26.31	26.76
60	27.22	27.67	28.12	28.58	29.03	29.48	29.94	30.39	30.84	31.30
70	31.75	32.21	32.66	33.11	33.57	34.02	34.47	34.93	35.38	35.83
80	36.29	36.74	37.20	37.65	38.10	38.56	39.01	39.46	39.92	40.37
90	40.82	41.28	41.73	42.18	42.64	43.09	43.55	44.00	44.45	44.91

KILOGRAMS TO POUNDS
(1 kilogram = 2.2046 pounds)

Kilograms	0	1	2	3	4	5	6	7	8	9
0	0.00	2.20	4.41	6.61	8.82	11.02	13.23	15.43	17.64	19.84
10	22.05	24.25	26.46	28.66	30.86	33.07	35.27	37.48	39.68	41.89
20	44.09	46.30	48.50	50.71	52.91	55.12	57.32	59.52	61.73	63.93
30	66.14	68.34	70.55	72.75	74.96	77.16	79.37	81.57	83.77	85.98
40	88.18	90.39	92.59	94.80	97.00	99.21	101.41	103.62	105.82	108.03
50	110.23	112.43	114.64	116.84	119.05	121.25	123.46	125.66	127.87	130.07
60	132.28	134.48	136.69	138.89	141.09	143.30	145.50	147.71	149.91	152.12
70	154.32	156.53	158.73	160.94	163.14	165.35	167.55	169.75	171.96	174.16
80	176.37	178.57	180.78	182.98	185.19	187.39	189.60	191.80	194.00	196.21
90	198.41	200.62	202.82	205.03	207.23	209.44	211.64	213.85	216.05	218.26

U. S. GALLONS TO LITERS

1 U. S. Gallon = 3.785329 Liter

Gallon	0	1	2	3	4	5	6	7	8	9
0	0	3.79	7.57	11.36	15.14	18.93	22.71	26.50	30.28	34.07
10	37.85	41.64	45.42	49.21	52.99	56.78	60.57	64.35	68.14	71.92
20	75.71	79.49	13.28	87.01	90.85	94.63	98.42	102.20	105.99	109.77
30	113.56	117.35	121.13	124.92	128.70	132.49	136.27	140.06	143.84	147.63
40	151.41	155.20	158.98	162.77	166.55	170.34	174.13	177.91	181.70	185.48
50	189.27	193.05	196.84	200.62	204.41	208.19	211.98	215.76	219.55	223.33
60	227.12	230.91	234.69	238.48	242.26	246.05	249.83	253.62	257.40	261.19
70	264.97	268.76	272.54	276.33	280.11	283.90	287.69	291.47	295.26	299.04
80	302.83	306.61	310.40	314.18	317.97	321.75	325.54	329.32	333.11	336.89
90	340.68	344.46	348.25	352.04	355.82	359.60	363.39	367.18	370.96	374.75

LITER TO U. S. GALLON

1 Liter = 0.264168 U. S. Gallon

Liter	0	1	2	3	4	5	6	7	8	9
0	0	0.26	0.53	0.79	1.06	1.32	1.59	1.85	2.11	2.38
10	2.64	2.91	3.17	3.43	3.70	3.96	4.23	4.49	4.76	5.02
20	5.28	5.55	5.81	6.08	6.34	6.60	6.87	7.13	6.60	7.66
30	7.93	8.19	8.45	8.72	8.98	9.25	9.51	9.77	10.04	10.30
40	10.57	10.83	11.10	11.36	11.62	11.89	12.15	12.42	12.68	12.94
50	13.21	13.47	13.74	14.00	14.27	14.53	14.79	15.06	15.32	15.59
60	15.85	16.11	16.38	16.64	16.91	17.17	17.44	17.70	17.96	18.23
70	18.49	18.76	19.02	19.28	19.55	19.81	20.08	20.34	20.61	20.87
80	21.13	21.40	21.66	21.93	22.19	22.45	22.72	22.98	23.25	23.51
90	23.78	24.04	24.30	24.57	24.83	25.10	25.36	25.62	25.89	26.15

CONVERSION TABLE – PRESSURE

POUNDS PER SQUARE INCH TO KILOGRAMS PER SQUARE CENTIMETER

(1 pound per square inch = .0703066 kilogram per square centimeter)

1 to 30		31 to 60		61 to 90		91 to 200		205 to 400		410 to 700		710 to 1000		1010 to 1500	
Lbs. Per Sq. In.	Kg. Per Sq. Cm.	Lbs. Per Sq. In.	Kg. Per Sq. Cm.	Lbs. Per Sq. In.	Kg. Per Sq. Cm.	Lbs. Per Sq. In.	Kg. Per Sq. Cm.	Lbs. Per Sq. In.	Kg. Per Sq. Cm.	Lbs. Per Sq. In.	Kg. Per Sq. Cm.	Lbs. Per Sq. In.	Kg. Per Sq. Cm.	Lbs. Per Sq. In.	Kg. Per Sq. Cm.
1	.07	31	2.18	61	4.29	91	6.40	205	14.41	410	28.83	710	49.92	1010	71.01
2	.14	32	2.25	62	4.36	92	6.47	210	14.76	420	29.53	720	50.62	1020	71.71
3	.21	33	2.32	63	4.43	93	6.54	215	15.12	430	30.23	730	51.32	1030	72.42
4	.28	34	2.39	64	4.50	94	6.61	220	15.47	440	30.93	740	52.03	1040	73.12
5	.35	35	2.46	65	4.57	95	6.68	225	15.82	450	31.64	750	52.73	1050	73.82
6	.42	36	2.53	66	4.64	96	6.75	230	16.17	460	32.34	760	53.43	1060	74.52
7	.49	37	2.60	67	4.71	97	6.82	235	16.52	470	33.04	770	54.14	1070	75.23
8	.56	38	2.67	68	4.78	98	6.89	240	16.87	480	33.75	780	54.84	1080	75.93
9	.63	39	2.74	69	4.85	99	6.96	245	17.23	490	34.45	790	55.54	1090	76.63
10	.70	40	2.81	70	4.92	100	7.03	250	17.58	500	35.15	800	56.25	1100	77.34
11	.77	41	2.88	71	4.99	105	7.38	255	17.93	510	35.86	810	56.95	1120	78.74
12	.84	42	2.95	72	5.06	110	7.73	260	18.28	520	36.56	820	57.65	1140	80.15
13	.91	43	3.02	73	5.13	115	8.09	265	18.63	530	37.26	830	58.35	1160	81.56
14	.98	44	3.09	74	5.20	120	8.44	270	18.98	540	37.97	840	59.06	1180	82.96
15	1.05	45	3.16	75	5.27	125	8.79	275	19.33	550	38.67	850	59.76	1200	84.37
16	1.12	46	3.23	76	5.34	130	9.14	280	19.69	560	39.37	860	60.46	1220	85.77
17	1.20	47	3.30	77	5.41	135	9.49	285	20.04	570	40.07	870	61.17	1240	87.18
18	1.27	48	3.37	78	5.48	140	9.84	290	20.39	580	40.78	880	61.87	1260	88.59
19	1.34	49	3.45	79	5.55	145	10.19	295	20.74	590	41.48	890	62.57	1280	89.99
20	1.41	50	3.52	80	5.62	150	10.55	300	21.09	600	42.18	900	63.28	1300	91.40
21	1.48	51	3.59	81	5.69	155	10.90	310	21.80	610	42.89	910	63.98	1320	92.80
22	1.55	52	3.66	82	5.77	160	11.25	320	22.50	620	43.59	920	64.68	1340	94.21
23	1.62	53	3.73	83	5.84	165	11.60	330	23.20	630	44.29	930	65.39	1360	95.62
24	1.69	54	3.80	84	5.91	170	11.95	340	23.90	640	45.00	940	66.09	1380	97.02
25	1.76	55	3.87	85	5.98	175	12.30	350	24.61	650	45.70	950	66.79	1400	98.43
26	1.83	56	3.94	86	6.05	180	12.66	360	25.31	660	46.40	960	67.49	1420	99.84
27	1.90	57	4.01	87	6.12	185	13.01	370	26.01	670	47.11	970	68.20	1440	101.24
28	1.97	58	4.08	88	6.19	190	13.36	380	26.72	680	47.81	980	68.90	1460	102.65
29	2.04	59	4.15	89	6.26	195	13.71	390	27.42	690	48.51	990	69.60	1480	104.05
30	2.11	60	4.22	90	6.33	200	14.06	400	28.12	700	49.21	1000	70.31	1500	105.46

CONVERSION TABLE – DEGREE

DEGREES TO RADIANS

$$1\ \text{DEGREE} = \frac{\pi}{180} = 0.01745\ \text{RADIANS}$$

Degrees						Minutes		Seconds	
0°	0.00000 00	60°	1.04719 76	120°	2.09439 51	0	0.00000 00	0	0.00000 00
1	0.01745 33	61	1.06465 08	121	2.11184 84	1	0.00029 09	1	0.00000 48
2	0.03490 66	62	1.08210 41	122	2.12930 17	2	0.00058 18	2	0.00000 97
3	0.05235 99	63	1.09955 74	123	2.14675 50	3	0.00087 27	3	0.00001 45
4	0.06981 32	64	1.11701 07	124	2.16420 83	4	0.00116 36	4	0.00001 94
5	0.08726 65	65	1.13446 40	125	2.18166 16	5	0.00145 44	5	0.00002 42
6	0.10471 98	66	1.15191 73	126	2.19911 49	6	0.00174 53	6	0.00002 91
7	0.12217 30	67	1.16937 06	127	2.21656 82	7	0.00203 62	7	0.00003 39
8	0.13962 63	68	1.18682 39	128	2.23402 14	8	0.00232 71	8	0.00003 88
9	0.15707 96	69	1.20427 72	129	2.25147 47	9	0.00261 80	9	0.00004 36
10	0.17453 29	70	1.22173 05	130	2.26892 80	10	0.00290 89	10	0.00004 85
11	0.19198 62	71	1.23918 38	131	2.28638 13	11	0.00319 98	11	0.00005 33
12	0.20943 95	72	1.25663 71	132	2.30383 46	12	0.00349 07	12	0.00005 82
13	0.22689 28	73	1.27409 04	133	2.32128 79	13	0.00378 15	13	0.00006 30
14	0.24434 61	74	1.29154 36	134	2.33874 12	14	0.00407 24	14	0.00006 79
15	0.26179 94	75	1.30899 69	135	2.35619 45	15	0.00436 33	15	0.00007 27
16	0.27925 27	76	1.32645 02	136	2.37364 78	16	0.00465 42	16	0.00007 76
17	0.29670 60	77	1.34390 35	137	2.39110 11	17	0.00494 51	17	0.00008 24
18	0.31415 93	78	1.36135 68	138	2.40855 44	18	0.00523 60	18	0.00008 73
19	0.33161 26	79	1.37881 01	139	2.42600 77	19	0.00552 69	19	0.00009 21
20	0.34906 59	80	1.39626 34	140	2.44346 10	20	0.00581 78	20	0.00009 70
21	0.36651 91	81	1.41371 67	141	2.46091 42	21	0.00610 87	21	0.00010 18
22	0.38397 24	82	1.43117 00	142	2.47836 75	22	0.00639 95	22	0.00010 67
23	0.40142 57	83	1.44862 33	143	2.49582 08	23	0.00669 04	23	0.00011 15
24	0.41887 90	84	1.46607 66	144	2.51327 41	24	0.00698 13	24	0.00011 64
25	0.43633 23	85	1.48352 99	145	2.53072 74	25	0.00727 22	25	0.00012 12
26	0.45378 56	86	1.50098 32	146	2.54818 07	26	0.00756 31	26	0.00012 61
27	0.47123 89	87	1.51843 64	147	2.56563 40	27	0.00785 40	27	0.00013 09
28	0.48869 22	88	1.53588 97	148	2.58308 73	28	0.00814 49	28	0.00013 57
29	0.50614 55	89	1.55334 30	149	2.60054 06	29	0.00843 58	29	0.00014 06
30	0.52359 88	90	1.57079 63	150	2.61799 39	30	0.00872 66	30	0.00014 54
31	0.54105 21	91	1.58824 96	151	2.63544 72	31	0.00901 75	31	0.00015 03
32	0.55850 54	92	1.60570 29	152	2.65290 05	32	0.00930 84	32	0.00015 51
33	0.57595 87	93	1.62315 62	153	2.67035 38	33	0.00959 93	33	0.00016 00
34	0.59341 19	94	1.64060 95	154	2.68780 70	34	0.00989 02	34	0.00016 48
35	0.61086 52	95	1.65806 28	155	2.70526 03	35	0.01018 11	35	0.00016 97
36	0.62831 85	96	1.67551 61	156	2.72271 36	36	0.01047 20	36	0.00017 45
37	0.64577 18	97	1.69296 94	157	2.74016 69	37	0.01076 29	37	0.00017 94
38	0.66322 51	98	1.71042 27	158	2.75762 02	38	0.01105 38	38	0.00018 42
39	0.68067 84	99	1.72787 60	159	2.77507 35	39	0.01134 46	39	0.00018 91
40	0.69813 17	100	1.74532 93	160	2.79252 68	40	0.01163 55	40	0.00019 39
41	0.71558 50	101	1.76278 25	161	2.80998 01	41	0.01192 64	41	0.00019 88
42	0.73303 83	102	1.78023 58	162	2.82743 34	42	0.01221 73	42	0.00020 36
43	0.75049 16	103	1.79768 91	163	2.84488 67	43	0.01250 82	43	0.00020 85
44	0.76794 49	104	1.81514 24	164	2.86234 00	44	0.01279 91	44	0.00021 33
45	0.78539 82	105	1.83259 57	165	2.87979 33	45	0.01309 00	45	0.00021 82
46	0.80285 15	106	1.85004 90	166	2.89724 66	46	0.01338 09	46	0.00022 30
47	0.82030 47	107	1.86750 23	167	2.91469 99	47	0.01367 17	47	0.00022 79
48	0.83775 80	108	1.88495 56	168	2.93215 31	48	0.01396 26	48	0.00023 27
49	0.85521 13	109	1.90240 89	169	2.94960 64	49	0.01425 35	49	0.00023 76
50	0.87266 46	110	1.91986 22	170	2.96705 97	50	0.01454 44	50	0.00024 24
51	0.89011 79	111	1.93731 55	171	2.98451 30	51	0.01483 53	51	0.00024 73
52	0.90757 12	112	1.95476 88	172	3.00196 63	52	0.01512 62	52	0.00025 21
53	0.92502 45	113	1.97222 21	173	3.01941 96	53	0.01541 71	53	0.00025 70
54	0.94247 78	114	1.98967 53	174	3.03687 29	54	0.01570 80	54	0.00026 18
55	0.95993 11	115	2.00712 86	175	3.05432 62	55	0.01599 89	55	0.00026 66
56	.097738 44	116	2.02458 19	176	3.07177 95	56	0.01628 97	56	0.00027 15
57	0.99483 77	117	2.04203 52	177	3.08923 28	57	0.01658 06	57	0.00027 63
58	1.01229 10	118	2.05948 85	178	3.10668 61	58	0.01687 15	58	0.00028 12
59	1.02974 43	119	2.07694 18	179	3.12413 94	59	0.01716 24	59	0.00028 60
60	1.04719 76	120	2.09439 51	180	3.14159 27	60	0.01745 33	60	0.00029 09

CONVERSION TABLE – DEGREE

RADIANS TO DEGREES

$$1 \text{ RADIAN} = \frac{180}{\pi} = 57.29578 \text{ DEGREES}$$

	Radians	Tenths	Hundredths	Thousandths	Ten-thousandths
1	57°17′44″.8	5°43′46″.5	0°34′22″.6	0° 3′26″.3	0° 0′20″.6
2	114°35′29″.6	11°27′33″.0	1° 8′45″.3	0° 6′52″.5	0° 0′41″.3
3	171°53′14″.4	17°11′19″.4	1°43′07″.9	0°10′18″.8	0° 1′01″.9
4	229°10′59″.2	22°55′05″.9	2°17′30″.6	0°13′45″.1	0° 1′22″.5
5	286°28′44″.0	28°38′52″.4	2°51′53″.2	0° 17′11″.3	0° 1′43″.1
6	343°46′28″.8	34°22′38″.9	3°26′15″.9	0°20′37″.6	0° 2′03″.8
7	401° 4′13″.6	40° 6′25″.4	4° 0′38″.5	0°24′03″.9	0° 2′24″.4
8	458°21′58″.4	45°50′11″.8	4°35′01″.2	0°27′30″.1	0° 2′45″.0
9	515°39′43″.3	51°33′58″.3	5° 9′23″.8	0°30′56″.4	0° 3′05″.6

EXAMPLES

1. Change 87° 26' 34" to radian
   Solution: From table on opposite page

87°	=	1.5184364	radians
26'	=	0.0075631	radians
34"	=	0.0001648	radians
87° 26' 34"	=	1.5261643	radians

2. Change 1.5262 radians to degrees
   Solution: From table above

1	radian	=	57° 17' 44.8"
0.5		=	28° 38' 52.4"
0.02		=	1° 8' 45.3"
0.006		=	0° 20' 37.6"
0.0002		=	0° 0' 41.3"
1.5262		=	86° 83' 221.4"
		=	87° 26' 41.4"

CONVERSION TABLE – DEGREE

MINUTES AND SECONDS TO DECIMALS OF A DEGREE				DECIMALS OF A DEGREE TO MINUTES AND SECONDS			
'	°	"	°	°	' and "	°	' and "
0	0.0000	0	0.00000	0.000	0' 0"	0.50	30' 0"
1	0167	1	028	001	0' 4"	51	30' 36"
2	0333	2	056	002	0' 7"	52	31' 12"
3	0500	3	083	003	0' 11"	53	31' 48"
4	0667	4	111	004	0' 14"	54	32' 24"
5	0.0833	5	0.00139	0.005	0' 18"	0.55	33' 0"
6	1000	6	167	006	0' 22"	56	33' 36"
7	1167	7	194	007	0' 25"	57	34' 12"
8	1333	8	222	008	0' 29"	58	34' 48"
9	1500	9	250	009	0' 32"	59	35' 24"
10	0.1667	10	0.00278	0.00	0' 0"	0.60	36' 0"
11	1833	11	306	01	0' 36"	61	36' 36"
12	2000	12	333	02	1' 12"	62	37' 12"
13	2167	13	361	03	1' 48"	63	37' 48"
14	2333	14	389	04	2' 24"	64	38' 24"
15	0.2500	15	0.00417	0.05	3' 0"	0.65	39' 0"
16	2667	16	444	06	3' 36"	66	39' 36"
17	2833	17	472	07	4' 12"	67	40' 12"
18	3000	18	500	08	4' 48"	68	40' 48"
19	3167	19	528	09	5' 24"	69	41' 24"
20	0.3333	20	0.00556	0.10	6' 0"	0.70	42' 0"
21	3500	21	583	11	6' 36"	71	42' 36"
22	3667	22	611	12	7' 12"	72	43' 12"
23	3833	23	639	13	7' 48"	73	43' 48"
24	4000	24	667	14	8' 24"	74	44' 24"
25	0.4167	25	0.00694	0.15	9' 0"	0.75	45' 0"
26	4333	26	722	16	9' 36"	76	45' 36"
27	4500	27	750	17	10' 12"	77	46' 12"
28	4667	28	778	18	10' 48"	78	46' 48"
29	4833	29	806	19	11' 24"	79	47' 24"
30	0.5000	30	0.00833	0.20	12' 0"	0.80	48' 0"
31	5167	31	861	21	12' 36"	81	48' 36"
32	5333	32	889	22	13' 12"	82	49' 12"
33	5500	33	917	23	13' 48"	83	49' 48"
34	5667	34	944	24	14' 24"	84	50' 24"
35	0.5833	35	0.00972	0.25	15' 0"	0.85	51' 0"
36	6000	36	01000	26	15' 36"	86	51' 36"
37	6167	37	028	27	16' 12"	87	52' 12"
38	6333	38	056	28	16' 48"	88	52' 48"
39	6500	39	083	29	17' 24"	89	53' 24"
40	0.6667	40	0.01111	0.30	18' 0"	0.90	54' 0"
41	6833	41	139	31	18' 36"	91	54' 36"
42	7000	42	167	32	19' 12"	92	55' 12"
43	7167	43	194	33	19' 48"	93	55' 48"
44	7333	44	222	34	20' 24"	94	56' 24"
45	0.7500	45	0.01250	0.35	21' 0"	0.95	57' 0"
46	7667	46	278	36	21' 36"	96	57' 36"
47	7833	47	306	37	22' 12"	97	58' 12"
48	8000	48	333	38	22' 48"	98	58' 48"
49	8167	49	361	39	23' 24"	99	59' 24"
50	0.8333	50	0.01389	0.40	24' 0"	1.00	60' 0"
51	8500	51	417	41	24' 36"	10	66' 0"
52	8667	52	444	42	25' 12"	20	72' 0"
53	8833	53	472	43	25' 48"	30	78' 0"
54	9000	54	500	44	26' 24"	40	84' 0"
55	0.9167	55	0.01528	0.45	27' 0"	1.50	90' 0"
56	9333	56	556	46	27' 36"	60	96' 0"
57	9500	57	583	47	28' 12"	70	102' 0"
58	9667	58	611	48	28' 48"	80	108' 0"
59	9833	59	639	49	29' 24"	90	114' 0"
60	1.000	60	0.01667	0.50	30' 0"	2.00	120' 0"
'	°	"	°	°	' and "	°	' and "

CONVERSION TABLE – TEMPERATURE

CENTIGRADE – FAHRENHEIT

Degrees Cent., $C^{o} = \frac{5}{9}(F^{o} + 40) - 40$ Degrees Fahr., $F^{o} = \frac{9}{5}(C^{o} + 40) - 40$

NOTE: The numbers in boldface refer to the temperature either in degrees, Centigrade or Fahrenheit which it is desired to convert into the other scale. If converting from Fahrenheit to Centigrade degrees, the equivalent temperature will be found in the left column; while if converting from degrees Centigrade to degrees Fahrenheit, the answer will be found in the column on the right.

Centigrade		Fahrenheit	Centigrade		Fahrenheit	Centigrade		Fahrenheit	Centigrade		Fahrenheit
−73.3	**−100**	−148.0	−15.6	**4**	39.2	−3.3	**26**	78.8	9.4	**49**	120.2
−67.8	**−90**	−130.0	−15.0	**5**	41.0	−2.8	**27**	80.6	10.0	**50**	122.0
−62.2	**−80**	−112.0	−14.4	**6**	42.8	−2.2	**28**	82.4	10.6	**51**	123.8
−59.5	**−75**	−103.0	−13.9	**7**	44.6	−1.7	**29**	84.2	11.1	**52**	125.6
−56.7	**−70**	−94.0	−13.3	**8**	46.4	−1.1	**30**	86.0	11.7	**53**	127.4
−53.9	**−65**	−85.0	−12.8	**9**	48.2	−0.6	**31**	87.8	12.2	**54**	129.2
−51.1	**−60**	−76.0	−12.2	**10**	50.0	0.0	**32**	89.6	12.8	**55**	131.0
−48.4	**−55**	−67.0	−11.7	**11**	51.8	0.6	**33**	91.4	13.3	**56**	132.8
−45.6	**−50**	−58.0	−11.1	**12**	53.6	1.1	**34**	93.2	13.9	**57**	134.6
−42.8	**−45**	−49.0	−10.6	**13**	55.4	1.7	**35**	95.0	14.4	**58**	136.4
−40.0	**−40**	−40.0	−10.0	**14**	57.2	2.2	**36**	96.8	15.0	**59**	138.2
−37.2	**−35**	−31.0	−9.4	**15**	59.0	2.8	**37**	98.6	15.6	**60**	140.0
−34.4	**−30**	−22.0	−8.9	**16**	60.8	3.3	**38**	100.4	16.1	**61**	141.8
−31.6	**−25**	−13.0	−8.3	**17**	62.6	3.9	**39**	102.2	16.7	**62**	143.6
−28.8	**−20**	−4.0	−7.8	**18**	64.4	4.4	**40**	104.0	17.2	**63**	145.4
−26.1	**−15**	5.0	−7.2	**19**	66.2	5.0	**41**	105.8	17.8	**64**	147.2
−23.3	**−10**	14.0	−6.7	**20**	68.0	5.6	**42**	107.6	18.3	**65**	149.0
−20.6	**−5**	23.0	−6.1	**21**	69.8	6.1	**43**	109.4	18.9	**66**	150.8
−17.8	**0**	32.0	−5.6	**22**	71.6	6.7	**44**	111.2	19.4	**67**	152.6
−17.2	**1**	33.8	−5.0	**23**	73.4	7.2	**45**	113.0	20.0	**68**	154.4
−16.7	**2**	35.6	−4.4	**24**	75.2	7.8	**46**	114.8	20.6	**69**	156.2
−16.1	**3**	37.4	−3.9	**25**	77.0	8.3	**47**	116.6	21.1	**70**	158.0
						8.9	**48**	118.4			

CENTIGRADE – FAHRENHEIT (con't.)

Centigrade		Fahrenheit
21.7	**71**	159.8
22.2	**72**	161.6
22.8	**73**	163.4
23.3	**74**	165.2
23.9	**75**	167.0
24.4	**76**	168.8
25.0	**77**	170.6
25.6	**78**	172.4
26.1	**79**	174.2
26.7	**80**	176.0
27.2	**81**	177.8
27.8	**82**	179.6
28.3	**83**	181.4
28.9	**84**	183.2
29.4	**85**	185.0
30.0	**86**	186.8
30.6	**87**	188.6
31.1	**88**	190.4
31.7	**89**	192.2
32.2	**90**	194.0
32.8	**91**	195.8
33.3	**92**	197.6
33.9	**93**	199.4
34.4	**94**	201.2
35.0	**95**	203.0
35.6	**96**	204.8
36.1	**97**	206.6
36.7	**98**	208.4
37.2	**99**	210.2
37.8	**100**	212.0
43	**110**	230
49	**120**	248

Centigrade		Fahrenheit
54	**130**	266
60	**140**	284
65	**150**	302
71	**160**	320
76	**170**	338
83	**180**	356
88	**190**	374
93	**200**	392
99	**210**	410
100	**212**	413
104	**220**	428
110	**230**	446
115	**240**	464
121	**250**	482
127	**260**	500
132	**270**	518
138	**280**	536
143	**290**	554
149	**300**	572
154	**310**	590
160	**320**	608
165	**330**	626
171	**340**	644
177	**350**	662
182	**360**	680
188	**370**	698
193	**380**	716
199	**390**	734
204	**400**	752
210	**410**	770
215	**420**	788
221	**430**	806

Centigrade		Fahrenheit
226	**440**	824
232	**450**	842
238	**460**	860
243	**470**	878
249	**480**	896
254	**490**	914
260	**500**	932
265	**510**	950
271	**520**	968
276	**530**	986
282	**540**	1004
288	**550**	1022
293	**560**	1040
299	**570**	1058
304	**580**	1076
310	**590**	1094
315	**600**	1112
321	**610**	1130
326	**620**	1148
332	**630**	1166
338	**640**	1184
343	**650**	1202
349	**660**	1220
354	**670**	1238
360	**680**	1256
365	**690**	1274
371	**700**	1292
376	**710**	1310
382	**720**	1328
387	**730**	1346
393	**740**	1364
399	**750**	1382
404	**760**	1400

Centigrade		Fahrenheit
410	**770**	1418
415	**780**	1436
421	**790**	1454
426	**800**	1472
432	**810**	1490
438	**820**	1508
443	**830**	1526
449	**840**	1544
454	**850**	1562
460	**860**	1580
465	**970**	1598
471	**880**	1616
476	**890**	1634
482	**900**	1652
487	**910**	1670
493	**920**	1688
498	**930**	1706
504	**940**	1724
510	**950**	1742
515	**960**	1760
520	**970**	1778
526	**980**	1796
532	**990**	1814
538	**1000**	1832
565	**1050**	1922
593	**1100**	2012
620	**1150**	2102
648	**1200**	2192
675	**1250**	2282
704	**1300**	2372
734	**1350**	2462
760	**1400**	2552
787	**1450**	2642
815	**1500**	2732

CONVERSION FACTORS

(For conversion factors meeting the standards of the SI metric system, refer to ASTM E380-72)

MULTIPLY	BY	TO OBTAIN
centimeters	3.28083×10^{-2}	feet
centimeters	.3937	inches
cubic centimeters	6.102×10^{-2}	cubic inches
cubic feet	2.8317×10^{-2}	cubic meters
cubic feet	6.22905	gallons, British Imperial
cubic feet	28.3170	liters
cubic inches	16.38716	cubic centimeters
cubic meters	35.3145	cubic feet
cubic meters	1.30794	cubic yards
cubic yards	.764559	cubic meters
degrees angular	.0174533	radians
foot pounds	.13826	kilogram meters
feet	30.4801	centimeters
gallons, British Imperial	.160538	cubic feet
gallons, British Imperial	1.20091	gallons, U.S.
gallons, British Imperial	4.54596	liters
gallons, U.S.	.832702	gallons, British Imperial
gallons, U.S.	.13368	cubic feet
gallons, U.S.	3.78543	liters
grams, metric	2.20462×10^{-3}	pounds, avoirdupois
horse-power, metric	.98632	horse-power, U.S.
horse-power, U.S.	1.01387	horse-power, metric
inches	2.54001	centimeters
kilograms	2.20462	pounds
kilograms per sq. centimeter	14.2234	pounds per sq. inch
kilometers	.62137	miles, statute
liters	.26417	gallons, U.S.
meters	3.28083	feet
meters	39.37	inches
meters	1.09361	yards
miles, statute	1.60935	kilometer
milimeters	3.28083×10^{-3}	feet
milimeters	3.937×10^{-2}	inches
pounds avoirdupois	.453592	kilograms
pounds per square foot	4.88241	kilograms per sq. meter
pounds per square inch	7.031×10^{-2}	kilograms per sq. centimeter
radians	57.29578	degrees angular
square centimeters	.1550	square inches
square inches	6.45163	square centimeters
square meters	1.19599	square yards
square miles	2.590	square kilometers
square yards	.83613	square meters
tons, long	1016.05	kilograms
tons, long	2240.	pounds
tons, metric	2204.62	pounds
tons, metric	.98421	tons, long
tons, metric	1.10231	tons, short
tons, short	.892857	tons, long
tons, short	.907185	tons, metric
yards	.914402	meters

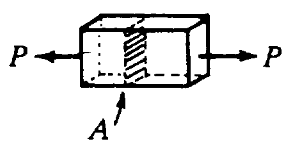
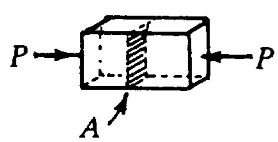
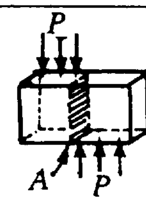
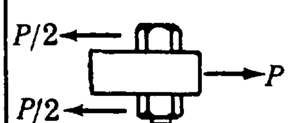
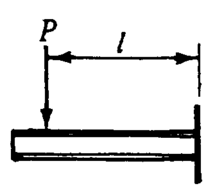
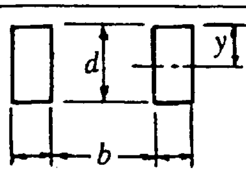
PART IV.

DESIGN OF STEEL STRUCTURES

STRESS AND STRAIN FORMULAS

DEFINITION OF SYMBOLS

- A = Cross sectional area, in^2.
- A_R = Required cross sectional Area, in^2
- I = Moment of inertia, in^4
- M = Moment, in-1b
- M_A = Allowable moment, in-lb
- P = Force, 1b
- P_A = Allowable force, 1b
- S = Tensile or compressive stress, psi
- S_B = Bending stress, psi
- S_S = Shear stress, psi
- S_A = Allowable tensile or compressive stress, psi
- S_{BA} = Allowable bending stress, psi.
- S_{SA} = Allowable shear stress, psi.
- y = Distance from neutral axis to extreme fiber, in
- Z = Section modulus, in^3

TYPE OF LOADING		EXAMPLES
 TENSION	$S = \frac{P}{A}$ (psi) $P_A = AS_A$ (lb) $A_R = \frac{P}{S_A}$ (in^2)	The stress in a 2 × ¼ in. bar made from SA 285-C steel due to 5,000 lb. tensional load is: Area, $A = 2 \times ¼ = 0.5\ in^2$; $S = \frac{P}{A} = \frac{5{,}000}{0.5} = 10{,}000$ psi
 COMPRESSION	$S = \frac{P}{A}$ (psi) $P_A = AS_A$ (lb) $A_R = \frac{P}{S_A}$ (in^2)	To support a load of 11,000 lbs. in compression, the required area of steel bar made from SA 285C steel is: $A_R = \frac{P}{S_A} = \frac{11{,}000}{22{,}000} = 0.5\ in^2$
 Single	$S_S = \frac{P}{A}$ (psi) $P_A = AS_{SA}$ (lb) $A_R = \frac{P}{S_{SA}}$ (in^2)	The required area of bolt made from SA-307 B steel to support a load of 15,000 lbs. in double shear: $A_R = \frac{P}{2S_A} = \frac{15{,}000}{\cdot 2 \times 10{,}000} = 0.75\ in^2$
 Double SHEAR	$S_S = \frac{P}{2A}$ (psi) $P_A = 2AS_{SA}$ (lb) $A = \frac{P}{2S_{SA}}$ (in^2)	
 BENDING	$M = Pl$ (in-lb) $M_A = ZS_A$ (in-lb) $Z_R = \frac{M}{S_{BA}}$ (in^3) $S = \frac{M}{Z}$ (psi) $S_A = \frac{M}{Z_{min}}$ (psi)	The maximum bending moment at the support of a cantilever beam due to a load of 1,000 lbs. acting at a distance of 60 inches from the support: $M = Pl = 1{,}000 \times 60 = 60{,}000$ in-lb. Section modulus If dimension $b = 2$ in. and $d = 4$ in,
 SECTION MODULUS	$Z = \frac{I}{y}$	axis of moment on the base. $I = 42.67$. $Z = I/y = 42.67/4 = 10.67\ in^3$ axis of moment through center, $I = 10.67$, $Z = I/y = 10.67/2 = 5.335\ in^3$

ALLOWABLE STRESSES

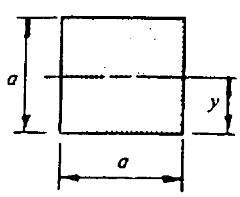
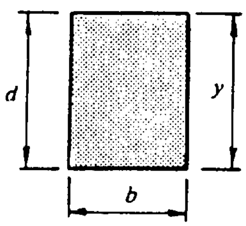
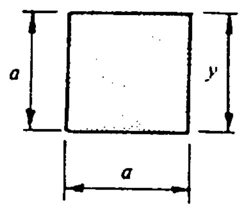
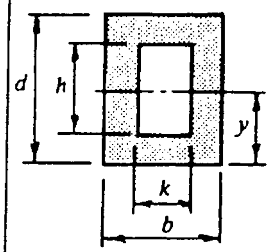
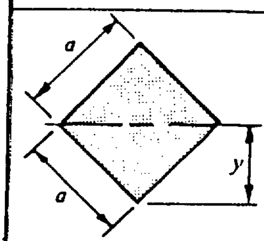
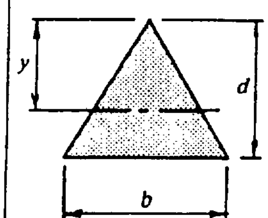
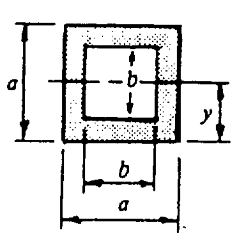
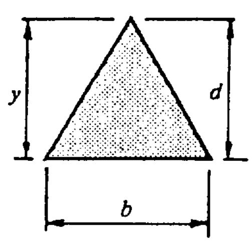
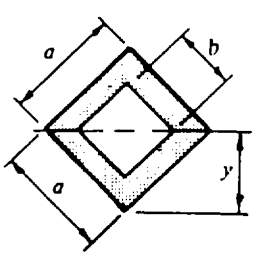
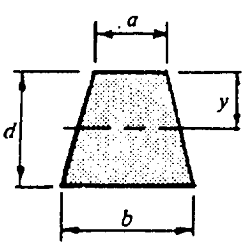
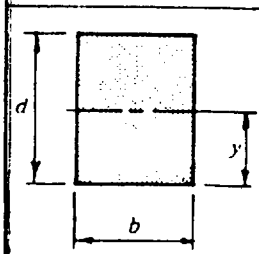
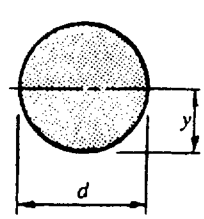
FOR NON PRESSURE PARTS OF VESSELS AND OTHER STRUCTURES

TYPE OF STRESS & JOINT	ALLOWABLE STRESS	SOURCE
STEEL Bearing Shear	1.60 × } The values of 0.80 × } tables UCS-23	CODE UCS-23 Notes
Compression Tension (except pin connection) Bending Shear	0.60 × 0.60 × 0.66 × 0.40 × } Specified minimum yield stress	American Institute of Steel Construction
Bearing (on projected area of bolts in shear on connection)	1.5 × Min. tensile strength	
WELDED JOINT OF STEEL		American Welding Society
Full penetration groove weld tension, compression, shear	same as for the steel welded	
Partial penetration groove weld 1. tension transverse to axis of weld, shear on throat 2. tension parallel to axis of weld or compression on throat	 13,600 psi same as for the steel welded	
Fillet weld, shear on throat	13,600 psi (using throat dimension) 9,600 psi (using leg dimension)	
Plug or slot weld	same as fillet weld	

PROPERTIES OF SECTIONS

DEFINITION OF SYMBOLS

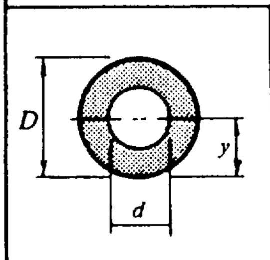
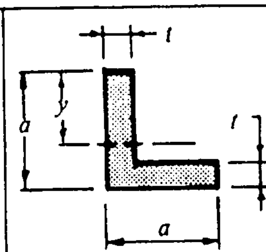
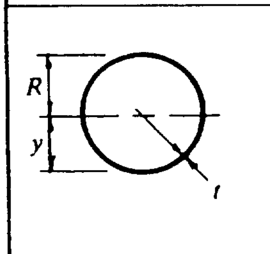
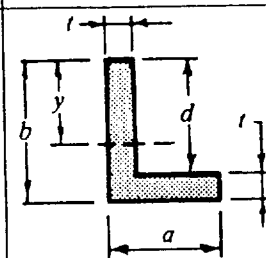
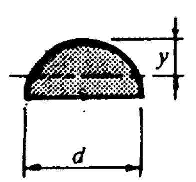
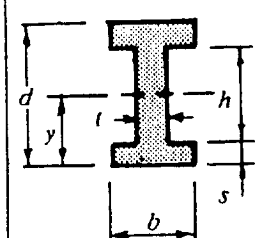
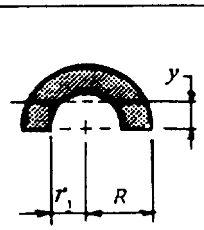
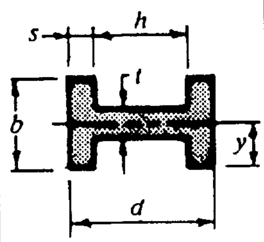
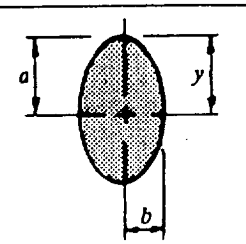
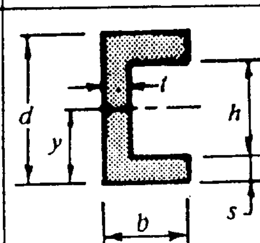
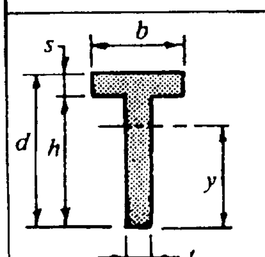
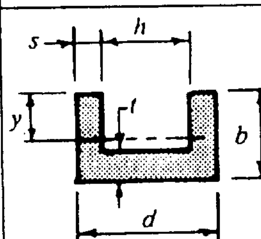
A = Area, in.^{2}
I = Moment of inertia, in.^{4}
r = Radius of gyration, $\sqrt{I/A}$
y = Distance from neutral axis to extreme fiber, in.
Z = Section modulus, I/y, in.^{3}

	$A = a^2$ $y = \frac{1}{2} a$ $I = a^4/12$ $Z = a^3/6$ $r = 0.289\ a$		$A = bd$ $y = d$ $I = bd^3/3$ $Z = bd^2/3$ $r = 0.577\ d$
	$A = a^2$ $y = a$ $I = a^4/3$ $Z = a^3/3$ $r = 0.577\ a$		$A = bd - hk$ $y = \frac{1}{2}d$ $I = (bd^3 - hk^3)/12$ $Z = (bd^3 - hk^3)/6\ d$ $r = 0.289 \sqrt{\frac{bd^3 - hk^3}{bd - hk}}$
	$A = a^2$ $y = 0.707\ a$ $I = a^4/12$ $Z = 0.118\ a^3$ $r = 0.289\ a$		$A = \frac{1}{2}\ bd$ $y = \frac{2}{3}\ d$ $I = bd^3/36$ $Z = bd^2/24$ $r = 0.236\ d$
	$A = a^2 - b^2$ $y = \frac{1}{2}\ a$ $I = (a^4 - b^4)/12$ $Z = (a^4 - b^4)/6a$ $r = 0.289 \sqrt{a^2 + b^2}$		$A = \frac{1}{2}\ bd$ $y = d$ $I = bd^3/12$ $Z = bd^2/12$ $r = 0.408\ d$
	$A = a^2 - b^2$ $y = 0.707\ a$ $I = (a^4 - b^4)/12$ $Z = (0.118\ a^4 - b^4)/a$ $r = 0.289 \sqrt{a^2 + b^2}$		$A = d(a+b)/2$ $y = d(a+2b)/3(a+b)$ $I = \frac{d^3\ (a^2 + 4\ ab + b^2)}{36\ (a+b)}$ $Z = \frac{d^2\ (a^2 + 4\ ab + b^2)}{12\ (a + 2b)}$ $r = \sqrt{I/A}$
	$A = bd$ $y = \frac{1}{2}d$ $I = bd^3/12$ $Z = bd^2/6$ $r = 0.289\ d$		$A = 0.7854d^2$ $y = d/2$ $I = 0.049\ d^4$ $Z = 0.098d^3$ $r = d/4$

PROPERTIES OF SECTIONS

DEFINITION OF SYMBOLS

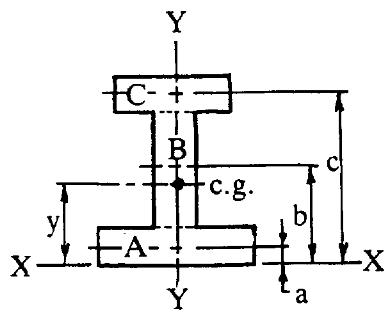
A = Area, in.^{2}
I = Moment of inertia, in.^{4}
r = Radius of gyration, $\sqrt{I/A}$
y = Distance from neutral axis to extreme fiber, in.
Z = Section modulus, I/y, in.^{3}

	$A = 0.7854\,(D^2 - d^2)$ $y = D/2$ $I = 0.049\,(D^4 - d^4)$ $Z = 0.098(D^4 - d^4)/D$ $r = \sqrt{D^2 + d^2}/4$		$A = t(2a - t)$ $Y = a - \frac{a^2 + at - t^2}{2(2a - t)}$ $I = \frac{1}{3}[ty^3 + a(a-y)^3 - (a-t)(a-y-t)^3]$ $Z = I/y$ $r = \sqrt{I/A}$
	Section of thin walled cylinder when $R > 10t$ $A = 2R\pi t$ $Y = R$ $I = R^3 t \pi$ $Z = R^2 t \pi$ $r = 0.707R$		$A = t(a + b - t)$ $Y = b - \frac{t(2d + a) + d^2}{2(d + a)}$ $I = \frac{1}{3}[ty^3 + a(b-y)^3 - (a-t)(b-y-t)^3]$ $Z = I/y$ $r = \sqrt{I/A}$
	$A = 0.393\,d^2$ $y = 0.288\,d$ $I = 0.007\,d^4$ $Z = 0.024\,d^3$ $r = 0.132\,d$		$A = bd - h(b - t)$ $y = d/2$ $I = [bd^3 - h^3(b-t)]/12$ $Z = \frac{bd^3 - h^3(b - t)}{6d}$ $r = \sqrt{I/A}$
	$A = 1.5708\,(R^2 - r_1^2)$ $y = 0.424(R^3 - r_1^3)/(R^2 - r_1^2)$ $I = 0.1098\,(R^4 - r_1^4) - \frac{0.283\,R^2 r_1^2\,(R - r_1)}{R + r_1}$ $Z = I/y$ $r = \sqrt{I/A}$		$A = bd - h(b - t)$ $Y = b/2$ $I = (2\,sb^3 + ht^3)/12$ $Z = (2\,sb^3 + ht^3)/6\,b$ $r = \sqrt{I/A}$
	$A = 3.1416\,ab$ $y = a$ $I = 0.7854\,a^3 b$ $Z = 0.7854\,a^2 b$ $r = a/2$		$A = bd - h(b - t)$ $y = d/2$ $I = [bd^3 - h^3(b-t)]/12$ $Z = [bd^3 - h^3(b-t)]/6d$ $r = \sqrt{\frac{bd^3 - h^3(b-t)}{12[bd - h(b-t)]}}$
	$A = bs + ht$ $y = d - \frac{d^2 t + s^2(b - t)}{2(bs + ht)}$ $I = \frac{1}{3}[ty^3 + b(d-y)^3 - (b-t)(d-y-s)^3]$ $Z = I/y$ $r = \sqrt{I/A}$		$A = bd - h(b - t)$ $y = b - \frac{2\,b^2 s + ht^2}{2\,bd - 2h(b - t)}$ $I = (2sb^3 + ht^3)/3 - A(b - y)^2$ $Z = I/y$ $r = \sqrt{I/A}$

CENTER OF GRAVITY

The center of gravity of an area or body is the point through which about any axis the moment of the area or body is zero. If a body of homogenous material at the center of gravity were suspended it would be balanced in all directions.

The center of gravity of symmetrical areas as square, rectangle, circle, etc. coincides with the geometrical center of the area. For areas which are not symmetrical or which are symmetrical about one axis only, the center of gravity may be determined by calculation.



EXAMPLE #1

The center of gravity is located on the centerline of symmetry. (Axis $y-y$)
To determine the exact location of it:

1. Divide the area into 3 rectangles and calculate the area of each. (A, B, C)
2. Determine the center of gravity of the rectangles and determine the distances a, b and c to a selected axis (x − x) perpendicular to axis y − y.
3. Calculate distance y to locate the center of gravity by the formula:

$$y = \frac{Aa + Bb + Cc}{A + B + C}$$

Assuming for areas of rectangles: $A = 16$, $B = 14$ and $C = 12$ square inches and for the distances of center of gravities: a = 1, b = 5 and c = 9 inches.

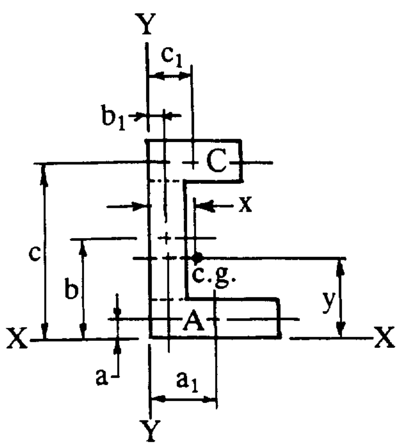
$$y = \frac{16 \times 1 + 14 \times 5 + 12 \times 9}{16 + 14 + 12} = 4.62 \text{ in.}$$

The area is not symmetrical about any axis. The center of gravity may be determined by calculating the moments with reference to two selected axes. To determine the distances of center of gravity to these axes:

1. Divide the area into 3 rectangles and calculate the areas of each. (A, B, C)
2. Determine the center of gravity of the rectangles and the distances, a, b and c to axis x-x and the distances a_1, b_1, c, to axis y − y.
3. Calculate distances x and y by the formulas:

$$x = \frac{Aa_1 + Bb_1 + Cc_1}{A + B + C}$$

$$y = \frac{Aa + Bb + Cc}{A + B + C}$$

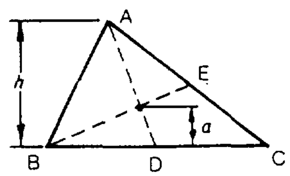


EXAMPLE #2

Assuming for areas of rectangles: $A = 16$, $B = 14$ and $C = 12$ square inches and for distances of center of gravities: $a = 1$, $b = 5$, $c = 9$: $a_1 = 4$, $b_1 = 1$ and $c_1 = 3$

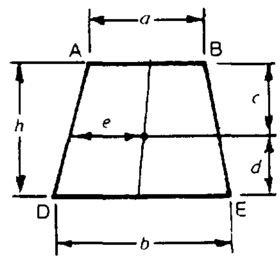
$$x = \frac{16 \times 4 + 14 \times 1 + 12 \times 3}{16 + 14 + 12} = 2.71 \text{ in.} \qquad y = \frac{16 \times 1 + 14 \times 5 + 12 \times 8}{16 + 14 + 12} = 4.62 \text{ in.}$$

CENTER OF GRAVITY



TRIANGLE

The center of gravity is at the intersection of lines AD and BE, which bisect the sides BC and AC. The perpendicular distance from the center of gravity to any one of the sides is equal to one-third the height perpendicular to that side. Hence, $a = h \div 3$.

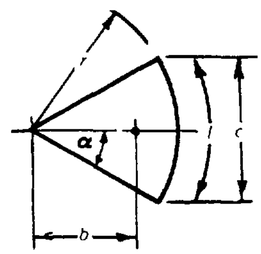


TRAPEZOID

The center of gravity is on the line joining the middle points of parallel lines AB and DE.

$$c = \frac{h\,(a + 2\,b)}{3\,(a + b)} \qquad d = \frac{h\,(2\,a + b)}{3\,(a + b)}$$

$$e = \frac{a^2 + ab + b^2}{3\,(a + b)}$$



SECTOR OF CIRCLE

Distance b from center of gravity to center of circle is:

$$b = \frac{2\,rc}{3\,l} = \frac{r^2 c}{3\,A} = 38.197\ \frac{r \sin \alpha}{\alpha}$$

in which A = area of sector, and α is expressed in degrees.

For the area of a half-circle:

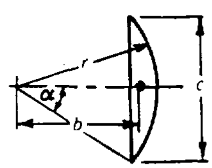
$$b = 4\,r \div 3\,\pi = 0.4244\,r$$

For the area of a quarter circle:

$$b = 4\,\sqrt{2} \times r \div 3\,\pi = 0.6002\,r$$

For the area of a sixth of a circle:

$$b = 2\,r \div \pi = 0.6366\,r$$

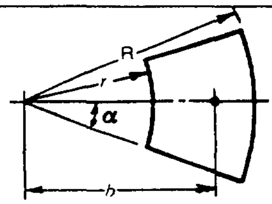


SEGMENT OF CIRCLE

The distance of the center of gravity from the center of the circle is:

$$b = \frac{c^3}{12\,A} = \frac{2}{3} \times \frac{r^3 \sin^3 \alpha}{A}$$

in which A = area of segment.

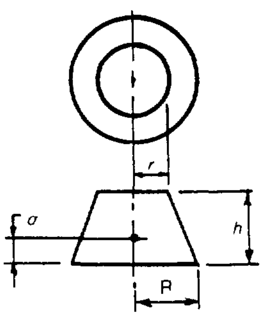


PART OF CIRCULAR RING

Distance b from center of gravity to center of circle is:

$$b = 38.197\ \frac{(R^3 - r^3) \sin \alpha}{(R^2 - r^2)\,\alpha}$$

Angle α is expressed in degrees.



FRUSTUM OF CONE

For a solid frustum of a circular cone the formula:

$$a = \frac{h\,(R^2 + 2\,Rr + 3\,r^2)}{4\,(R^2 + Rr + r^2)}$$

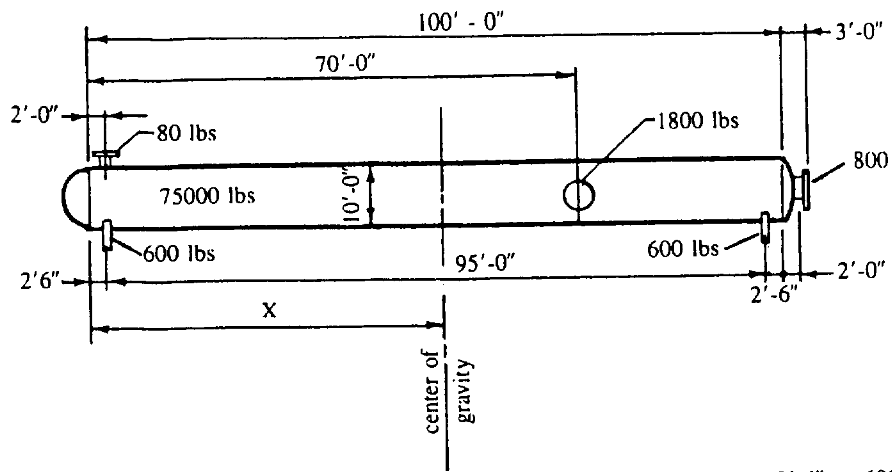
The location of the center of gravity of the conical surface of a frustum of a cone is determined by:

$$a = \frac{h\,(R + 2\,r)}{3\,(R + r)}$$

CENTER OF GRAVITY

EXAMPLES

A

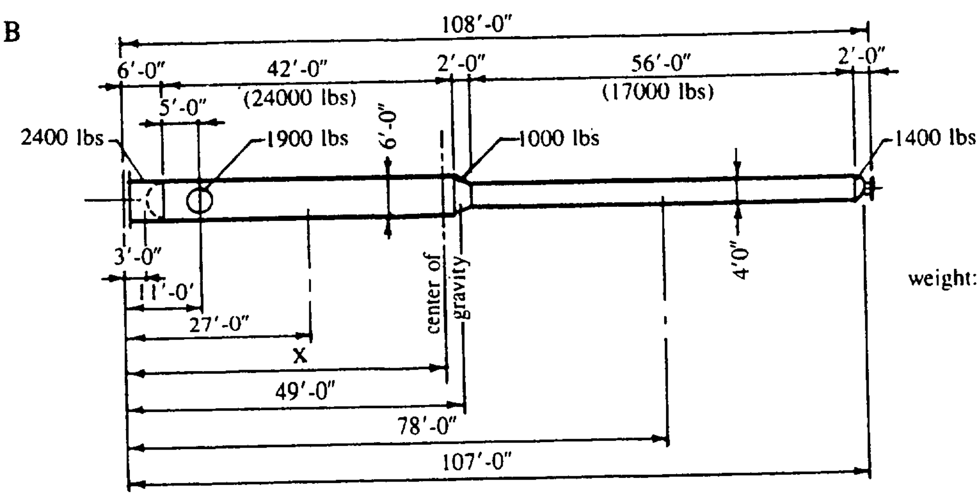


weight: 75000 lb
80 lb
1800 lb
800 lb
600 lb
600 lb
78880 lb

$$X = \frac{75000 \times 50' + 80 \times 2' + 1800 \times 70' + 800 \times 102' + 600 \times 2'\text{-}6'' + 600 \times 97'\text{-}6''}{78880 \text{ lbs}} =$$

$$= \frac{4{,}017{,}760}{78{,}880} = 50{,}935' = 50' - 11\text{-}1/4''$$

B



weight: 2400 lb
24000 lb
1000 lb.
17000 lb
1400 lb
1900 lb
47700 lb

$$X = \frac{2400 \times 3' + 24000 \times 27' + 1000 \times 49' + 17000 \times 78' + 1400 \times 107' + 1900 \times 11'}{47{,}700 \text{ lbs.}} =$$

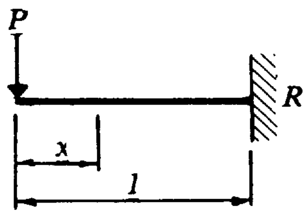
$$= \frac{2200{,}900}{47{,}700} = 46.14' = 46'\text{-}1\tfrac{11}{16}''$$

BEAM FORMULAS

DEFINITION OF SYMBOLS

E	=	Modulus of elasticity, psi.
I	=	Moment of inertia, $in.^4$
l	=	Length, in.
M	=	Moment of force, in. lb.
P	=	Force of concentrated load, lb.
R	=	Reaction, lb.
W	=	load, lb.
V	=	Total shear, lb.
v	=	Unit shear, lb./in.
w	=	uniformly distributed load lb./in.
x	=	Distance parallel to axis X, in.
Δ	=	Deflection, in.
θ	=	Angle of deflection, radians

1 Cantilever fixed at one end — Concentrated load at free end



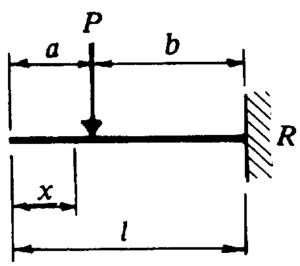
$$R = V = P$$

At support, $M_{max} = Pl$

$$M_x = Px$$

At free end, $\Delta_{max} = \frac{Pl^3}{3EI}$ $\quad \Delta_x = \frac{P}{6EI}(2l^3 - 3l^2x + x^3)$

2 Cantilever fixed at one end – Concentrated load at any point



$$R = V = P$$

At support, $M_{max} = Pb$

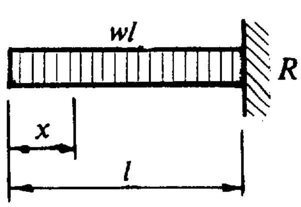
When $x > a$ $\quad M_x = P(x - a)$

At free end, $\Delta_{max} = \frac{Pb^3}{6EI}(3l - b)$

When $x < a$ $\quad \Delta_x = \frac{Pb^2}{6EI}(3l - 3x - b)$

When $x > a$ $\quad \Delta_x = \frac{P - x)^2}{3EI}(3b - l + x)$

3 Cantilever fixed at one end — Uniform load over entire span



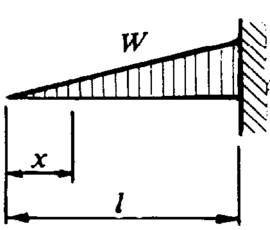
$$R = V = wl$$

$$Vx = wx$$

At support, $M_{max} = \frac{wl^2}{2}$ $\quad M_x = \frac{wx^2}{2}$

At free end, $\Delta_{max} = \frac{wl^4}{8EI}$ $\quad \Delta_x = \frac{w}{24EI}(x^4 - 4l^3x + 3l^4)$

4 Cantilever fixed at one end — Load increasing uniformly from free end to support



$R = V = W$ $\quad V_x = W\frac{x^2}{l^2}$ $\quad M_x = \frac{Wx^3}{3l^2}$

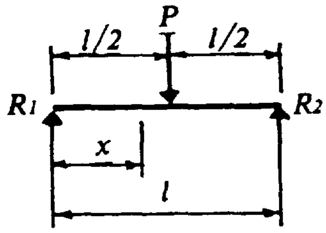
$W = \frac{pl}{2}$ $\quad$ At support, $M_{max} = \frac{Wl}{3}$

At free end, $\Delta_{max} = \frac{Wl^3}{15EI}$ $\quad \Delta_x = \frac{W}{60EIl^2}(x^5 - 5l^4x + 4l^5)$

At free end, $0 = +\frac{Wl^2}{12EI}$

BEAM FORMULAS

5 Supported at both ends — Concentrated load at mid-span



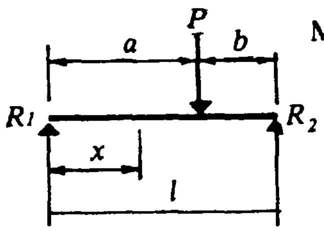
$R_1 = R_2 = V = P/2$

At load, $M_{max} = \dfrac{Pl}{4}$ When $x < l/2$ $M_x = \dfrac{Px}{2}$

At load, $\Delta_{max} = \dfrac{Pl^3}{48EI}$ At end, $\theta_1 = -\dfrac{Pl^2}{16EI} = -\theta_2$

When $x < l/2$ $\Delta_x = \dfrac{Px}{48EI}(3l^2 - 4x^2)$

6 Supported at both ends — Concentrated load at any point



Max when $a < b$ $R_1 = V_1 = \dfrac{Pb}{l}$ At load, $M_{max} = \dfrac{Pab}{l}$

Max when $a > b$ $R_2 = V_2 = \dfrac{Pa}{l}$ When $x < a$ $M_x = \dfrac{Pbx}{l}$

when $a > b$ $\Delta_{max} = \dfrac{Pb}{3EIl}\sqrt{\dfrac{(l^2 - b^2)^3}{3}}$ At load, $\Delta = \dfrac{Pa^2b^2}{3EIl}$

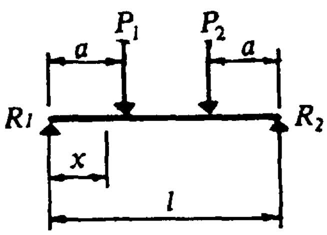
When $x < a$ $\Delta_x = \dfrac{Pbx}{6EIl}(l^2 - b^2 - x^2)$

At ends,

$\theta_1 = -\dfrac{P}{6EI}\left(2al + \dfrac{a^3}{l} - 3a^2\right)$

$\theta_2 = +\dfrac{P}{6EI}\left(al - \dfrac{a^3}{l}\right)$

7 Supported at both ends — Two unequal concentrated loads, equally spaced from ends



$R = V = P$ $M_{max} = Pa$ When $x < a$ $M_x = Px$

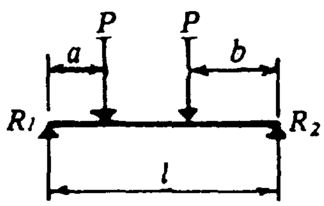
At center, $\Delta_{max} = \dfrac{Pa}{24EI}(3l^2 - 4a^2)$

When $x < a$ $\Delta_x = \dfrac{Px}{6EI}(3la - 3a^2 - x^2)$

When $x > a$ but $x < (l - a)$ $\Delta_x = \dfrac{Pa}{6EI}(3lx - 3x^2 - a^2)$

At ends, $\theta = Pa\ 2EI(l - a)$

8 Supported at both ends — Two equal concentrated loads, unequally spaced from ends



$R_1 = V_1 = \dfrac{P_1(l - a) + P_2 b}{l}$ $R_2 = V_2 = \dfrac{P_1 a + P_2(l - b)}{l}$

When $x > a$ but $x < (l - b)$ $V = R_1 - P_1$

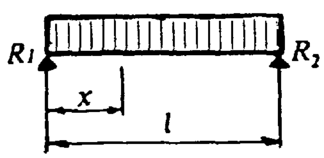
Max when $R_1 < P_1$ $M_1 = R_1 a$

Max when $R_2 < P_2$ $M_2 = R_2 b$

When $x < a$ $M_x = R_1 x$

When $x > a$ but $x < (l - b)$ $M_x = R_1 x - (x - a)$

9 Supported at both ends — Uniform load over entire span



$R = V = \dfrac{wl}{2}$ $V = w\left(\dfrac{l}{2} - x\right)$

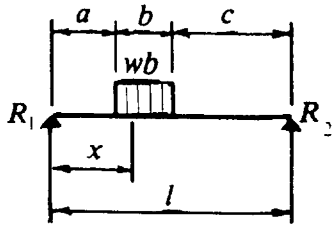
At center, $M_{max} = \dfrac{wl^2}{8}$ $M_x = \dfrac{wx}{2}(l - x)$

At center, $\Delta_{max} = \dfrac{5wl^4}{384EI}$ $\Delta_x = \dfrac{wx}{24EI}(l^3 - 2lx^2 + x^3)$

At ends, $\theta = \dfrac{wl^3}{24EI}$

BEAM FORMULAS

10 Supported at both ends Uniform load partially distributed over span



Max when $a<c$ $R_1 = V_1 = \frac{wb}{2l}(2c+b)$

Max when $a>c$ $R_2 = V = \frac{wb}{2l}(2a+b)$

When $x>a$ but $x<(a+b)$ $V_x = R_1 - w(x-a)$

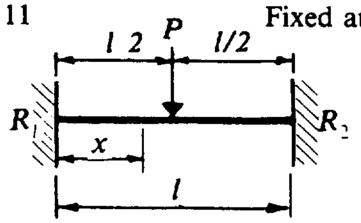
$M_{max} = R_1\left(a + \frac{R_1}{2w}\right)$ At $x = a + \frac{R_1}{w}$

When $x<a$ $M_x = R_1 x$

When $x>a$ but $x<(a+b)$ $M_x = R_1 x - \frac{w}{2}(x-a)^2$

When $x>(a+b)$ $M_x = R_2(l-x)$

11 Fixed at both ends Concentrated load at mid-span

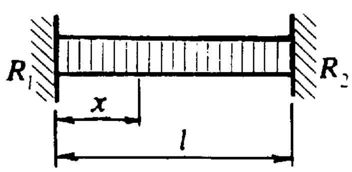


$R = V = \frac{P}{2}$ At center and at ends, $M_{max} = \frac{Pl}{8}$

When $x<l/2$ $M_x = \frac{P}{8}(4x - l)$

At center, $\Delta_{max} = \frac{Pl^3}{192EI}$ $\Delta_x = \frac{Px^2}{48EI}(3l - 4x)$

12 Fixed at both ends Uniform load over entire span



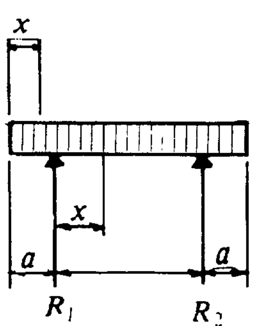
$R = V = \frac{wl}{2}$ $V_x = w\left(\frac{l}{2} - x\right)$

At ends, $M_{max} = wl^2/12$ At center, $M = wl^2/24$

$M_x = w/12\,(6lx - l^2 - 6x^2)$

At center, $\Delta_{max} = \frac{wl^4}{384EI}$ $\Delta_x = \frac{wx^2}{24EI}(l-x)^2$

13 Both ends are overhanging Uniform load over entire beam



$R = V_1 + V_2 = w(a + l/2)$ $V_{x1} = wx_1$ $V_x = w(x - l/2)$

For overhang, $M_{x1} = \frac{wx_1^2}{2}$ At support, $M = \frac{wa^2}{2}$

Between supports, $M_x = \frac{w}{2}(lx - x^2 - a^2)$

At center, $M_c = \frac{w}{8}(l^2 - 4a^2)$

When $a = .207 \times$ total length or $A = .3541$

$M = M_c = \frac{wl^2}{16}$

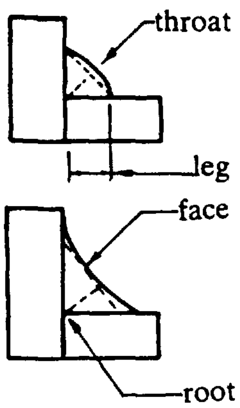
DESIGN OF WELDED JOINTS
FOR STRUCTURAL MEMBERS

GROOVE WELD

Groove welds are usually a continuation of the base metal. For groove welds the same strength is ascribed as for the members that they join.

FILLET WELD

Size of weld



The size of an equal-leg fillet weld is the leg dimension of the largest 45° right triangle inscribed in the cross section of the weld.

The size of an unequal-leg fillet weld is the shortest distance from the root to the face of the fillet weld.

Throat dimension = 0.707 × leg dimension

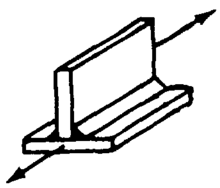
Minimum Weld size*

Thickness of the thicker plate, in.	½	¾	½	2¼	6	over 6
Minimum fillet weld size, in.	3/16	¼	5/16	⅜	½	⅝

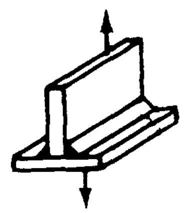
* Weld size need not to exceed the thickness of the thinner part joined

Economy of fillet welding

1. Use the minimum size of fillet weld required for the desired strength. Increasing the size of a fillet weld in direct proportion, the volume (and costs) of it will increase with the square of its size.
2. Locate weld to avoid eccentricity, to be readily accessible, and in down-welding position.
3. Apply fillet weld transversely to the force to achieve greater strength.



PARALLEL WELD



TRANSVERSE WELD

Allowable Load

The strength of the welds is a function of the welding procedure and the electrode used. For carbon steel joints commonly used maximum allowable static load 9,600 (9.6 kips) lbs per 1 square inch of the fillet weld leg-area, or 600 lbs on a 1/16" leg × 1" long fillet weld. For example: the allowable load on a ¼" × 1" long fillet weld 4×600 = 2,400 lbs.

Combined Loads

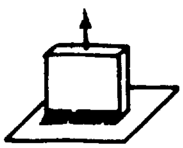
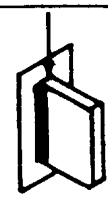
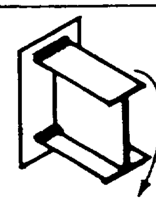
Shear stress and bending or torsional stresses due to eccentric loadings may be combined vectorially. It is based on the elastic theory and provides a simplified and conservative method.

DESIGN OF WELDED JOINTS
FOR STRUCTURAL MEMBERS

DEFINITION OF SYMBOLS

A_w = Length of weld, in.
f = Allowable load on weld, 9.6 kips per in^2. leg-area
M = Bending moment, kips
P = Allowable concentrated axial load, kips
S_w = Section Modulus of weld lines subjected to bending moment, in^2
V = Vertical shear, kips
w = Fillet weld leg dimension, in
W = Load on fillet weld, kips per lineal inch of weld
W_s = Average vertical shear on fillet weld, kips per lin. inch of weld
W_b = Bending force on weld, kips per lin. inch of weld

FORMULAS FOR FORCES ON WELD

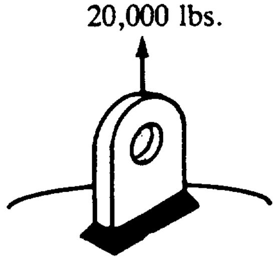
TENSION OR COMPRESSION	VERTICAL SHEAR	BENDING
 $W = \frac{P}{A_w}$	 $W_s = \frac{V}{A_w}$	 $W_b = \frac{M}{S_w}$

RESULTANT FORCE: $W = \sqrt{W_1^2 + W_2^2 + W_3^2}$

EXAMPLE #1

Determine the required size of fillet weld. The length of the weld is all around 8.5 inches and the tensional load 20 kips.

20,000 lbs.



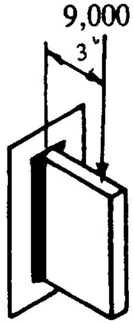
$$W = \frac{P}{A_w} = \frac{20}{8.5} = 2.35 \text{ kips per lin. in.}$$

$$w = \frac{W}{f} = \frac{2.35}{9.6} = 0.24; \text{ use } ¼'' \text{ fillet weld}$$

EXAMPLE #2

Determine the required size of fillet weld. The length of the weld 12 inches (6″ each side) and the load 9 kips.

9,000 lbs



Section modulus, (from table) $S_w = \frac{d^2}{3} = \frac{6^2}{3} = 12 \text{ in}^3$

Bending Force, $\frac{M}{S_w} = \frac{3 \times 9}{12} = 2.25$ kips per lin. inch

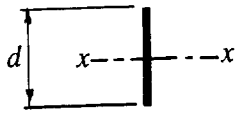
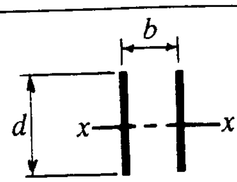
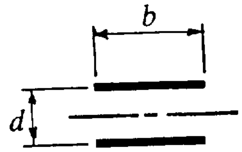
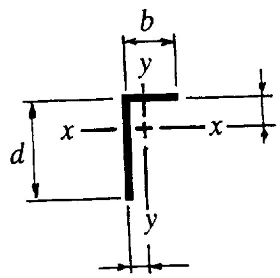
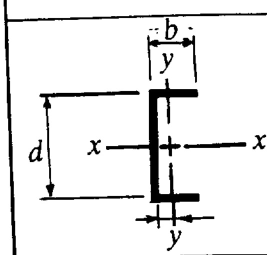
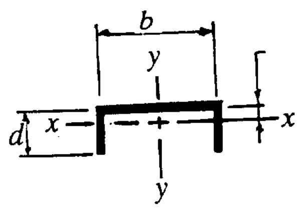
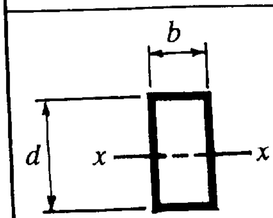
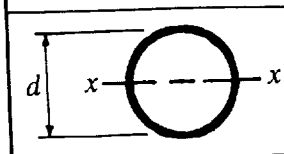
Shear Force $W_s = \frac{V}{A_w} = \frac{9}{12} = 0.75$ kips per lin. inch

Resultant force, $W = \sqrt{W_b^2 + W_s^2} = \sqrt{2.25^2 + 0.75^2} = 2.37$ kips per lin. inch.

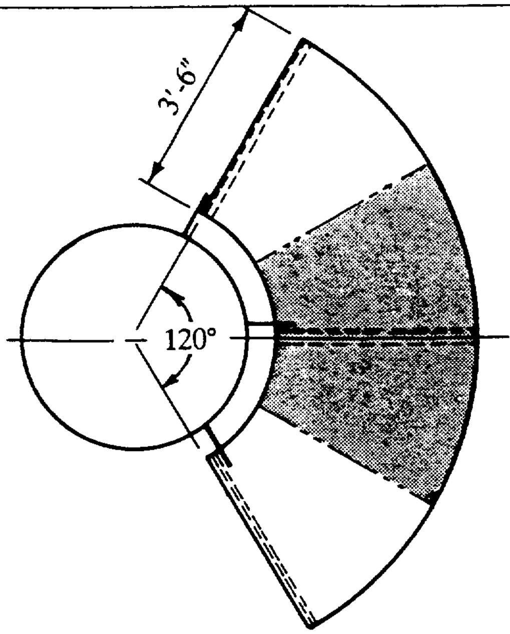
Fillet weld size, $w = \frac{W}{f} = \frac{2.37}{9.6} = .247''$; use ¼″ fillet weld

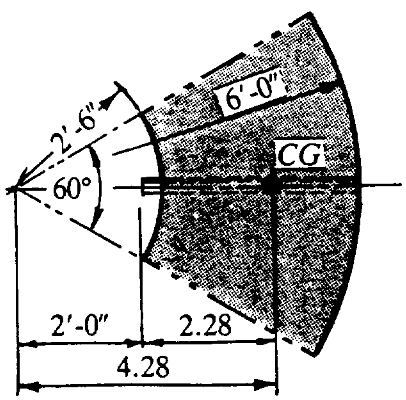
DESIGN OF WELDED JOINTS

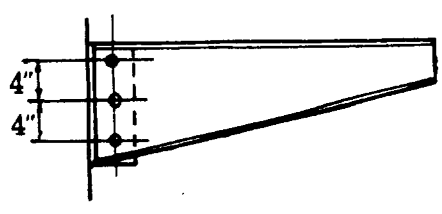
PROPERTIES OF WELD OUTLINES

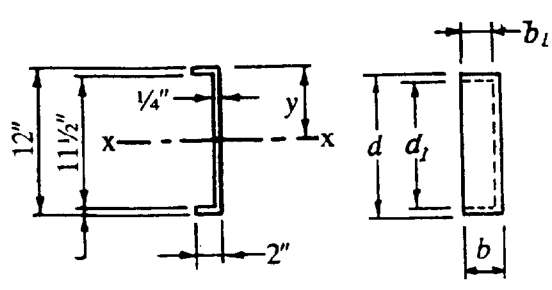
	$S_w = \frac{d^2}{6}$	
	$S_w = \frac{d^2}{3}$	
	$S_w = bd$	
	$S_w \text{ (top)} = \frac{d\,(4b + d)}{6}$ $S_w \text{ (bottom)} = \frac{d^3\,(4b+d)}{6\,(2b+d)}$ (max.stress at bottom)	
	$S_w = \text{bd} + \frac{d^2}{6}$	
	$S_w \text{ (top)} = \frac{d\,(2b+d)}{3}$ $S_w = \text{(bottom)} \frac{d^2\,(2b+d)}{3\,(b+d)}$ (max. force at bottom)	
	$S_w = bd + \frac{d^2}{3}$	
	$S_w = \frac{\pi\, d^2}{4}$	

EXAMPLE CALCULATIONS









EXAMPLE #1

A platform is supported by 3 equally spaced channels bolted to lugs. The floor load is 125 lbs per square feet.

The other design data are shown in the figures.

Determine the stresses in the channels and bolts.

One half of the total load is supported by the middle channel, thus the stress conditions only of this channel shall be investigated.

Area supported by the middle channel:

$$\frac{60}{360}\ .7854\ (12^2 - 5^2) = 15.577 \text{ sq. ft.}$$

Load: $15.577 \times 125 = 1947$ lbs

Center of gravity (see page 434):

$$b = 38.197\ \frac{(R^3 - r^3) \sin \alpha}{(R^2 - r^2) \alpha} =$$

$$38.197\ \frac{(6^3 - 2.5^3)\ 0.500}{(6_2 - 2.5^2)\ 30} = 4.28$$

Moment:
$1947 \times 2.28 \times 12 = 53{,}270$ in-1b

Moment of inertia:

$$I_{xx} = \frac{bd^3}{12} - \frac{b_1 d_1^3}{12} =$$

$$I_{xx} = \frac{2 \times 12^3}{12} - \frac{1.75 \times 11.5^3}{12} = 66.206$$

Section modulus:

$$Z = \frac{I}{y} = \frac{66.206}{6} = 11.034$$

Stress in channel at the support:

$$S = \frac{53{,}270}{11.034} = 4828 \text{ psi}$$

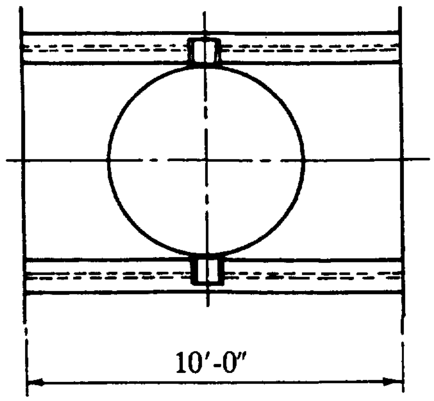
Stress in bolts: (center on bolts pattern)

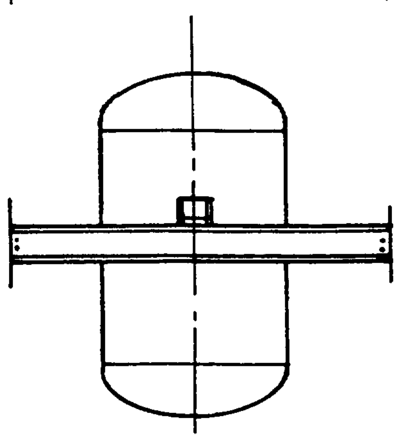
load on one bolt: $\frac{53{,}270}{8} = 6659$ lb.

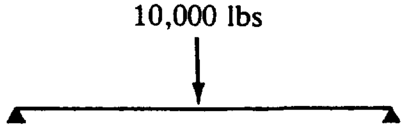
try ⅞ bolt; $A = 0.6013$ in^2

$$S = \frac{6659}{0.6013} = 11074 \text{ psi.}$$

EXAMPLE CALCULATIONS







EXAMPLE #2

A vertical vessel is supported by two beams.
The weight of the vessel is 20,000 lbs
l = 120 in   Assume pin joint

The load on one beam:

Moment:

$$M = \frac{Pl}{4} = \frac{10{,}000 \times 120}{4} = 300{,}000 \text{ in-lb}$$

Required section modulus:

$$Z = \frac{M}{S_A}$$

Assuming for allowable stress, S_A: 20,000 psi,

Section modulus:

$$Z = \frac{300{,}000}{20{,}000} = 15 \text{ in}^3$$

The section modulus of a wide flange 8WF 20 is 17 in^3
Moment of inertia: 69.2

Stress at the center of wide flange:

$$S = \frac{M}{Z} = \frac{300{,}000}{17} = 17{,}647 \text{ psi}$$

Deflection:

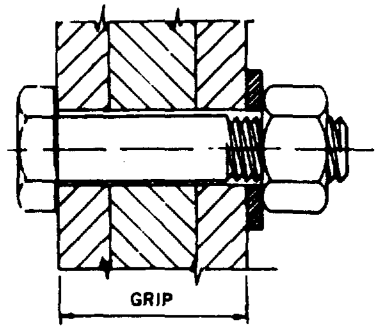
$$\Delta = \frac{Pl^3}{48EI} = \frac{10{,}000 \times 120^3}{48 \times 29{,}000{,}000 \times 69.2} =$$

$$.1794 \text{ in} \sim 3/16 \text{ in.}$$

BOLTED CONNECTIONS
FOR STRUCTURAL MEMBERS

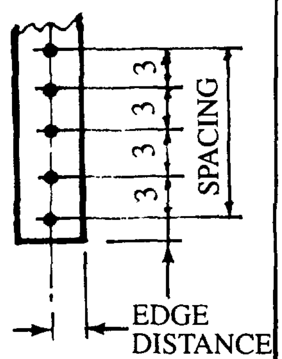
REQUIRED LENGTH OF BOLTS

NOMINAL BOLT DIAMETER in.	REQUIRED BOLT LENGTH = GRIP + DIMENSIONS BELOW, inches		
	NO WASHERS	1 WASHER	2 WASHERS
½	11/16	⅞	1
⅝	⅞	1 1/16	1 3/16
¾	1	1 3/16	1 5/16
⅞	1⅛	1 5/16	1 7/16
1	1¼	1 7/16	1 9/16
1⅛	1½	1 11/16	1 3/16
1¼	1⅝	1 13/16	1 15/16
1⅜	1¾	1 15/16	2 1/16
1½	1⅞	2 1/16	2 3/16



MINIMUM EDGE DISTANCE AND SPACE
The minimum distance from the center of bolt hole to any edge

BOLT DIAMETER in	MINIMUM EDGE DISTANCE	
	AT SHEARED EDGES	AT ROLLED OR GAS CUT EDGES
½	⅞	¾
⅝	1⅛	⅞
¾	1¼	1
⅞	1½	1⅛
1	1¾	1¼
1⅛	2	1½
1¼	2¼	1⅝
1½	2⅝	1⅞



BOLT HOLES shall be 1/16″ larger than bolt diameter.

ALLOWABLE LOADS in kips

SA 307 unfinished bolts and connected material: SA 283C, SA 285C, SA 36

Nominal Diameter of Bolt		⅝	¾	⅞	1	1⅛	1¼	1⅜	1½
Tensile Stress Area, in		0.2260	0.3345	0.4617	0.6057	0.7633	0.9691	1.1549	1.4053
Allowable Loads in Tension		4.52	6.69	9.23	12.11	15.27	19.38	23.10	28.11
Allowable Loads in Shear	Single	3.07	4.42	6.01	7.85	9.94	12.27	14.85	17.67
	Double	6.14	8.84	12.03	15.71	19.88	24.54	29.70	35.34

FOR BETTER ARRANGEMENT THIS PAGE IS BLANK IN THE PRINTED VERSION OF THE HANDBOOK.

PART V.

MISCELLANEOUS

ABBREVIATIONS

COMPILED: From 1. ASA Z32.13-1950 ABBREVIATIONS FOR USE ON DRAWINGS

2. ASA Z10.1-1941 ABBREVIATIONS FOR SCIENTIFIC & ENGINEERING TERMS

ADDED: ABBREVIATIONS GENERALLY USED ON VESSEL & PIPING DRAWINGS

AB	Anchor Bolt
AISC	American Institute of Steel Construction
ALLOW	Allowance Allowable
ANSI	American National Standards Institute
ASA	American Standard Association
API	American Petroleum Institute
APPROX	Approximately
ASB	Asbestos
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing Mat'ls.
AVG	Average
bbl	Barrel
BC	Bolt Circle
BEV	Bevel
BLD	Blind
BOP	Bottom of Pipe
BOT	Bottom
BRKT	Bracket
btu	British Thermal Unit
BW	Bevel Weld
BWG	Birmingham Wire Gauge
C	Degree Centigrade
CA	Corrosion Allowance

CCW	Counter Clockwise
cfm	Cubic Foot per Minute
CFW	Continuous Fillet Weld
CG	Commercial Grade
CG	Center of Gravity
cm	Centimeter
℄	Centerline
℄ to ℄	Centerline to Centerline
CO	Company
CONC	Concentric
CPLG	Coupling
CORR ALLOW	Corrosion Allowance
COUP	Coupling
CRS	Cold Rolled Steel
CS	Carbon Steel
C to C	Center to Center
CTR	Center
cu	Cubic
cu. ft.	Cubic Foot
CW	Clockwise
CWT	Hundred Weight
DC	Downcomer
DEH	Double Extra Heavy
DET	Detail
DIA	Diameter
DIAM	Diameter
DIM	Dimension
DP	Design Pressure

ABBREVIATIONS (cont.)

DT'L	Detail	HLA	High Level Alarm
DWG	Drawing	HLL	High Liquid Level
EA	Each	HLSD	High Level Shut
EH	Extra Heavy		Down
EL	Elevation	HR	Hot Rolled
ELEV	Elevation	HT	Heat Treatment
ELL	Elbow	ID	Inside Diameter
ELLIP	Ellipse, Elliptical,	in	inches
	Ellipsoid	INCL	Including, Included
EQ	Equal, Equally	INS	Inspection
ETC	Et Cetera	INT	Internal
EXT	External	JE	Joint Efficiency
F	Fahrenheit	kg	Kilogram
F-F	Face to Face	l	Liter
F&D	Flanged & Dished	lb	Pound
FF	Flat Face	lbf	Pound Force
FIG	Figure	lbs	Pounds
FIN	Finish	LC	Level Control
FLG	Flange	LCV	Liquid Control Valve
FS	Far Side, Forged	LG	Long
	Steel	LG	Level Gage
ft	Foot, Feet	Lin. ft.	Lineal Foot (Feet)
FT^3	Cubic Foot	LLA	Low Level Alarm
FW	Fillet Weld	LLC	Liquid Level Con-
g	Gram		trol
GA	Gage	LLSD	Low Level Shut
GALV	Galvanized		Down
gal	Gallon	LR	Long Radius
GG	Gage Glass	LS	Low Stage
GOL	Gage of Outstanding	LWN	Long Welding Neck
	Leg	m	Meter
gpd	Gallon per Day	MB	Machine Bolt
gpm	Gallon per Minute	MK	Mark
GR	Grade	MAT'L	Material
HVY	Heavy	MAWP	Maximum Allowable
HD	Head		Working Pressure
HEMIS	Hemispherical	MAX	Maximum
HEX	Hexagonal	MH	Manhole
HH	Handhole	MIN	Minimum
HL	Hole	MK'D	Marked

ABBREVIATIONS (cont.)

mm	Millimeter	RAD	Radial
MMSCF	Million Standard	REF	Reference
	Cubic Feet	REINF	Reinforcing
MSCF	Thousand Standard	REPAD	Reinforcing Pad
	Cubic Feet	REQ'D	Required
MW	Manway	RF	Raised Face
N	North	RJ	Ring Joint
N & C	New & Cold	RTJ	Ring Type Joint
NLL	Normal Liquid Level	RV	Relief Valve
NO	Number	S	Schedule
NOM	Nominal	S/C	Shop Coat
NPS	National Pipe Size	SCF	Standard Cubic Foot
NPT	American National	SCH	Schedule
	Taper Pipe Thread	SCR	Screw
NS	Near Side	SCR'D	Screwed
NTS	Not to Scale	SDV	Shutdown Valve
OA	Overall	SERV	
OD	Outside Diameter	Sht.	Service Sheet
OR	Outside Radius	SF	Straight Flange
OSHA	Occupational Safety and	SHT	Sheet
	Health Administration	SM	Seam
oz	Ounce	SMLS	Seamless
ozs	Ounces	SO	Slip On
P	Pressure	SPA	Spacing
PBE	Plain Both Ends	SPEC	Specification
PC	Pressure Control	SP GR	Specific Gravity
PCS	Pieces	SQ	Square
PCV	Pressure Control	SR	Short Radius
	Valve	SS	Stainless Steel
PI	Pressure Indicator	S-S	
PL	Plate	S/S	Seam to Seam
PROJ	Projection	STD	Standard
PSE	Plain Small End	STL	Steel
psi	Pound per Square	STR	Straddle
	Inch	SUPT	Support
psia	Pound per Square	SYM	Symmetrical
	Inch Absolute	T&B	Top & Bottom
psig	Pound per Square	TC	Temperature Control
	Inch Gage	TBE	Threaded Both Ends

ABBREVIATIONS (cont.)

PSV	Pressure Safety Valve	TYP	Typical
R	Radius	USAS	United States of Ameri-
TEMA	Tubular Exchanger		ca Standards Institute
	Manufacturers	VA	Valve
	Association	VOL	Volume
THD	Threaded, Thread	W/	With
THK	Thick	WG	Water Gallon
TI	Temperature	WN	Welding Neck
	Indicator	W/ OUT	Without
TLE	Threaded Large End	WP	Working Pressure
TOC	Top of Concrete	WT	Weight
TOS	Top of Steel	XH	Extra Heavy
TS	Tube Sheet	XXH	Double Extra
TSE	Threaded Small End		Heavy
T-T	Tangent to Tangent	XX STG	Double Extra
TW	Tack Weld		Strong
TW	Thermowell		

CODES, STANDARDS, SPECIFICATIONS

PRESSURE VESSELS, BOILERS

ASME Boiler and Pressure Vessel Code, 1995

I	Power Boilers
II	Material Specifications
III	Nuclear Power Plant Components
IV	Heating Boilers
V	Nondestructive Examination
VI	Recommended Rules for Care and Operation of Heating Boilers
VII	Recommended Rules for Care of Power Boilers
VIII	Pressure Vessels — Division 1, Division 2 — Alternative Rules
IX	Welding and Brazing Qualifications
X	Fiberglass-Reinforced Plastic Pressure Vessels
XI	Rules for Inservice Inspection of Nuclear Power Plant Components

British Standards Institution (BSI)

1500 — Fusion Welded Pressure Vessels for Use in the Chemical, Petroleum and Allied Industries

1515 — Fusion Welded Pressure Vessels for Use in the Chemical, Petroleum and Allied Industries (advanced design and construction)

Canadian Standards Association (CSA)

B-51-M1991 - Code for the Construction and Inspection of Boilers and Pressure Vessels

TANKS

American Petroleum Institute (API)

Spec 12B Specification for Bolted Tanks for Storage of Production Liquids, 1990

Spec 12D Specification for Field Welded Tanks for Storage of Production Liquids, 1982

Spec 12F	Specification for Shop Welded Tanks for Storage of Production Liquids, 1988
Std 620	Recommended Rules for Design and Construction of Large Welded, Low-Pressure Storage Tanks, 1990
Std 650	Welded Steel Tanks for Oil Storage, 1988

Underwriters Laboratories, Inc. (UL)

No. 142	Steel Aboveground Tanks for Flammable and Combustible Liquids
No. 58	Steel Underground Tanks for Flammable and Combustible Liquids

American Water Works Association (AWWA)

D100-84	AWWA Standard for Welded Steel Tanks for Water Storage

National Fire Protection Association (NFPA)

No. 30	Flammable & Combustible Liquids Code
No. 58	Liquified Petroleum Gases, Storage and Handling
No. 59	Liquified Petroleum Gases at Utility Gas Plants

PIPING

American National Standards Institute (ANSI)

B31.1 — 1992	Power Piping
B31.2 — 1968	Fuel Gas Piping
B31.3 — 1993	Chemical Plant and Petroleum Refinery Piping
B31.4 — 1989	Liquid Petroleum Transportation Piping Systems
B31.4 — 1992	Refrigeration Piping with 1978 Addenda
B31.8 — 1992	Gas Transmission and Distribution Piping Systems

HEAT EXCHANGERS

Expansion Joint Manufacturers Association, Inc.

Standards, 5th Edition with 1985 Addenda and Practical Guide to Expansion Joints

PIPES

American National Standards Institute (ANSI)

ANSI B36.19-1976 Stainless Steel Pipe

ANSI/ASME B36.10M-1985 Welded and Seamless Wrought Steel Pipe

FITTINGS, FLANGES, AND VALVES

American National Standards Institute (ANSI)

ANSI B16.25-1992	Buttwelding Ends
ANSI B16.10-1992	Face-to-Face and End-to-End Dimensions of Ferrous Valves
ANSI B16.9-1993	Factory-Made Wrought Steel Buttwelding Fittings
ANSI B16.14-1991	Ferrous Pipe Plugs, Bushings, and Locknuts with Pipe Threads
ANSI B16.11-1991	Forged Steel Fittings, Socket-Welding and Threaded
ANSI B16.5 1988	Pipe Flanges and Flanged Fittings, Steel, Nickel Alloy and Other Special Alloys
ANSI B16.20-1993	Ring-Joint Gaskets and Grooves for Steel Pipe Flanges

MATERIALS

The American Society for Testing and Materials (ASTM)

1989 Annual Book of ASTM Standards, Section 1 Iron and Steel Products
Volume 01.01/Steel Piping, Tubing and Fittings, 131 Standards
Volume 01.03/Steel Plate, Sheet, Strip, and Wire, 95 Standards
Volume 01.04/Structural Steel, Concrete Reinforcing Steel, Pressure Vessel Plate and Forgings, Steel Rails, Wheels, and Tires — 135 Standards

MISCELLANEOUS

International Conference of Building Officials (ICBO)

Uniform Building Code — 1991

Steel Structures Painting Council (SSPC)

Steel Structures Painting Manual
Volume 1, Good Painting Practice
Volume 2, Systems and Specifications

Uniform Boiler and Pressure Vessel Laws Society

Synopsis of Boiler and Pressure Vessel Laws, Rules and Regulations by States, Cities, Counties and Provinces (United States and Canada) —1990

Environment Protection

Code of Federal Regulations, Protection of Environment, 1988 40- Parts 53 to 60
(Obtainable from any Government Printing Office)

American Society of Civil Engineers (ASCE)

Minimum Design Loads for Buildings and Other Structures
ASCE 7-88 (Formerly ANSI A58.1)

TABULATION OF THE BOILER AND PRESSURE VESSEL LAWS OF THE UNITED STATES AND CANADA

JURISDICTION	I	II	IV	VIII(1)	VIII(2)	XI
Alabama	N	N	N	N	N	N
Alaska	Y	Y	Y	Y	Y	N
Arizona	Y	N	Y	N	N	N
Arkansas	Y	Y	Y	Y	Y	Y
California	Y	Y	Y	Y	Y	Y
Colorado	Y	Y	Y	Y	Y	Y
Connecticut	Y	Y	Y	N	N	N
Delaware	Y	Y	Y	Y	Y	Y
Florida	Y	N	Y	Y	N	N
Georgia	Y	Y	Y	Y	Y	Y
Hawaii	Y	Y	Y	Y	Y	Y
Idaho	Y	Y	Y	Y	Y	N
Illinois	Y	N	Y	Y	Y	Y
Indiana	Y	Y	Y	Y	Y	N
Iowa	Y	Y	Y	Y	Y	Y
Kansas	Y	Y	Y	N	N	Y
Kentucky	Y	Y	Y	Y	N	N
Louisiana	Y	N	Y	N	N	N
Maine	Y	N	Y	Y	Y	N
Maryland	Y	Y	Y	Y	Y	Y
Massachusetts	Y	Y	Y	Y	N	Y
Michigan	Y	Y	Y	Y*	N	Y
Minnesota	Y	N	Y	Y	Y	Y
Mississippi	Y	N	Y	Y	N	N
Missouri	Y	Y	Y	Y	Y	Y
Montana	Y	N	Y	N	N	N
Nebraska	Y	N	Y	N	N	N
Nevada	Y	N	Y	Y	Y	N
New Hampshire	Y	N	Y	Y	N	N
New Jersey	Y	Y	Y	Y	Y	Y
New Mexico	Y	N	Y	N	N	N
New York	Y	N	Y	Y	N	N
North Carolina	Y	Y	Y	Y	Y	Y
North Dakota	Y	N	Y	Y	Y	N
Ohio	Y	Y	Y	Y	Y	Y
Oklahoma	Y	N	Y	Y	Y	N
Oregon	Y	Y	Y	Y	Y	Y
Pennsylvania	Y	Y	Y	Y	Y	Y
Puerto Rico	Y	Y	Y	Y	Y	Y
Rhode Island	Y	Y	Y	Y	Y	Y
South Carolina	N	N	N	N	N	N
South Dakota	Y	N	Y	N	N	N
Tennessee	Y	Y	Y	Y	Y	Y
Texas	Y	Y	Y	N	N	Y
Utah	Y	Y	Y	Y	Y	Y
Vermont	Y	N	Y	Y	Y	N
Virginia	Y	Y	Y	Y	Y	Y

KEY: ASME Code
SEC
I- Power Boilers
III (1)- Nuclear Components
IV- Heating Boilers
VIII (1)- Pressure Vessels
VIII (2)- Pressure Vessels
XI- Inservice Inspection, Nuclear

Y- Required by Law
N- Law does not cover
*- Only portions of Code or call juridiction

SOURCE:
This condensed tabulation of data is taken from Synopsis of Boiler and Pressure Vessel Laws, Rules and Regulations. Copyright 1994 Uniform Boiler and Pressure Vessel Laws Society.

It does not list all the exemption and variances in the many laws and regulations. More detailed information is available under the Society's Synopsis. Further information may be obtained from the jurisdictional authority or the Society.

TABULATION OF THE
BOILER AND PRESSURE VESSEL LAWS
OF THE UNITED STATES AND CANADA
(continued)

JURISDICTION	I	II	IV	VIII(1)	VIII(2)	XI
Washington	Y	Y	Y	Y	Y	Y
West Virginia	Y	N	N	Y	N	N
Wisconsin	Y	Y	Y	Y	Y	Y
Wyoming	Y	N	N	Y	N	N
Alberta	Y	Y	Y	Y	Y	Y
British Columbia	Y	Y	Y	Y	Y	Y
Manitoba	Y	Y	Y	Y	Y	Y
New Brunswick	Y	Y	Y	Y	Y	Y
New Foundland & Labrador	Y	N	Y	Y	Y	N
Northwest Territories	Y	N	Y	Y	Y	N
Nova Scotia	Y	N	N	Y	Y	N
Ontario	Y	Y	Y	Y	Y	Y
Prince Edward Island	Y	Y	Y	Y	Y	N
Quebec	Y	Y	Y	Y	Y	N
Saskatchewan	Y	Y	Y	Y	Y	Y
Yukon Territory	Y	Y	Y	Y	N	N
Albuquerque	Y	N	Y	N	N	N
Buffalo	Y	Y	Y	Y	N	N
Chicago	Y	Y	Y	Y	Y	Y
Denver	Y	Y	Y	Y	Y	Y
Des Moines	Y	N	Y	N	N	N
Detroit	Y	Y	Y	Y	Y	Y
Los Angeles	Y	Y	Y	Y	Y	N
Memphis	Y	Y	Y	Y	Y	Y
Miami	Y	Y	Y	Y	Y	N
Milwaukee	Y	Y	Y	Y	Y	N
New Orleans	Y	Y	Y	Y	Y	Y
New York City	Y	N	Y	Y	N	N
Omaha	Y	N	Y	Y	N	N
St. Joseph	Y	Y	Y	Y	Y	N
St. Louis	Y	N	Y	Y	Y	N
Seattle	Y	Y	Y	Y	Y	Y
Spokane	Y	N	Y	Y	Y	N
Tacoma	Y	Y	Y	Y	Y	N
Tucson	Y	N	Y	Y	Y	N
Tulsa	Y	N	Y	Y	Y	N
University City	Y	N	Y	Y	Y	N
Dade County	Y	N	Y	Y	Y	N
Jefferson Parish	Y	Y	Y	Y	Y	N
St. Louis County	Y	Y	Y	Y	Y	N
District of Columbia	Y	Y	Y	Y	Y	Y

KEY: ASME Code SEC
- I- Power Boilers
- III (1)- Nuclear Components
- IV- Heating Boilers
- VIII (1)- Pressure Vessels
- VIII (2)- Pressure Vessels
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LIST OF ORGANIZATIONS

SPONSORING OR PUBLISHING CODES AND STANDARDS OR SPECIFICATIONS DEALING WITH PIPING AND PRESSURE VESSELS

NAME & ADDRESS	ABBREVIATION
AMERICAN BUREAU OF SHIPPING 45 Eisenhower Drive Paramus, NJ 07652 (201) 368-9100	
ENGINEERING & SAFETY SERVICE **AMERICAN INSURANCE SERVICES GROUP, INC.** 85 John Street, New York, NY 10038	AISG, INC.
AMERICAN NATIONAL STANDARDS INSTITUTE** 11 West 42nd Street, New York, NY 10036 (212) 642-4900 ** Formerly: United States of America Standards Institute (USAS) and prior to 1966 American Standards Association (ASA)	ANSI
AMERICAN PETROLEUM INSTITUTE 1220 L Street, Northwest Washington, D.C. 20005 (202) 682-8375	API
AMERICAN SOCIETY OF MECHANICAL ENGINEERS 345 East 47th Street New York, N.Y. 10017 (212) 705-7722	ASME
AMERICAN SOCIETY FOR TESTING AND MATERIALS 1916 Race Street Philadelphia, PA 19103 (215) 299-5585	ASTM
AMERICAN WATER WORKS ASSOCIATION 6666 West Quincy Avenue Denver, CO 80235 (303) 794-7711	AWWA
AMERICAN WELDING SOCIETY P.O. Box 351040 Miami, FL 33135 For Orders Only 800-334-9353	AWS
BRITISH STANDARDS INSTITUTION* 389 Chiswick High Road London W4 4AL *British Standard Publications are available from The American National Standards Institute	BSI
CANADIAN STANDARDS ASSOCIATION 178 Rexdale Blvd. Rexdale, ON Canada M9W 1R3	CSA
COMMERCIAL UNION INSURANCE COMPANY OF AMERICA 1 Beacon Street Boston, MA 02108 (617) 725-7304	

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NAME & ADDRESS	ABBREVIATION
COMPRESSED GAS ASSOCIATION, INC. 1725 Jefferson Davis Highway, Suite 1004 Arlington, Va 22202 (703) 412-0900	CGA
EXPANSION JOINT MANUFACTURERS ASSOCIATION 25 North Broadway, Tarrytown, NY 10591	EJMA
HEAT EXCHANGE INSTITUTE, INC. 1300 Summer Ave., Cleveland, OH 44115 (216) 241-7333	
INTERNATIONAL CONFERENCE OF BUILDING OFFICIALS 5360 S. Workman Mill Rd. Whittier, CA 90601 (310) 699-0541	ICBO
THE NATIONAL BOARD OF BOILER AND PRESSURE VESSEL INSPECTORS 1055 Crupper Ave., Columbus OH 43229 (614) 888-8320	NBBI
NATIONAL FIRE PROTECTION ASSOCIATION P.O. Box 9101, Batterymarch Park Quincy, MA 02269 (617) 770-3000 (800) 344-3555	NGPA
OCCUPATIONAL SAFETY AND HEALTH ADMINISTRATION 200 Constitution Avenue, N.W. Washington, D.C. 20210 (800) 344-3555	OSHA
STEEL TANK INSTITUTE 570 Oakwood Rd., Lake Zurich, IL 60047 (708) 438-TANK	
STEEL STRUCTURES PAINTING COUNCIL 40 24th Street, 6th Floor, Pittsburgh, PA 15222 Telephone: (412) 687-1113 Fax: (412) 687-1153	SSPC
TUBULAR EXCHANGER MANUFACTURERS 25 North Broadway, Tarrytown, NY 10591 (914) 332-0040	
UNDERWRITERS LABORATORIES, INC. 333 Pfingsten Road, Northbrook, IL 60062 (708) 272-8800	UL
UNITED STATES COAST GUARD 2100 Second St. S.W., Washington, D.C. 20593 (202) 267-2967	
UNIFORM BOILER AND PRESSURE VESSEL LAWS SOCIETY 308 N. Evergreen Rd., Suite 240 Louisville, KY 40243 (502) 244-6029	UBPVLS

LIST OF ORGANIZATIONS

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NAME & ADDRESS	ABBREVIATION
UNITED STATES ENVIRONMENT PROTECTION AGENCY 401 M Street, S.W., Washington, D.C. 20460	USEPA
WELDING RESEARCH COUNCIL 345 East 47th St. New York, NY 10017 (212) 705-7956	WRC
AMERICAN SOCIETY OF CIVIL ENGINEERS 345 E. 47th Street New York, NY 10017 (800) 548-2723	ASCE

LITERATURE

1. S. Timoshenko, *Strength of Materials,* 1955, D. Van Nostrand Co., New York.

2. S.P. Timoshenko,*Theory of Plates and Shells, 1959, McGraw-Hill Book Co., New York.*

3. *R.J. Roark and W.C. Young, Formulas for Stress and Strain,* 5th Ed. 1975, McGraw-Hill Book Co., New York.

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SUBJECTS

COVERED BY THE WORK(S) LISTED UNDER LITERATURE

(The numbers refer to the work(s) dealing with the subject.)

SUBJECTS *(continued)*

DEFINITIONS

Abrasion — The removal of surface material from any solid through the frictional action of another solid, a liquid, or a gas or combination thereof.

Absolute Pressure — The pressure above the absolute zero value of pressure that theoretically obtains in empty space or at the absolute zero of temperatre, as distinguished from gage pressure.

Alloy — Any of a large number of substances having metallic properties and consisting of two or more elements; with few exceptions, the components are usually metallic elements.

Angle Joint — A joint between two members located in intersecting planes between zero (a butt joint) and 90 deg. (a corner joint). (Code UA-60)

Angle Valve — A valve, usually of the globe type, in which the inlet and outlet are at right angles.

Annealing — Annealing generally refers to the heating and controlled cooling of solid material for the purpose of removing stresses, making it softer, refining its structure or changing its ductility, toughness or other properties. Specific heat treatments covered by the term annealing include black annealing, blue annealing, box annealing, bright annealing, full annealing, graphitizing, maleabilizing and process annealing.

Arc Welding — A group of welding processes wherein coalescence is produced by heating with an electric arc, with or without the application of pressure and with or without the use of filler metal.

Automatic Welding — Welding with equipment which performs the entire welding operation without constant observation and adjustment of the controls by an operator. The equipment may or may not perform the loading and unloading of the work.

Backing — Material backing up the joint during welding to facilitate obtaining a sound weld at the root.

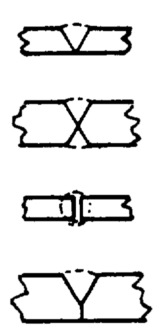
Backing Strip is a backing in a form of a strip.

Brittle Fracture — The tensile failure with negligible plastic deformation of an ordinary ductile metal.

Brittleness — Materials are said to be brittle when they show practically no permanent distortion before failure.

Bushing — A pipe fitting for connecting a pipe with a female fitting of larger size. It is a hollow plug with internal and external threads.

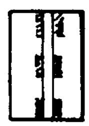
Butt Weld — A weld joining two members lying approximately in the same plane. Butt welded joints in pressure vessel construction shall have complete penetration and fusion.



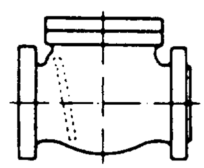
Types of butt welded joints: Single or Double Beveled Joint, Square Butt Joint. Full Penetration, Partial Penetration Butt Joints. Butt Joints with or without backing strips.

Centroid of an Area (Center of Gravity of an Area) — That point in the plane of the area about any axis through which the moment of the area is zero; it coincides with the center of gravity of the area materialized as an infinitely thin homogeneous and uniform plate.

Chain Intermittent Fillet Welds — Two lines of intermittent fillet welding in a tee or lap joint, in which the increments of welding in one line are approximately opposite to those in the other line.



Check Valve — A valve designed to allow a fluid to pass through in one direction only. A common type has a plate so suspended that the reverse flow aids gravity in forcing the plate against a seat, shutting off reverse flow.



Chipping — One method of removing surface defects such as small fissures or seams from partially worked metal. If not eliminated, the defects might carry through to the finished material. If the defects are removed by means of a gas torch the term "deseaming" or "scarfing" is used.

Clad Vessel — A vessel made from plate having a corrosion resistant material integrally bonded to a base of less resistant material. (Code UA-60)

Complete Fusion — Fusion which has occurred over the entire base-metal surfaces exposesd for welding.

Complete Penetration — Penetration which extended completely through the joint.

Corner Joint — A welded joint at the junction of two parts located approximately at right angles to each other.

Corrosion — Chemical erosion by motionless or moving agents. Gradual destruction of a metal or alloy due to chemical processes such as oxidation or the action of a chemical agent.

Corrosion Fatigue — Damage to or failure of a metal due to corrosion combined with fluctuating fatigue stresses.

Coupling — A threaded sleeve used to connect two pipes. They have internal threads at both ends to fit external threads on pipe.

Creep — Continuous increase in deformation under constant or decreasing stress. The term is usually used with reference to the behavior of metals under tension at elevated temperatures. The similar yielding of a material under compressive stress is usually called *plastic flow* or *flow*.

Damaging Stress — The least unit stress, of a given kind and for a given material and condition of service, that will render a member unfit for service before the end of its normal life. It may do this by producing excessive set, or by causing creep to occur at an excessive rate, or by causing fatigue cracking, excessive strain hardening, or rupture.

Deformation (Strain) — Change in the form or in the dimension of a body produced by stress. *Elongation* is often used for tensile strain, *compression* or *shortening* for compressive strain, and *detrusion* for shear strain. *Elastic deformation* is such deformation as disappears on removal of stress; *permanent deformation* is such deformation as remains on removal of stress.

Design Pressure — The pressure used in determining the minimum permissible thickness or physical characteristics of the different parts of the vessel. (Code UA-60)

Design Temperature — The mean metal temperature (through the thickness) expected under operating conditions for the part considered. (Code UG-20)

Discontinuity, Gross Structural — A source of stress or strain intensification which affects a relatively large portion of a structure and has a significant effect on the overall stress or strain pattern or on the structure as a whole. Examples of gross structural discontinuities are head-to-shell and flange-to-shell junctions, nozzles, and junctions between shells of different diameters or thicknesses.

Discontinuity, Local Structural — A source of stress or strain intensification which affects a relatively small volume of material and does not have a significant effect on the overall stress or strain pattern or on the structure as a whole. Examples are small fillet radii, small attachments, and partial penetration welds.

Double-Welded Butt Joint — A butt joint welded from both side.

Double-Welded Lap Joint — A lap joint in which the overlapped edges of the members to be joined are welded along the edges of both members.

Ductility — The ability of a metal to stretch and become permanently deformed without breaking or cracking. Ductility is measured by the percentage reduction in area and percentage elongation of test bar.

Eccentricity — A load or component of a load normal to a given cross section of a member is eccentric with respect to that section if it does not act through the centroid. The perpendicular distance from the line of action of the load to either principal central axis is the *eccentricity* with respect to that axis.

Efficiency of a Welded Joint — The efficiency of a welded joint is expressed as a numerical quantity and is used in the design of a joint as a multiplier of the appropriate allowable stress value. (Code UA-60)

Elastic — Capable of sustaining stress without permanent deformation; the term is also used to denote conformity to the law of stress-strain proportionality. An elastic stress or elastic strain is a stress or strain within the elastic limit.

Elastic Limit The least stress that will cause permanent set.

Electroslag Welding — A welding process in which consumable electrodes are fed into a joint containing flux; the current melts the flux, and the flux in turn melts the faces of the joint and the electrodes, allowing the weld metal to form a continuously cast ingot between the joint faces. Used in pressure vessel construction when back of the welding is not accessible. All butt welds joined by electroslag welding shall be examined radiographically for their full length. (Code UW-11) (a) (6)

Endurance Limit (Fatigue Strength) — By endurance limit of a material is usually meant the maximum stress which can be reversed an indefinitely large number of times without producing fracture.

Erosion-Corrosion — Attack on a metal surface resulting from the combined effects of erosion and corrosion.

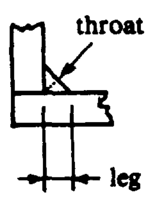
Expansion Joint — A joint whose primary purpose is not to join pipe but to absorb that longitudinal expansion in the pipe line due to heat.

Factor of Safety — The ratio of the load that would cause failure of a member or structure, to the load that is imposed upon it in service.

Fatigue — Tendency of materials to fracture under many repetitions of a stress considerably less than the ultimate static strength.

Fiber Stress — A term used for convenience to denote the longitudinal tensile or compressive stress in a beam or other member subject to bending. It is sometimes used to denote this stress at the point or points most remote from the neutral axis, but the term ***stress in extreme fiber*** is preferable for this pupose. Also, for convenience, the longitudinal elements or filaments of which a beam may be imagined as composed are called ***fibers.***

Fillet Weld — A weld of approximately triangular cross section joining two surfaces approximately at right angles to each other.



The effective stress-carrying area of a fillet weld is assumed to be the product of the throat dimension and the length of the weld. Fillet welds are specified by their leg dimension.

The throat dimension of an equal legged fillet weld is 0.707 times the leg dimension.
Fillet welds may be employed as strength welds for pressure parts of vessels within the limitations given in Table UW-12 of the Code. The allowable load on fillet welds shall equal the product of the weld area (based on minimum leg dimension), the allowable stress value in tension of the material being welded, and a joint efficiency of 55%. (Code UW-18) The allowable stress values for fillet welds attaching nozzles and their reinforcements to vessels are (in shear) 49% of stress value for the vessel material. (Code (UW-15)

Filler Metal — Material to be added in making a weld.

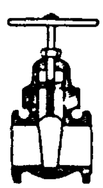
Full Fillet Weld — A fillet weld whose size is equal to the thickness of the thinner member joined.

Gage Pressure — The amount by which the total absolute pressure exceeds the ambient atmospheric pressure.

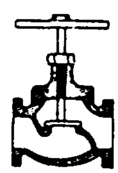
Galvanizing — Applying a coating of zinc to ferrous articles. Application may be by hot dip process or electrolysis.

Gas Welding — A group of welding processes wherein coalescence is produced by heating with a gas flame with or without application of pressure and with or without the use of filler metal.

Gate Valve — A valve employing a gate, often wedge-shaped, allowing fluid to flow when the gate is lifted from the seat. Such valves have less resistance to flow than globe valves.

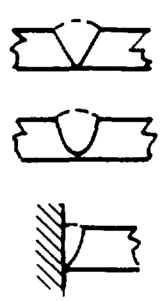


Globe Valve — One with a somewhat globe shaped body with a manually raised or lowered disc which when closed rests on a seat so as to prevent passage of a fluid.



Graphitization — Precipitation of carbon in the form of graphite at grain boundaries, as occurs if carbon steel is in service long enough above 775°F, and C-Mo steel above 875°F. Graphitization appears to lower steel strength by removing the strengthening effect of finely disperse iron carbides (cementite) from grains. Fine-grained, aluminum-killed steels seem to be particularly susceptible to graphitization.

Groove Weld — A weld made by depositing filler metal in a groove between two members to be joined.



Standard shapes of grooves: V, U and J. Each may be single or double.
Stress values for groove welds in tension 74% and in shear 60% of the stress value of vessel material joined by the weld. (Code UW-15)

Head — The end (enclosure) of a cylindrical shell. The most commonly used types of heads are hemispherical, ellipsoidal, flanged and dished (torispherical), conical and flat.

Heat Treatment — Heat treating operation performed either to produce changes in mechanical properties of the material or to restore its maximum corrosion resistance. There are three principal types of heat treatment; annealing, normalizing, and post-weld heat treatment.

High-Alloy Steel — Steel containing large percentages of elements other than carbon.

Hydrogen Brittleness — Low ductility of a metal due to its absorption of hydrogen gas, which may occur during an electrolytic process or during cleaning. Also known as acid brittleness.

Hydrostatic Test — The completed vessel filled with water shall be subjected to a test pressure which is equal to 1½ times the maximum allowable working pressure to be marked on the vessel or 1½ times the design pressure by agreement between the user and the manufacturer. (Code UG-99)

Impact Stress — Force per unit area imposed to material by a suddenly applied force.

Impact Test — Determination of the degree of resistance of a material to breaking by impact, under bending, tensile and torsion loads; the energy absorbed is measured by breaking the material by a single blow.

Intermittent Weld — A weld whose continuity is broken by unwelded spaces.

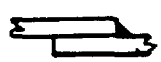
Isotropic — Having the same properties in all directions. In discussions pertaining to strength of materials, isotropic usually means having the same strength and elastic properties (modulus of elasticity, modulus of rigidity, Poisson's ratio) in all directions.

Joint Efficiency — A numerical value expressed as the ratio of the strength of a riveted, welded, or brazed joint to the strength of the parent metal.

Joint Penetration — The minimum depth a groove weld extends from its face into a joint, exclusive of reinforcement.

Killed Steel — Thoroughly deoxidized steel, (for example, by addition of aluminum or silicon), in which the reaction between carbon and oxygen during solidification is suppressed. This type of steel has more uniform chemical composition and properties as compared to other types.

Lap Joint — A welded joint in which two overlapping metal parts are joined by means of a fillet, plug or slot welds.



Layer or Laminated Vessel — A vessel having a shell which is made up of two or more separate layers. (Code UA-60)

Leg — See under Fillet Weld.

Lethal Substances — Poisonous gases or liquids of such a nature that a very small amount of the gas or of the vapor of the liquid is dangerous to life when inhaled. It is the responsibility of the user of the vessel to determine that the gas or liquid is lethal. (Code UW-2)

Ligament — The section of solid material in a tube sheet or shell between adjacent holes.

Lined Vessel — A vessel having a corrosion resistant lining attached intermittently to the vessel wall. (Code UA-60)

Liquid Penetrant Examination (PT). A method of nondestructive examination which provides for the detection of discontinuities open to the surface in ferrous and nonferrous materials which are nonporous. Typical discontinuities detectable by this method are cracks, seams, laps, cold shuts, and laminations. (Code UA-60)

Loading — Loadings (loads) are the results of various forces. The loadings to be considered in designing a vessel: internal or external pressure, impact loads, weight of the vessel, superimposed loads, wind and earthquake, local load, effect of temperature gradients. (Code UG-22)

Low-Alloy Steel — A hardenable carbon steel generally containing not more than about 1% carbon and one or more of the following alloyed components: $<$ (less than) 2% manganese, $<$ 4% nickel, $<$ 2% chromium, 0.6% molybdenum, and $<$ 0.2% vanadium.

Magnetic Particle Examination (MT). A method of detecting cracks and similar discontinuities at or near the surface in iron and the magnetic alloys of

Malleable Iron — Cast iron heat-treated to reduce its brittleness. The process enables the material to stretch to some extent and to stand greater shock.

Material Test Report — A document on which the material manufacturer records the results of tests examinations, repairs, or treatments required by the basic material specification to be reported. (Code UA-60)

Maximum Allowable Stress Value — The maximum unit stress permissible for any specified material that may be used in the design formulas given in the Code. (UG-23)

Maximum Allowable Working Pressure — The maximum gage pressure permissible at the top of a completed vessel in its operating position for a designated temperature. This pressure is based on the weakest element of the vessel using norminal thicknesses exclusive of allowances for corrosion and thickness required for loadings other than pressure. (Code UA-60)

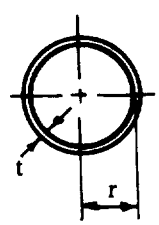
Membrane Stress — The component of normal stress which is uniformly distributed and equal to the average value of stress across the thickness of the section under consideration.

Metal Arc Welding — An arc welding process in which the electrode supplies the filler metal to the weld.

Modulus of Elasticity (Young's Modulus) — The rate of change of unit tensile or compressive stress with respect to unit tensile or compressive strain for the condition of uniaxial stress within the proportional limit. For most, but not all materials, the modulus of elasticity is the same for tension and compression. For nonisotropic materials such as wood, it is necessary to distinguish between the moduli of elasticity in different directions.

Modulus of Rigidity (Modulus of Elasticity in Shear) — The rate of change of unit shear stress with respect to unit shear strain, for the condition of pure shear within the proportional limit.

Moment of Inertia of an Area (Second Moment of an Area) — The moment of inertia of an area with respect to an axis is the sum of the products obtained by multiplying each element of the area by the square of its distance from the axis.



The Moment of Inertia (I) for thin walled cylinder about its transverse axis; $I = \pi r^3 t$
where r = mean radius of cylinder
t = wall thickness

Needle Valve — A valve provided with a long tapering point in place of the ordinary valve disk. The tapering point permits fine graduation of the opening.

Neutral Axis — The line of zero fiber stress in any given section of a member subject to bending; it is the line formed by the intersection of the neutral surface and the section.

Neutral Surface — The longitudinal surface of zero fiber stress in a member subject to bending; it contains the neutral axis of every section.

Nipple — A tubular pipe fitting usually threaded on both ends and under 12 inches in length. Pipe over 12 inches long is regarded as cut pipe.

Non-Pressure Welding — A group of welding processes in which the weld is made without pressure.

Normalizing — Heating to about 100° F. above the critical temperature and cooling to room temperature in still air. Provision is often made in normalizing for controlled cooling at a slower rate, but when the cooling is prolonged the term used is annealing.

Notch Sensitivity — A measure of the reduction in strength of a metal caused by the presence of a notch.

Notch Strength — The ratio of maximum tensional load required to fracture a notched specimen to the original minimum cross-sectional area.

Notch Test — A tensile or creep test of a metal to determine the effect of a surface notch.

Operating Pressure — The pressure at the top of a pressure vessel at which it normally operates. It shall not exceed the maximum allowable working pressure and it is usually kept at a suitable level below the setting of the pressure relieving devices to prevent their frequent opening. (Code UA-60)

Operating or Working Temperature — The temperature that will be maintained in the metal of the part of the vessel being considered for the specified operation of the vessel (see UG-20 and UG-23). (Code UA-60)

Oxidation or scaling of metals occurs at high temperatures and access of air. Scaling of carbon steels from air or steam is negligible up to 1000°F. Chromium increases scaling resistance of carbon steels. Decreasing oxidation resistance makes austenitic stainless steels unsuitable for operating temperatures above 1500°F.

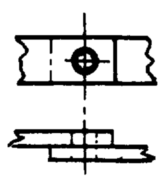
P-Number — The number of welding procedure-group. The classification of materials based on hardenability characteristic and the purpose of grouping is to reduce the number of weld procedures. (Code Section IX)
All carbon steel material listed in the Code (with the exception of SA-612) are classified as P-No. 1.

Pass — The weld metal deposited by one progression along the axis of a weld.

Plasticity — The property of sustaining appreciable (visible to the eye) permanent deformation without rupture. The term is also used to denote the property of yielding or flowing under steady load.

Plug Valve — One with a short section of a cone or tapered plug through which a hole is cut so that fluid can flow through when the hole lines up with the inlet and outlet, but when the plug is rotated 90°, flow is blocked.

Plug Weld — A weld made in a circular hole in one member of a lap joint. The hole may or may not be partially or comppletely filled with weld metal.



For pressure vessel construction plug welds may be used in lap joints in reinforcements around openings, in non pressure structural attachments (Code UW-17) and for attachment of heads with certain restrictions. (Code Table UW-12)

Pneumatic Test — The completed vessel may be tested by air pressure in lieu of hydrostatic test when the vessel cannot safely be filled with water or the traces of testing liquid cannot be tolerated (in certain services). The pneumatic test pressure shall be 1.25 times the maximum allowable working pressure to be stamped on the vessel. (Code UG-100)

Poisson's Ratio — The ratio of lateral unit strain to longitudinal unit strain, under the condition of uniform and uniaxial longitudinal stress within the proportional limit.

Porosity — Gas pockets or voids in metal. (Code UA-60)

Postweld Heat Treatment — Heating a vessel to a sufficient temperature to relieve the residual stresses which are the result of mechanical treatment and welding.
Pressure vessels and parts shall be postweld heat treated:
When the vessels are to contain lethal substances, (Code UW-2)
Unfired Steam Boilers (UW-2)
Pressure vessels and parts subject to direct firing when the thickness of welded joints exceeds 5/8 in. (UW-2)
When the carbon (P-No. 1) steel material thickness exceeds 1½ in. at welded connections and attachments (see Code Table UCS-56 for exceptions).

Preheating — Heat applied to base metal prior to welding operations.

Pressure Relief Valve — A valve which relieves pressure beyond a specified limit and recloses upon return to normal operating conditions.

Pressure Vessel — A metal container generally cylindrical or spheroid, capable of withstanding various loadings.

Pressure Welding — A group of welding processes wherein the weld is completed by use of pressure.

Primary Stress — A normal stress or a shear stress developed by the imposed loading which is necessary to satisfy the simple laws of equilibrium of external and internal forces and moments. The basic characteristics of a primary stress is that it is not self-limiting. Primary stresses which considerably exceed the yield strength will result in failure or at least, in gross distortion. A thermal stress is not classified as a primary stress. Primary membrane stress is divided into "general" and "local" categories. A general primary membrane stress is one which is so distributed in the structure that no redistribution of load occurs as a result of yielding. Examples of primary stress are: general membrane stress in a circular cylindrical or a spherical shell due to internal pressure or to distributed live loads; bending stress in the central portion of a flat head due to pressure.

Quench Annealing — Annealing an austenitic ferrous alloy by heating followed by quenching from solution temperatures. Liquids used for quenching are oil, fused salt or water, into which a material is plunged.

Radiographing — The process of passing electronic radiations through an object and obtaining a record of its soundness upon a sensitized film. (Code UA-60)

Radius of Gyration — The radius of gyration of an area with respect to a given axis is the square root of the quantity obtained by dividing the moment of inertia of the area with respect to that axis by the area.

Random Lengths — A term indicating no specified minimum or maximum length with lengths falling within the range indicated.

Refractory — A material of very high melting point with properties that make it suitable for such uses as high-temperature lining.

Residual Stress — Stress remaining in a structure or member as a result of thermal or mechanical treatment, or both.

Resistance Welding — A pressure welding process wherein the heat is produced by the resistance to the flow of an electric current.

Root of Weld — The bottom of the weld.

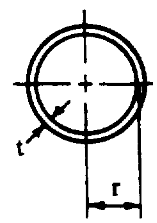
Scale — An iron oxide formed on the surface of hot steel, sometimes in the form of large sheets which fall off when the sheet is rolled.

Scarf — Edge preparation; preparing the contour on the edge of a member for welding.

Seal Weld — Seal weld used primarily to obtain tightness.

Secondary Stress — A normal stress or a shear stress developed by the constraint of adjacent parts or by self-constraint of a structure. The basic characteristic of a secondary stress is that it is self-limiting. Local yielding and minor distortions can satisfy the conditions which cause the stress to occur and failure from one application of the stress is not to be expected. Examples of secondary stress are: general thermal stress; bending stress at a gross structural discontinuity.

Section Modulus — The term pertains to the cross section of a beam. The *section modulus* with respect to either principal central axis is the moment of inertia with respect to that axis divided by the distance from that axis to the most remote point of the section. The section modulus largely determines the flexural strength of a beam of given material.



Section Modulus (Z) of a thin walled cylinder ($r>10t$) about its transverse axis:

$$Z = r^2 \pi t$$

where r = mean radius of cylinder, in.
t = wall thickness, in.

Shell — Structural element made to enclose some space. Most of the shells are generated by the revolution of a plane curve.
In the terminology of this book shell is the cylindrical part of a vessel or a spherical vessel is called also a spherical shell.

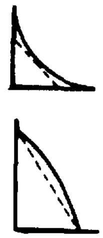
Shear Stress — The component of stress tangent to the plane of reference.

Shielded Metal-Arc Welding — An arc weldingprocess wherein coalescence is produced by heating with an electric arc between a covered metal electrode and the work. Shielding is obtained from decomposition of the electrode covering. Pressure is not used and filler metal is obtained from the electrode.

Single-Welded Butt Joint — A butt joint welded from one side only.

Single-Welded Lap Joint — A lap joint in which the overlapped edges of the members to be joined are welded along the edge of one member.

Size of Weld — Groove Weld: The depth of penetration.



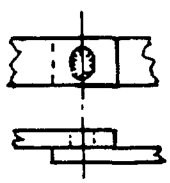
Equal Leg Fillet Weld: the leg length of the largest isosceles right-triangle which can be inscribed within the fillet weld cross section.

Unequal Leg Fillet Weld: The leg length of the largest right triangle which can be inscribed within the fillet weld cross section.

Slag — A result of the action of a flux on nonmetallic constituents of a processed ore, or on the oxidized metallic constituents that are undesirable. Usually consist of combinations of acid oxides and basic oxides with neutral oxides added to aid fusibility.

Slenderness Ratio — The ratio of the length of a uniform column to the least radius of gyration of the cross section.

Slot Weld — A weld made in an elongated hole (slot) in one member of a lap joint, joining that member to that portion of the surface of the other member which is exposed through the hole. The hole may or may not be filled completely with weld metal.

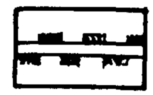


Specific Gravity — The ratio of the density of a material to the density of some standard material, such as water at a specified temperature, for example, 4 °C or 60 °F. or (for gases) air at standard conditions of pressure and temperature.

Spot Welding — Electric-resistance welding in which fusion is limited to a small area directly between the electrode tips.

Stability of Vessels — (Elastic Stability) The strength of a vessel to resist buckling or wrinkling due to axial compressive stress. The stability of a vessel is severely affected by out of roundness.

Staggered Intermittent Fillet Welds — Two lines of intermittent fillet welding in a tee or lap joint, in which the increments of welding in one line are staggered with respect to those in the other line.



Static Head — The pressure of liquids that is not moving, against the vessel wall, is due solely to the "Static Head", or height of the liquid. This pressure shall be taken into consideration in designing vessels.

Strain — Any forced change in the dimensions of a body. A stretch is a *tensile strain;* a shortening is a *compressive strain;* an angular distortion is a *shear strain.* The word *strain* is commonly used to connote *unit strain.*

Stress — Internal force exerted by either of two adjacent parts of a body upon the other across an imagined plane of separation. When the forces are parallel to the plane, the stress is called *shear stress;* when the forces are normal to the plane the stress is called *normal stress;* when the normal stress is directed toward the part on which it acts it is called *compressive stress;* when it is directed away from the part on which it acts it is called *tensile stress.*

Stresses in Pressure Vessels — Longitudinal (meridional) S_1 stress

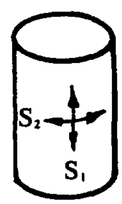
Circumferential (hoop) S_2 stress

S_1 and S_2 called membrane (diaphragm) stress for vessels having a figure of revolution

Bending stress

Shear stress

Discontinuity stresses at an abrupt change in thickness or shape of the vessel.



Stud — A threaded fastener without a head, with threads on one end or both ends, or threaded full length. (Code UA-60)

Submerged Arc Welding — An arc welding process wherein coalescence is produced by heating with an arc or arcs between a bare metal electrode or electrodes and the work. The welding is shielded by a blanket of granular, fusible material on the work. Pressure is not used and filler metal is obtained from the electrode and sometimes from a supplementary welding rod.

Tack Weld — A weld made to hold parts of a weldment in proper alignment until the final welds are made.

Tee Joint — A welded joint at the junction of two parts located approximately at right angles to each other in the form of a T.

Tensile Strength — The maximum stress a material subjected to a stretching load can withstand without tearing.

Tensile Stress — Stress developed by a material bearing tensile load.

Test — Trial to prove that the vessel is suitable for the design pressure.
See Hydrostatic test, Pneumatic test.

Test Pressure — The requirements for determining the test pressure based on calculations are outlined in UG-99(c) for the hydrostatic test and in UG-100(b) for the pneumatic test. The basis for calculated test pressure in either of these paragraphs is the highest permissible internal pressure as determined by the design formulas, for each element of the vessel using nominal thicknesses with corrosion allowances included and using the allowable stress values for the temperature of the test. (Code UA-60)

Thermal Fatigue — The development of cyclic thermal gradients producing high cyclic thermal stresses and subsequent local cracking of material.

Thermal Stress — A self-balancing stress produced by a nonuniform distribution of temperature or by differing thermal coefficients of expansion. Thermal stress is developed in a solid body whenever a volume of material is prevented from assuming the size and shape that it normally should under a change in temperature.

Thickness of Vessel Wall

1. The "required thickness' is that computed by the formulas in this Division, before corrosion allowance is added (see UG-22).
2. The "design thickness' is the sum of the required thickness and the corrosion allowance (see UG-25).
3. The "nominal thickness" is the thickness selected as commercially availble, and as supplied to the manufacturer; it may exceed the design thickness. (Code UA-60)

Throat — See under Fillet Weld.

Tolerances — For plates the maximum permissible undertolerance is the smaller value of 0.01 in. or 6% of the design thickness. (Code UG-16)
The manufacturing undertolerance on wall thickness of heads, pipes and pipefittings shall be taken into account and the next heavier commercial wall thickness may then be used.

U.M. Plate — Universal Mill Plate or plate rolled to width by vertical rolls as well as to thickness by horizontal rolls.

Ultrasonic Examination (UT) — a nondestructive means for locating and identifying internal discontinuitis by detecting the reflections they produce of a beam of ultrasonic vibrations (Code UA-60)

Undercut — A groove melted into the base metal adjacent to the toe of a weld and left unfilled by weld metal.

Unit Strain — Unit tensile strain is the elongation per unit length; unit compressive strain is the shortening per unit length; unit shear strain is the change in angle (radians) between two lines originally at right angles to each other.

Unit Stress — The amount of stress per unit of area.

Vessel — A container or structural envelope in which materials are processed, treated, or stored; for example, pressure vessels, reactor vessels, agitator vessels, and storage vessels (tanks).

Weaving — A technique of depositing weld metal in which the electrode is oscillated from side to side.

Weld — A localized coalescence of metal produced by fusion with or without use of filler metal, and with or without application of pressure.

Weld Metal — The metal resulting from the fusion of the base metal and the filler metal.

Welding — The metal joining process used in making welds.
In the construction of vessels the welding processes are restricted by the Code (UW-27) as follows:

1. Shielded metal arc, submerged arc, gas metal arc, gas tungsten arc, plasma arc, atomic hydrogen metal arc, oxyfuel gas welding, electroslag, and electron beam.
2. Pressure welding processes: flash, induction, resistance, pressure thermit, and pressure gas.

Welding Procedure — The materials, detailed methods and practices involved in the production of a welded joint.

Welding Rod — Filler metal, in wire or rod form, used in the gas welding process, and in those arc welding processes wherein the electrode does not furnish the deposited metal.

Wrought Iron — Iron refined to a plastic state in a puddling furnace. It is characterized by the presence of about 3 per cent of slag irregularly mixed with pure iron and about 0.5 per cent carbon.

Yield Point — The lowest stress at which strain increases without increase in stress. For some purposes it is important to distingish between the *upper* yield point, which is the stress at which the stress-strain diagram first becomes horizontal, and the *lower* yield point, which is the somewhat lower and almost constant stress under which the metal continues to deform. Only a few materials exhibit a true yield point; for some materials the term is sometimes used as synonymous with yield strength.

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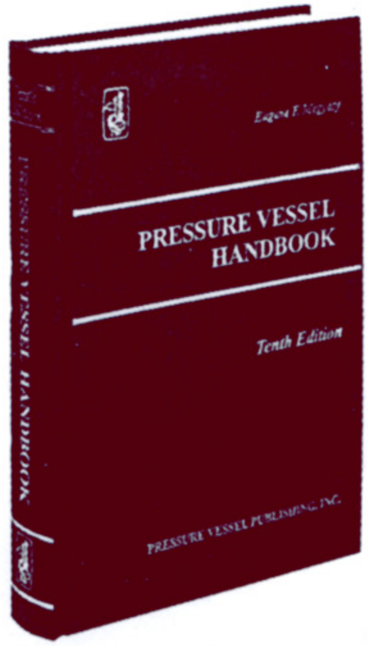

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