PRESSURE VESSEL DESIGN OVER VIEW

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CONTENTS

DESIGN MARGIN AND CODE COMPARISION

COMPARISON of the various pressure vessel codes

INTERGRAPH

Allowable stress is base on these characteristics of the metal

ASME Section VIII Division 1

S = smaller of: UTS / 3.5 or Yield / 1.5 = 20 000 psi (138 MPa)

ASME Section VIII Division 2

Sm = smaller of: UTS / 2.4 or Yield / 1.5 = 25 300 psi (174 MPa)

Both based on PED European requirements

EN 13445

f = smaller of: UTS / 2.4 or Yield / 1.5 = 25 300 psi (174 MPa)

PD 5500

f = smaller of: UTS / 2.35 or Yield / 1.5 = 25 300 psi (174 MPa)

We consider Carbon Steel for simplicity

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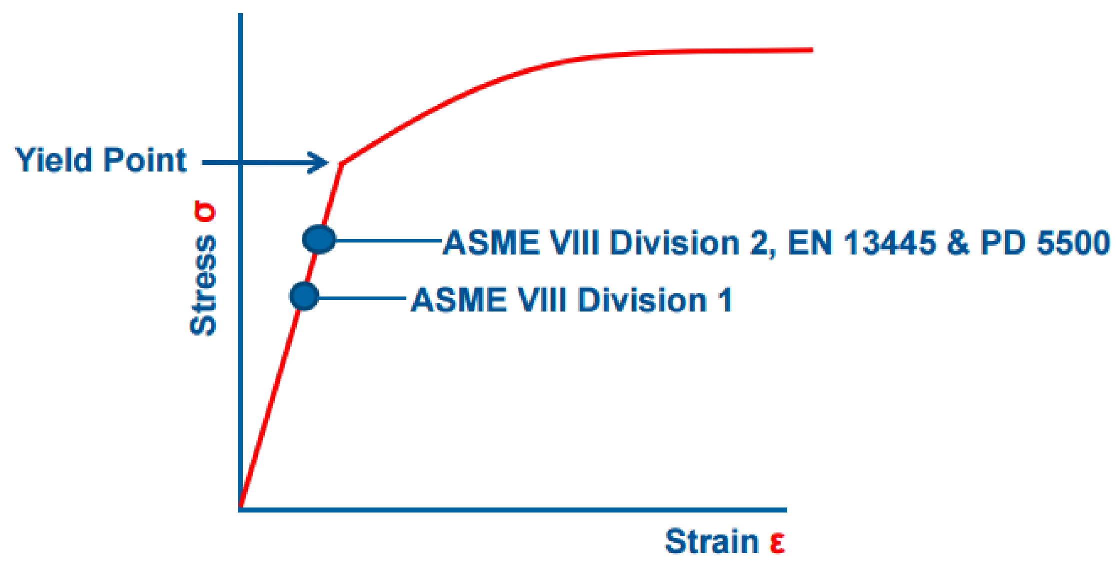
DESIGN MARGIN AND CODE COMPARISION

We look at this on the Stress Strain diagram

ASME VIII, Division 1 has a larger safety margin – safer

This code is still the favoured code throughout the World



LOADINGS TO BE CONSIDERED IN DESIGN

As per UG-22

(a) internal or external design pressure (as defined in UG-21);

(b) weight of the vessel and normal contents under operating or test conditions;

(c) superimposed static reactions from weight of attached equipment, such as motors, machinery, other vessels, piping, linings, and insulation;

(d) the attachment of: *(1)* internals (see Nonmandatory Appendix D);

(2) vessel supports, such as lugs, rings, skirts, saddles, and legs (see Nonmandatory Appendix G);

(e) cyclic and dynamic reactions due to pressure or thermal variations, or from equipment mounted on a vessel, and mechanical loadings;

(f) wind, snow, and seismic reactions, where required;

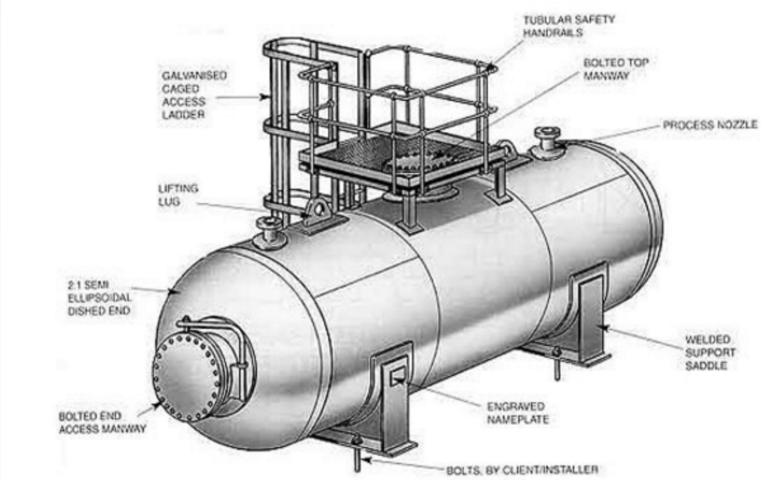
(g) impact reactions such as those due to fluid shock;

(h) temperature gradients and differential thermal expansion;

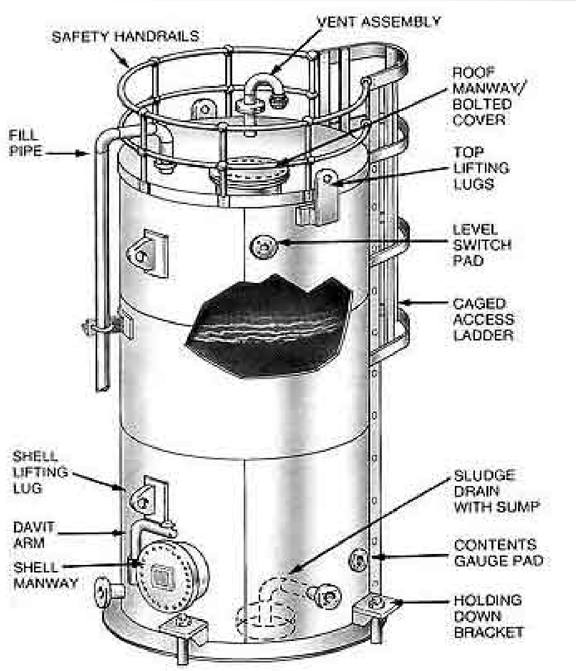
(i) abnormal pressures, such as those caused by deflagration;

(j) test pressure and coincident static head acting during the test (see UG-99).

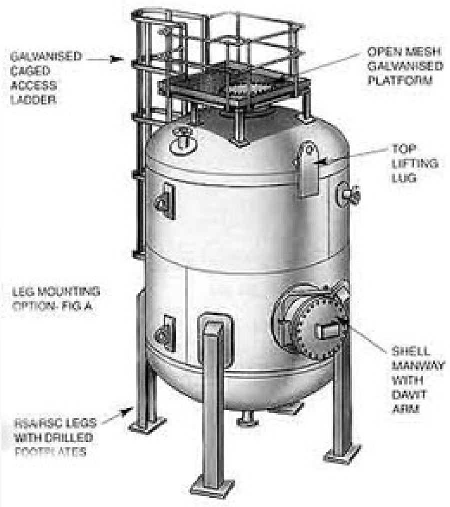
PRESSURE VESSEL COMPONENTS AND DESIGN



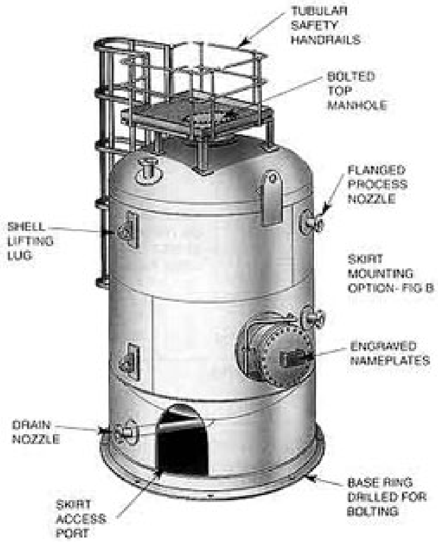
Horizontal Vessel with Saddles



Vertical Vessel with Top& Bot Flat Heads

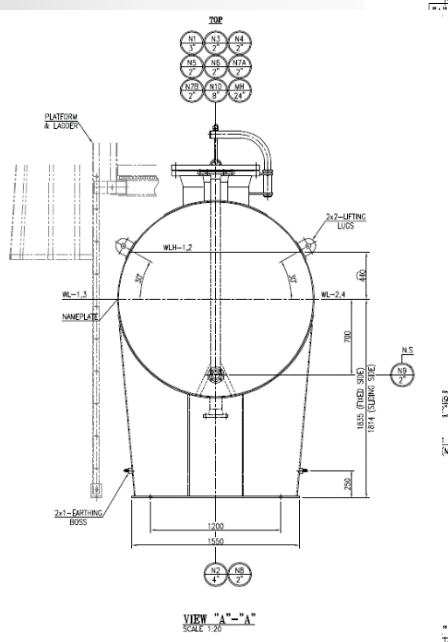


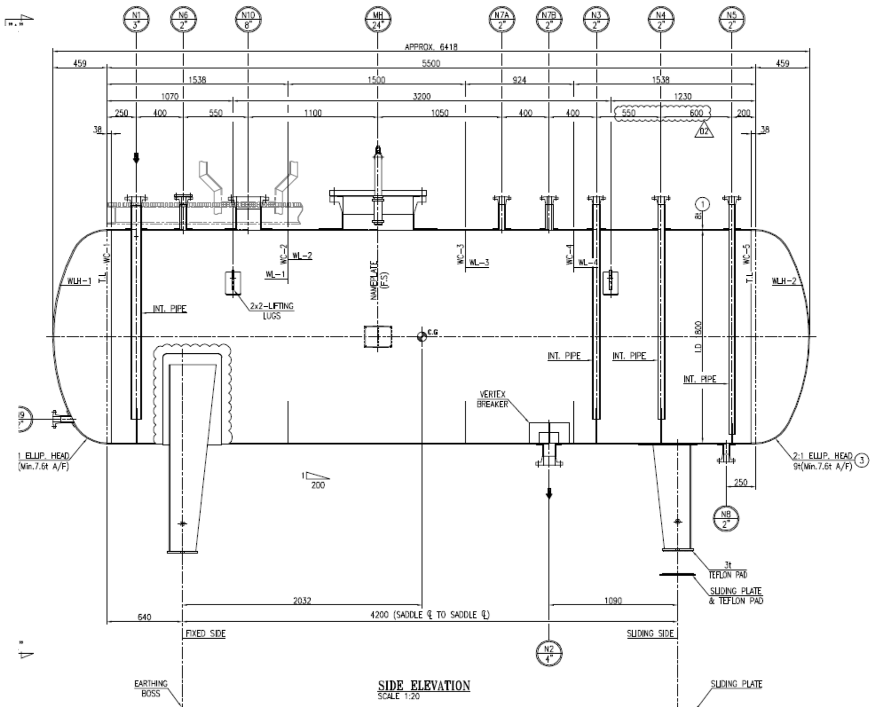
Vertical Vessel with Legs



Vertical Vessel with Skirts

PRESSURE VESSEL GENERAL ARANGEMENT (GA)





NOZZLE LIST

NOZZLE MARK	Q'TY /1 SET	SIZE (DN)	SIZE (NPS)	FLANGE CLASS	FLANGE TYPE	FLANGE SCH.	SERVICE	PROJECTION FROM ℄	REINF. PAD TH'K	REINF. PAD O.D	REMARK
MH	1	600	24	150	WN.RF	8t	MANHOLE	1190	8	1000	W/DAVIT
N1	1	80	3	150	WN.RF	40	INLET	1185	8	180	W/INT. PIPE
N2	1	100	4	150	WN.RF	40	OUTLET	1090	8	210	V/BREAKER
N3	1	50	2	150	WN.RF	40	BYPASS LINE	1185	8	150	W/INT. PIPE
N4	1	50	2	150	WN.RF	40	TEST LINE	1185	8	150	W/INT. PIPE
N5	1	50	2	150	WN.RF	40	LEVEL TRANSMITTER	1185	8	150	W/STILLING WELL
N6	1	50	2	150	WN.RF	40	SPARE	1185	8	150	W/BLIND
N7A/B	2	50	2	150	WN.RF	40	PVRV	1185	8	150	
N8	1	50	2	150	WN.RF	40	DRAIN	1060	8	150	
N9	1	50	2	150	WN.RF	40	TEMPERATURE INDICATOR	SEE DWG.	9	150	
N10	1	200	8	150	WN.RF	40	GAUGE HATCH	1185	8	400	

MAXIMUM NOZZLE LOADS

NOZZLE MARK	SIZE (NPS)	FORCES (kN) Fx	Fy	Fz	MOMENTS (kN-m) Mx	My	Mz
N3,N4,N6	2	1.65	1.65	1.29	0.27	0.34	0.43
N1	3	2.36	2.36	1.87	0.58	0.73	0.94
N2	4	3.0	3.0	2.4	0.96	1.22	1.55

DESIGN DATA

CODE			ASME SEC.VIII DIV.1 2017 EDITION / CODE CASE: N/A
ASME CERTIFICATION MARKED			NO / U-DESIGNATOR: NO
TAG NO. / QUANTITY			T-6202 / 1 UNIT
FLUID NAME			FOAM CONCENTRATE (AR-AFFF)
DENSITY OF CONTENT		kg/m³	1200
PRESS.	DESIGN (INT./EXT.)	mbar g	20 / -5
	OPERATING (MIN./MAX.)	mbar g	-3 / 12
	HYDRO.TEST (HOR.)	mbar g	30
	PNEUM.TEST	mbar g	NONE
TEMP.	DESIGN	°C	60
	OPERATING	°C	AMB
M.D.M.T.			0 °C @ 20 mbarg
IMPACT TEST			NO
CORROSION ALLOWANCE (INT.)		mm.	1.5
RADIOGRAPHY (S/H)			SPOT (UW-11(b)) / FULL (UW-11(a))
JOINT EFFICIENCY (S/H)			0.85 / 1.0
M.A.W.P. (INTERNAL)	PRESS.		20 mbarg @ 60 °C
(HOT & CORRODED)	LIMITING PART		ALL CHAMBER
M.A.W.P. (EXTERNAL)	PRESS.		-5 mbarg @ 60 °C
(HOT & CORRODED)	LIMITING PART		SHELL & NOZZLE MH, N1~N8
STRESS RELIEVED			NO
POSTWELD HEAT TREATMENT			NO
SPECIAL SERVICE			NO
SURFACE AREA		m²	55.88
INSULATION		mm.	NO
FIREPROOFING		mm.	NO
SURFACE PREPARATION (EXT.)			AS PER SPEC. OITS-003
PAINTING SPEC. (EXT.)			AS PER SPEC. OITS-003
INTERNAL LINING			INTERNAL EPOXY COATING
CAPACITY (ACTUAL/WORKING)		m³	15.523 / 13
WEIGHT	EMPTY	kg	9705
	OPERATING	kg	28371
	TEST	kg	25260
WIND DESIGN			NOTE 7
EARTH QUAKE			N/A
DESIGN LIFETIME			25 YEARS

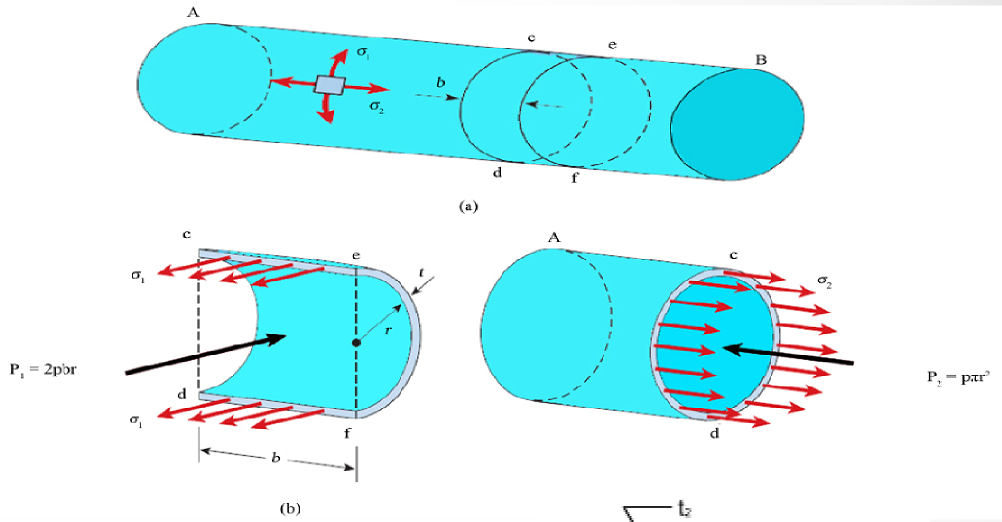
MATERIAL SPECIFICATION

SHELL / HEAD	A283-C / A283-C
FLANGE (SHELL / NOZZLE)	- / A105
NOZZLE NECK (PIPE / PLATE)	A106-B, A312-TP316 / A283-C
GASKET	NOTE 5
INTERNAL PARTS	A283-C / A312-TP316
EXTERNAL PARTS	A283-C
PLATFORM & LADDER	A36
NAMEPLATE / EARTHING BOSS	A240-304 / A479-304
STUD BOLT/NUT	A193-B8M / A194-8M
CHEMICAL BOLT/NUT	HILTI (HIT-RE 500-SD HIT-C TYPE)

MATERIAL LIST (FOR ONE UNIT)

NO.	DESCRIPTION	SIZE	MATERIAL	Q'TY	SPARE	REMARK
1	SHELL	PL-8t	A283-C	1 SET		
2	LEFT HEAD	PL-9t	A283-C	1		
3	RIGHT HEAD	PL-9t	A283-C	1		

DESIGN : SHELL, SPHERICAL HEAD



Shell Design

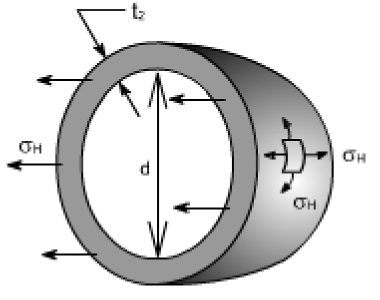
Circumferential Stress

$$t = \frac{PR}{SE - 0.6P} \quad \text{or} \quad P = \frac{SEt}{R + 0.6t}$$

Longitudinal Stress

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

Force diagram



Hemispherical Heads.

$$t = \frac{PL}{2SE - 0.2P} \quad \text{or} \quad P = \frac{2SEt}{L + 0.2t}$$

E = joint Efficiency

P = internal design pressure

R = inside radius

S = maximum allowable stress value

t = minimum required thickness

DESIGN : ELLIPS HEADS, TRANSITION

Ellipsoidal Heads

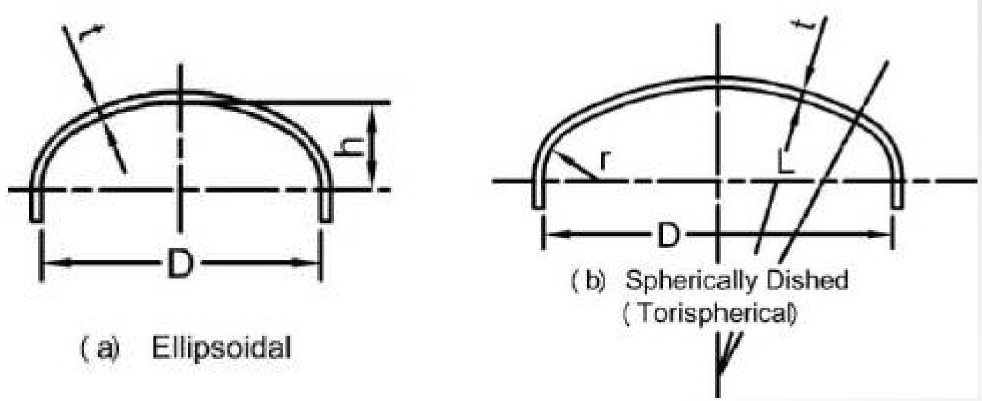
$$t = \frac{PD}{2SE - 0.2P} \quad \text{or} \quad P = \frac{2SEt}{D + 0.2t}$$

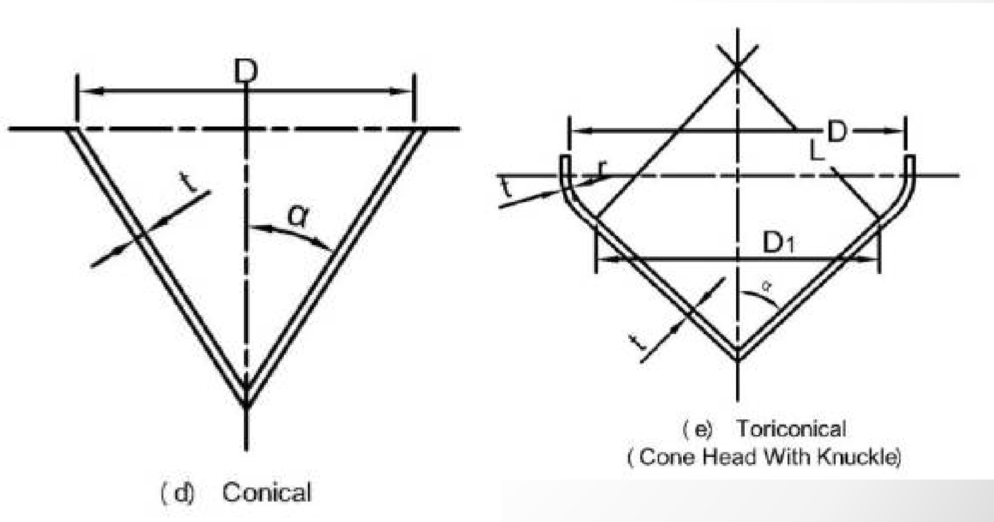
Torispherical Heads

$$t = \frac{0.885PL}{SE - 0.1P} \quad \text{or} \quad P = \frac{SEt}{0.885L + 0.1t}$$

Conical Heads and Sections (Without Transition Knuckle)

$$t = \frac{PD}{2\cos\alpha(SE - 0.6P)} \quad \text{or} \quad P = \frac{2SEt\cos\alpha}{D + 1.2t\cos\alpha}$$





DESIGN : FLAT HEAD

The minimum required thickness of flat unstayed circular heads, covers and blind flanges

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

Blind flange is attached by bolts

$$t = d\sqrt{CP/SE + 1.9Wh_G/SEd^3}$$

Circular Flat Heads

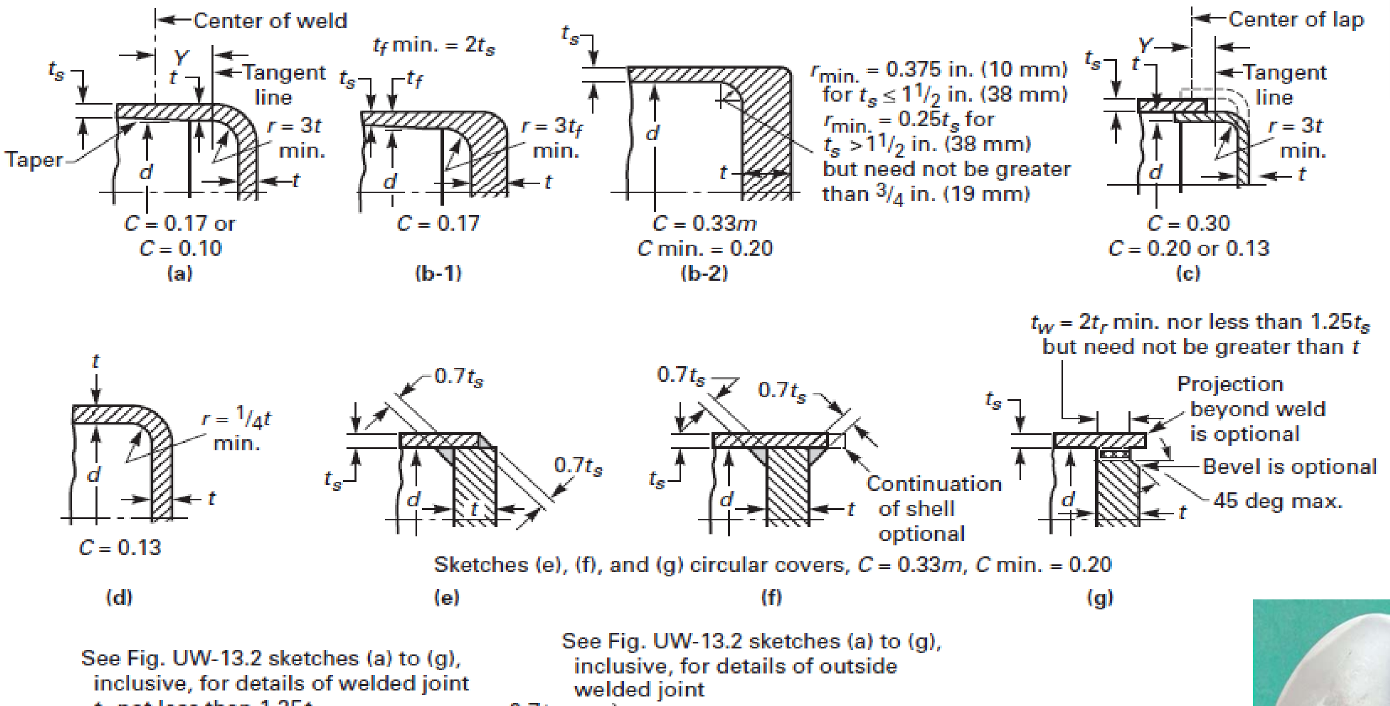
Flat unstayed may be square, rectangular, elliptical, obround, segmental, or otherwise noncircular

$$t = d\sqrt{ZCP/SE} \qquad Z = 3.4 - \frac{2.4d}{D}$$

Rectangular Flat Heads

DESIGN : FLAT HEAD

Figure UG-34
Some Acceptable Types of Unstayed Flat Heads and Covers



Sample of Flat Head with Fillet Corner

DESIGN : MINIMUM THICKNESS AS PER UG-16

**Minimum thickness shall be 1/16 in. (1.5 mm) exclusive of any corrosion allowance.
Exceptions are:

1. heat transfer plates of plate-type heat exchangers
2. inner pipe of double pipe heat exchangers
3. or to pipes and tubes that are enclosed and protected from mechanical damage by a shell, casing, or ducting, where such pipes or tubes are NPS 6 (DN 150) and less

Minimum thickness of shells and heads of **unfired steam boilers shall be 1/4 in. (6 mm) exclusive of any corrosion allowance

Minimum thickness of shells and heads used in **compressed air service, steam service, and water service, made from materials listed in Table UCS-23, shall be 3/32 in. (2.5 mm) exclusive of any corrosion allowance

DESIGN : PLATE, PIPE & FROM HEADS UNDERTOLERANCE

UG-16

**Plate material shall not be ordered with a nominal thickness thinner than the design thickness.

**Plate material with an actual thickness less than the design thickness shall not be used unless the difference in thicknesses is less than the smaller of 0.01 in.(0.3 mm) or 6% of the design thickness

** The nominal thickness of pipe shall be less by Pipe tolerance 12.5% of nominal thickness

UG-81 TOLERANCE FOR FORMED HEADS

**The inner surface of a torispherical, toriconical, hemispherical, or ellipsoidal head shall not deviate outside of the specified shape by more than 1.25% of D nor inside the specified shape by more than 0.625 % of D,

Hemispherical heads or any spherical portion of a torispherical or ellipsoidal head designed for **external pressure shall, in addition to satisfying above, meet the tolerances specified for spheres in UG-80(b) using a value of 0.5 for L/Do .

DESIGN : PLATE, PIPE & FROM HEADS UNDERTOLERANCE

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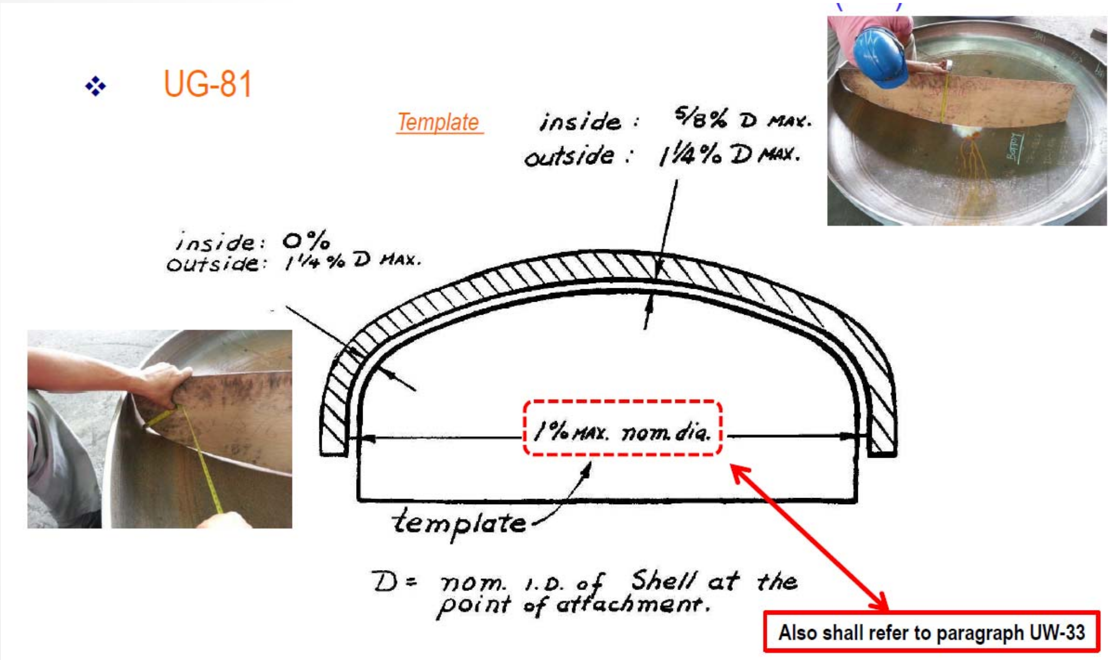
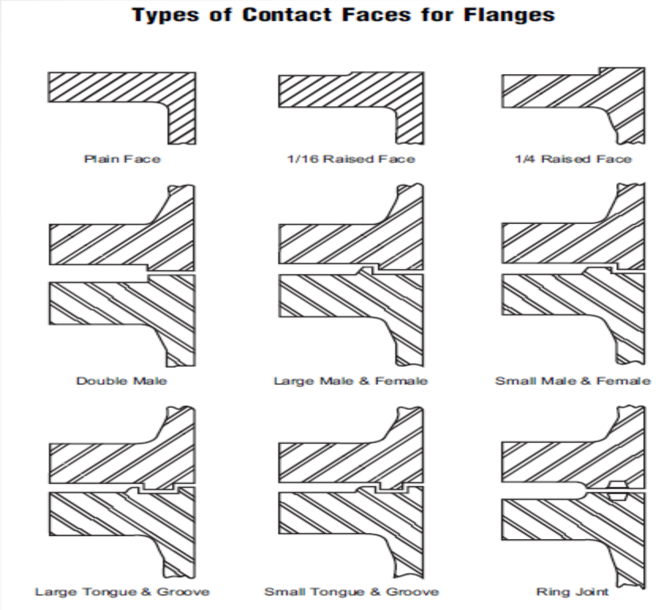


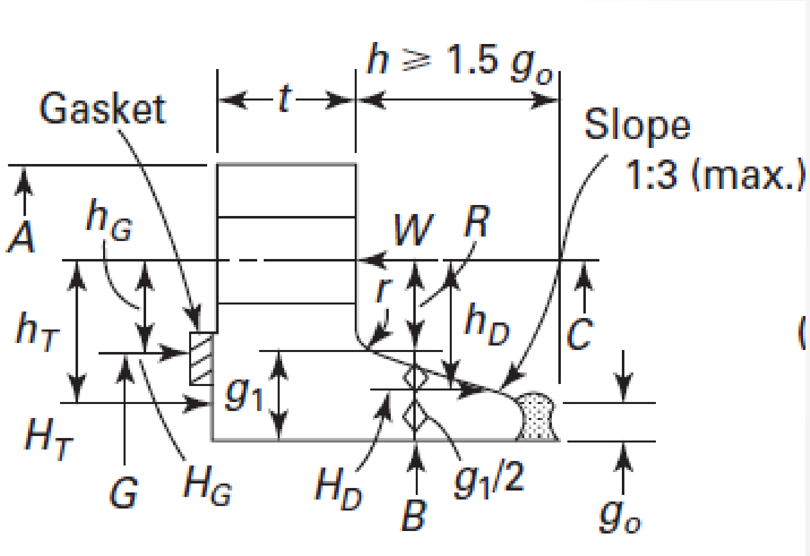
The knuckle radius shall not be less than that specified.

DESIGN : BODY FLANGES



Body Flange

Flanges will be governed by one of two conditions:
1. Gasket seating force, Hg
2. Hydrostatic end force, H

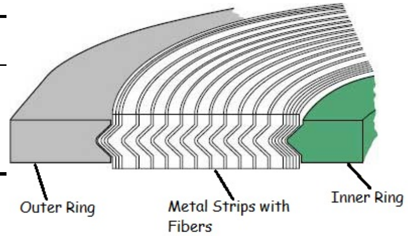


Forces Acting to Flange

DESIGN : GASKET

Gasket Type

Type of Gasket		Surface Finish
1	Ring Type (Flat)	Concentric Serrated or stock finish
2	Solid Metal a. Flat b. Profile c. Profile with Filler	 Concentric Serrated Very Smooth Smooth
3	Spiral Wound (Note 1) a. Inner Ring Only (Style RIR) b. Outer Ring Only (Style CG) c. Inner and Outer Ring (Style CGI) d. No Inner or Outer Ring (Style R)	 Smooth or Serrated; 125 to 250 AARH
4	Metal Jacketed a. Flat Metal jacketed b. Corrugated Metal Jacketed	 Very Smooth
5	Corrugated Metal a. With Filler b. Without Filler	 Smooth
6	Elastomers	Concentric Serrated
7	Ring Type Joint (RTJ) a. Hex b. Oval	 Very Smooth
8	Special a. Delta Ring b. Lens Ring c. Double Cone d. Bridgman e. O-Ring (Metal)	 Very Smooth



Spiral Wound


O-Ring gaskets


Flat Metal jacketed

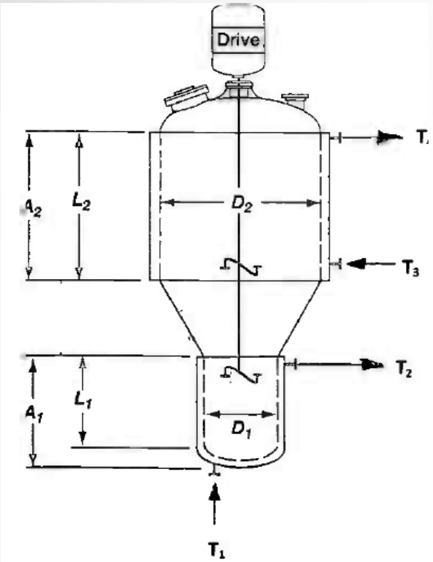

Corrugated Metal Jacketed

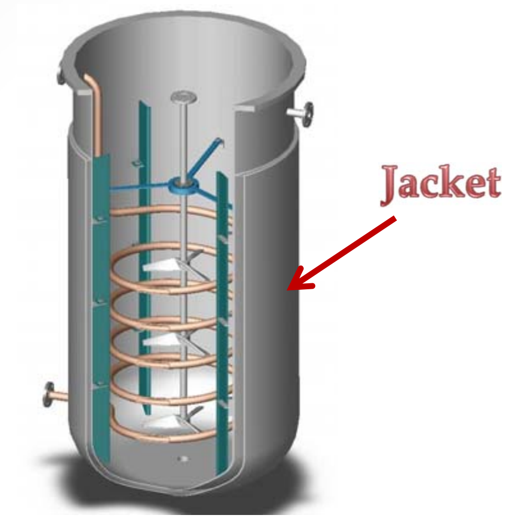

Elastomer gasket

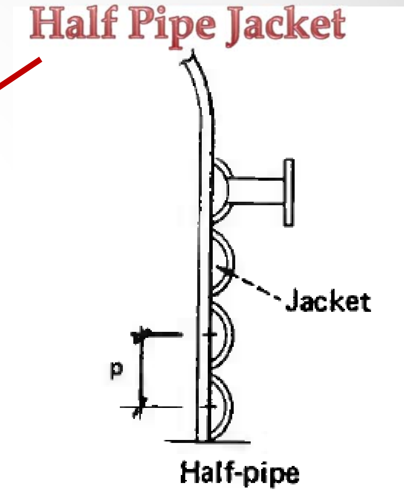

Ring Type Joint gaskets


Kammprofile gaskets

DESIGN : JACKET VESSEL







Permissible Pressure P′ In Half-pipe Jackets

$$P' = F/K$$

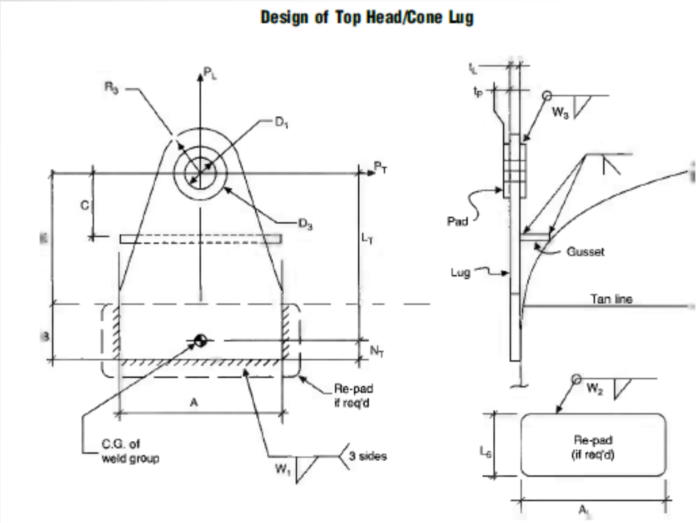
P′ = permissible jacket pressure, psi
F = 1.5*S* - *S′* (*F shall not exceed 1.5 S*)
S = maximum allowable tensile stress at design temperature of shell or head material, psi
S′ = actual longitudinal tensile stress in shell or head due to internal pressure and other axial forces, psi. When axial forces are negligible, *S′* shall be taken as *PR*/2*t* . When the combination of axial forces and pressure stress (*PR*/2*t*) is such that *S′* would be a negative number, then *S ′* shall be taken as zero.
K = factor obtained from Figure EE-1, Figure EE-2, or Figure EE-3

Minimum Thickness Of A Half-pipe Jacket

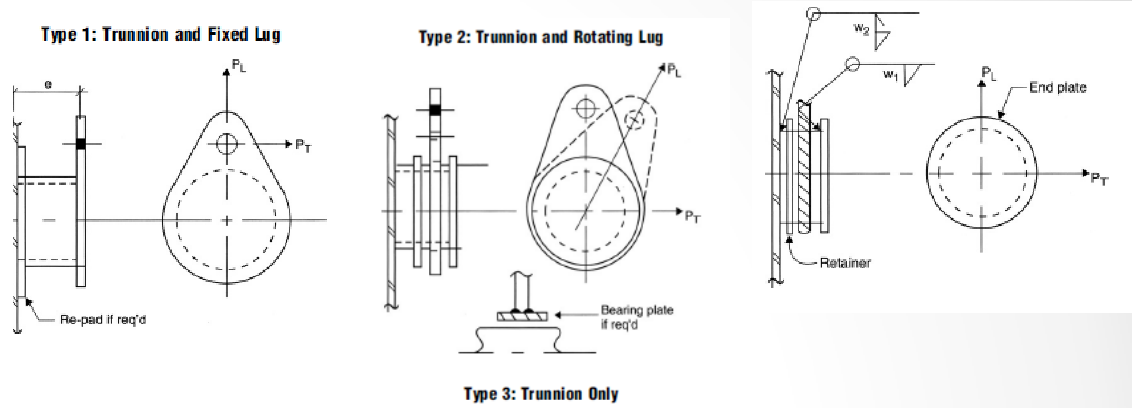
$$T = \frac{P_1 r}{0.85 S_1 - 0.6 P_1}$$

T= minimum thickness of half-pipe jacket, in.
r = inside radius of jacket defined in Figure EE-4, in.
S1 = allowable tensile stress of jacket material at design temperature, psi
P1 = design pressure in jacket, psi. (*P*1 shall not exceed *P′*.)

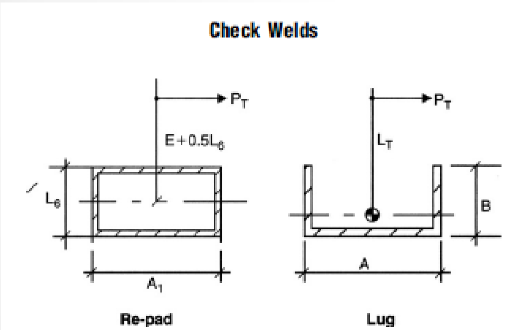
DESIGN : LIFTING PARTS



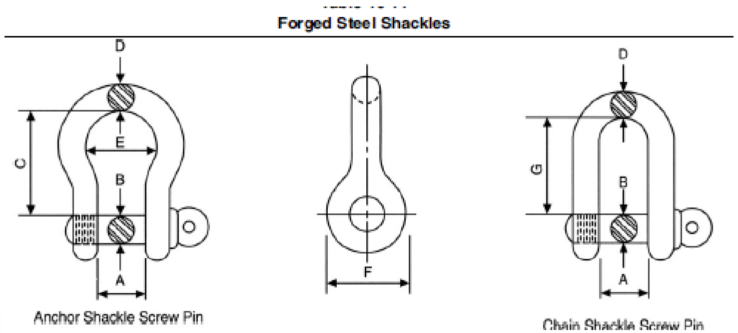
Ear Lug



Trunnion Types



Welding Detail of Ear Lug

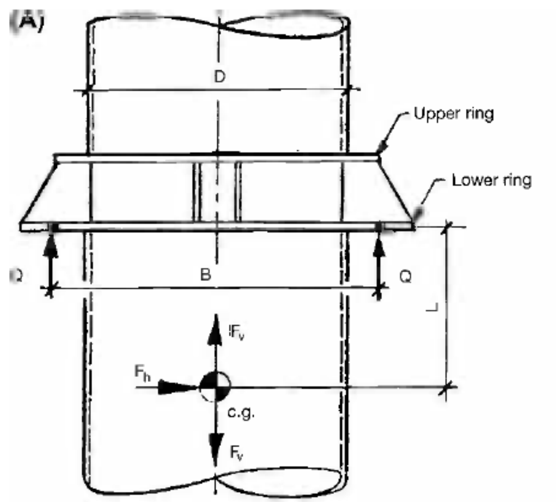


Sample of Lifting Gear : Shackles

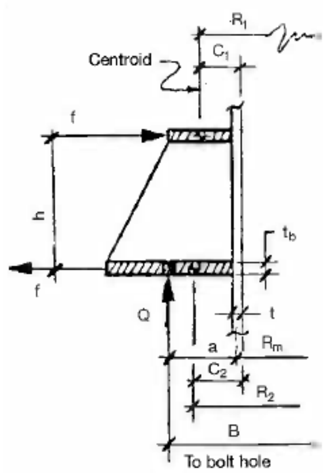
Sample Vessel with Trunnion

DESIGN :SUPPORT LUG

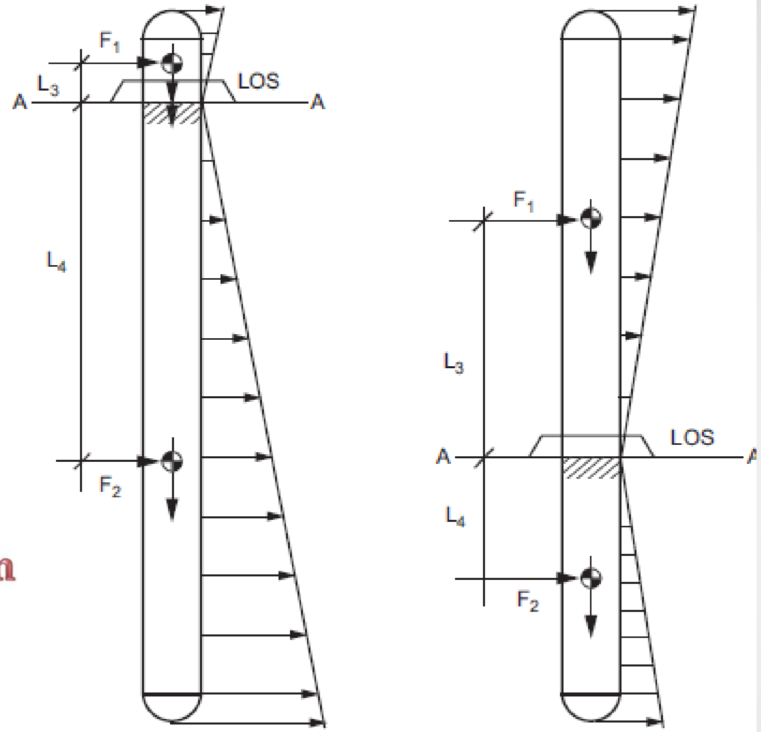
Lateral Force induce Bending Moment at Support



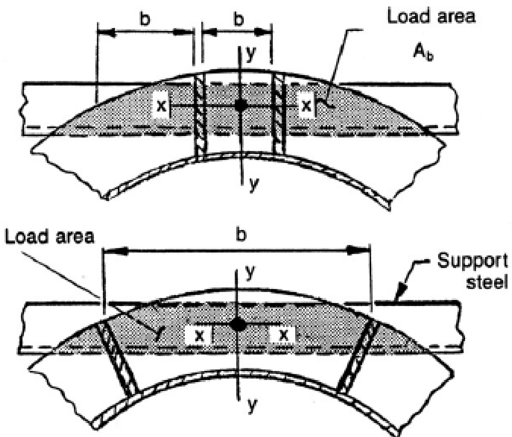
Support Lugs with Stiffener Rings



Load diagram



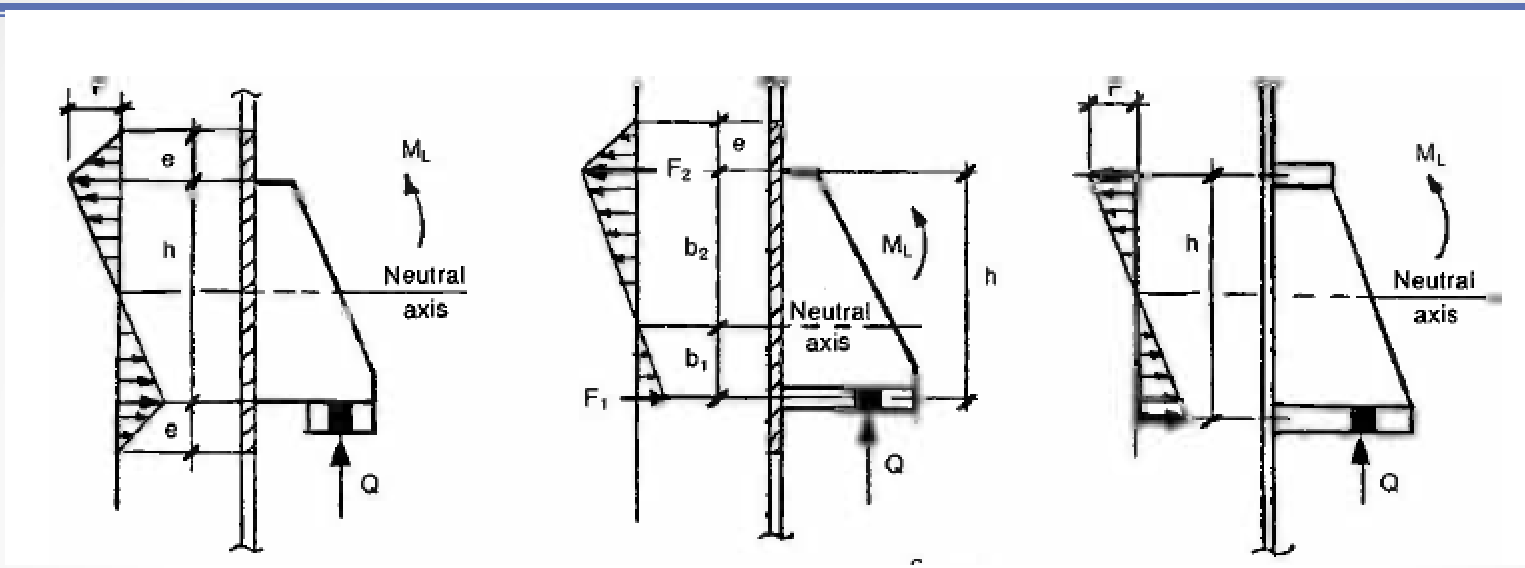
UPPER PORTION GOVERNS



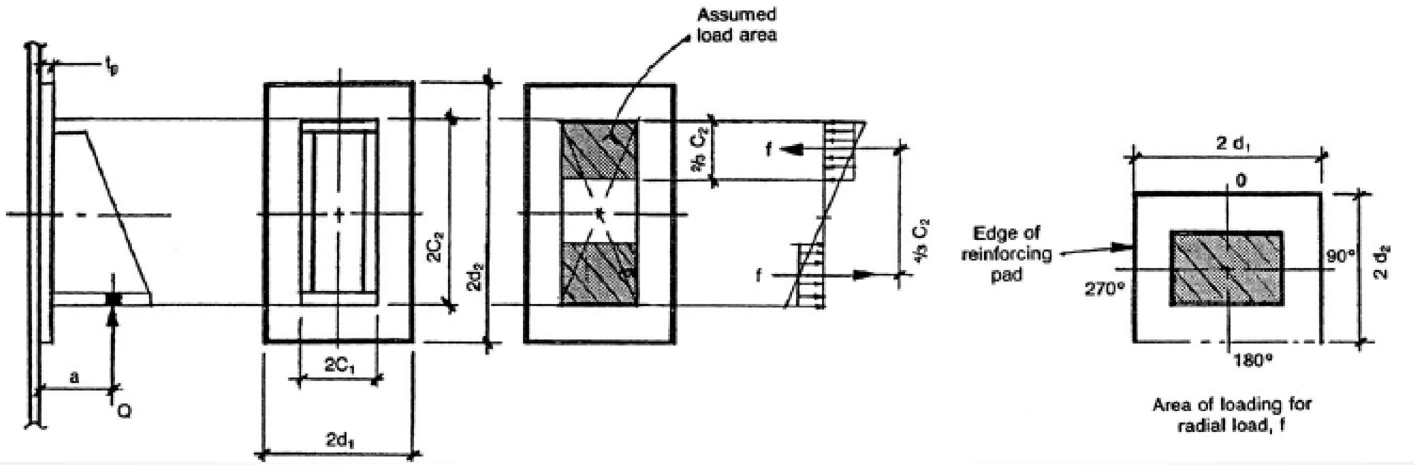
Bearing structure support to be considered

Sample Real job of Support Lugs with Stiffener Rings

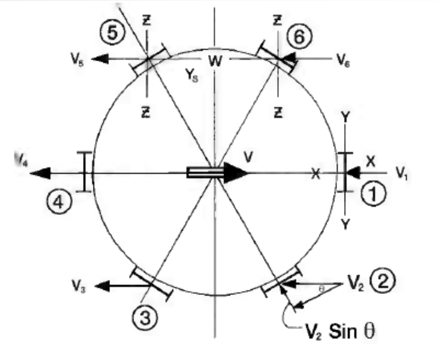
DESIGN :SUPPORT LUG



Analysis when Reinforcing Pads are Used Load diagram



DESIGN : LEGS



Wind load direction acting to vessel with Legs

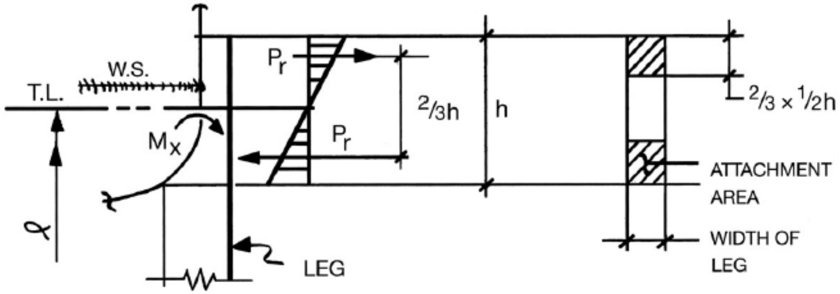
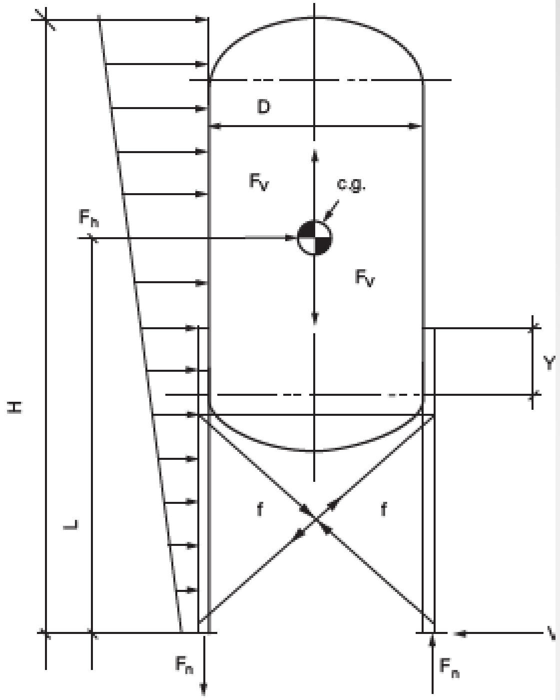
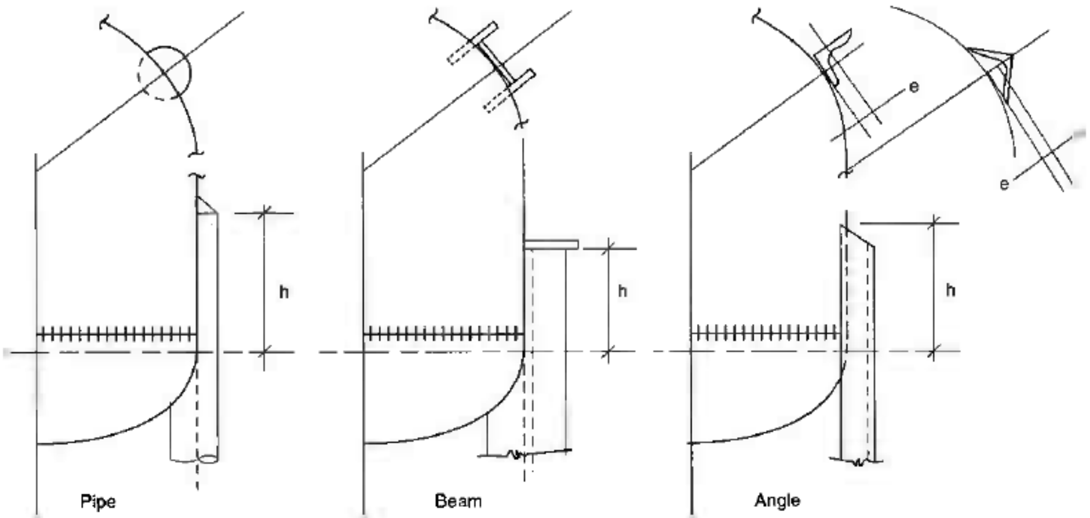


Figure 4-14. Application of local loads in head and shell.

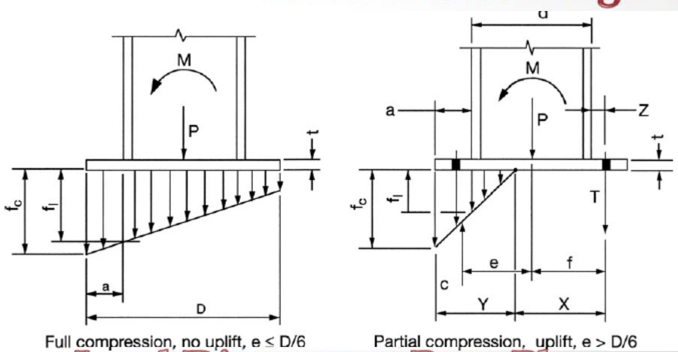
Load direction at Legs attached to Vessel



Lateral Force Diagram

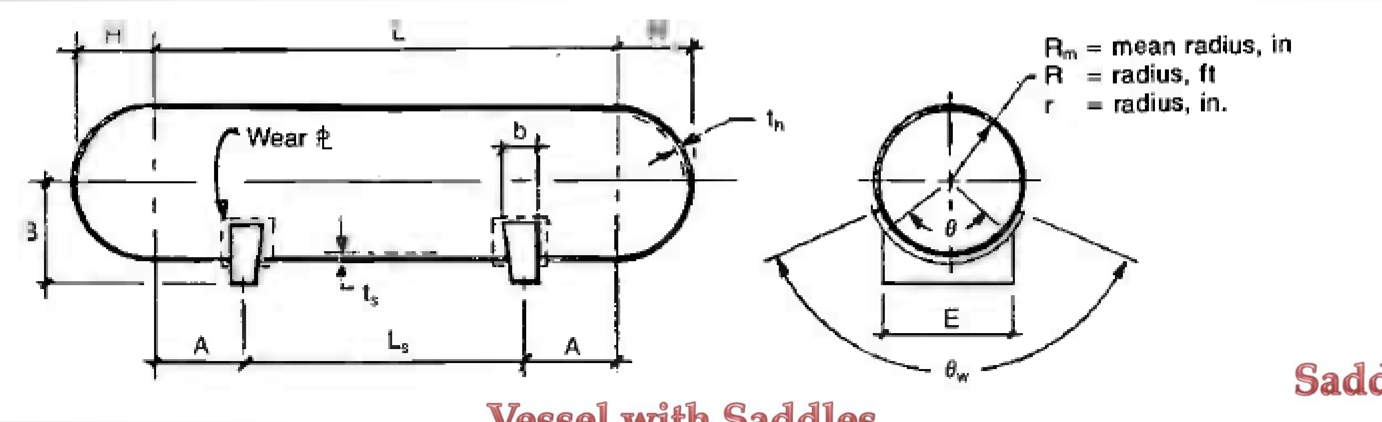


Type of Leg Support

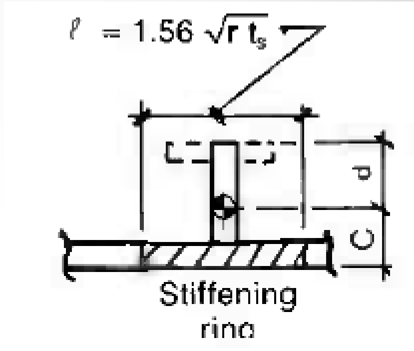


Load Diagram at Base Plate

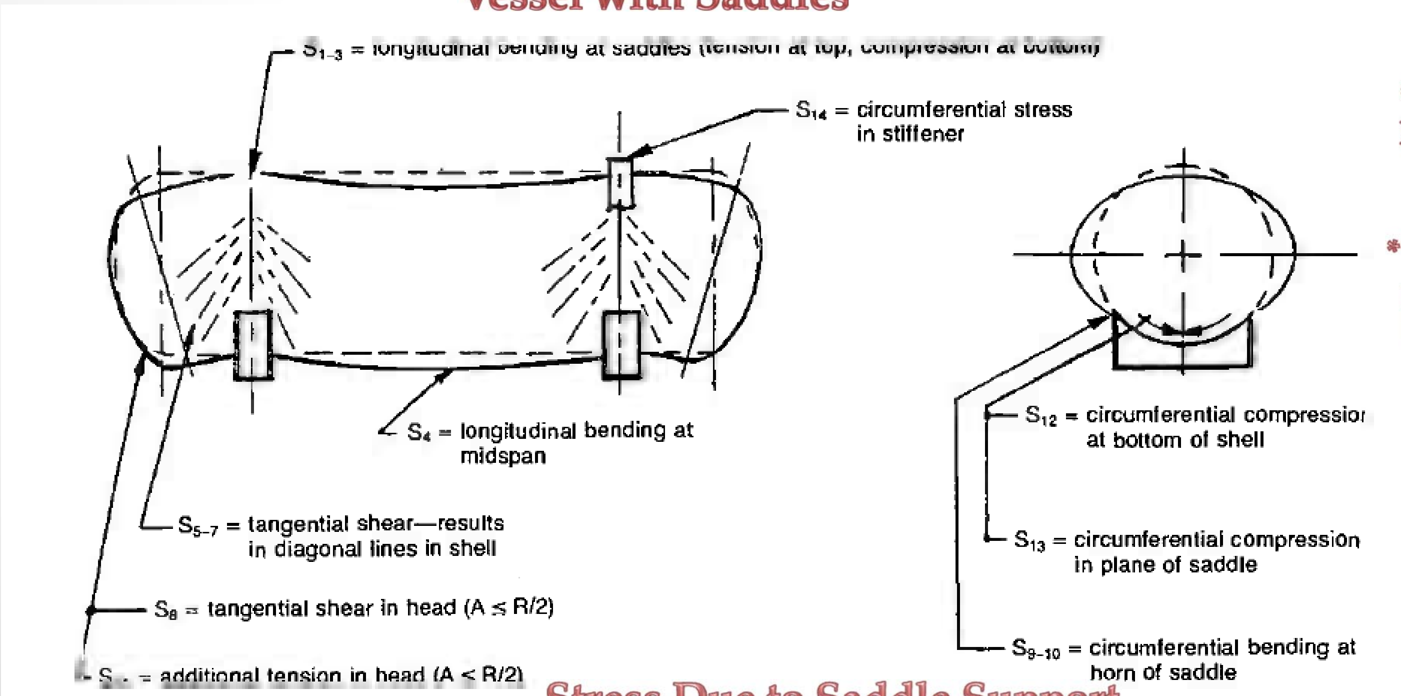
DESIGN : SADDLES



Vessel with Saddles



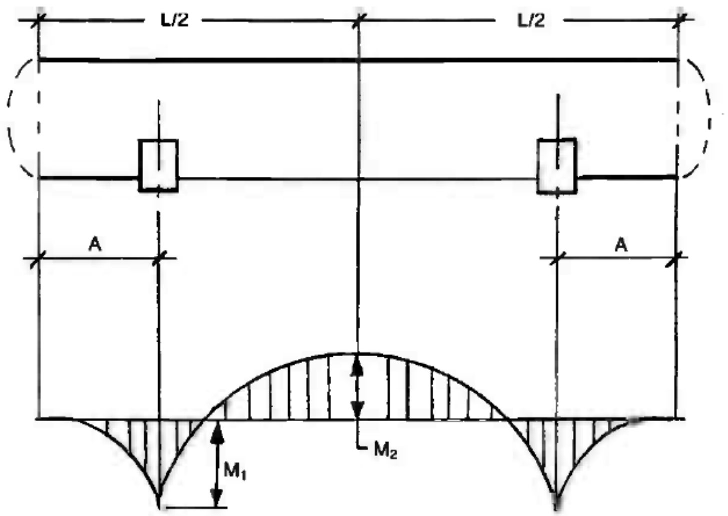
Saddles with Stiffener Ring



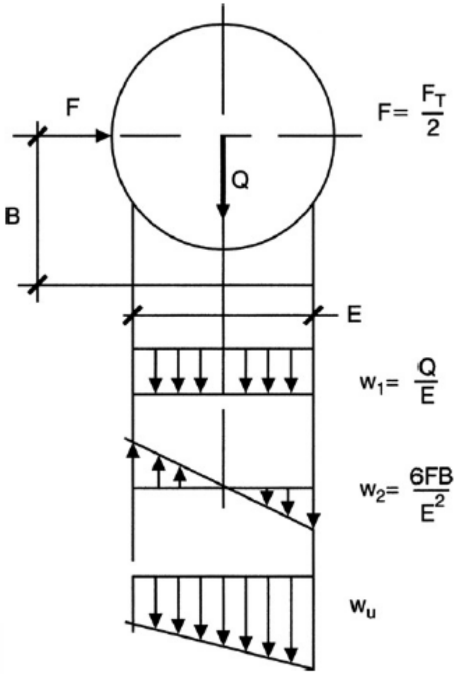
Stress Due to Saddle Support

Note:
****Horizontal vessels avoid locating longitudinal weld seams in the bottom 120° sector.**
****Design method: L.P. Zick's paper entitled "Stresses in large cylindrical pressure vessels on two saddle supports" .**

DESIGN : SADDLES



Stress Due to Saddle Support



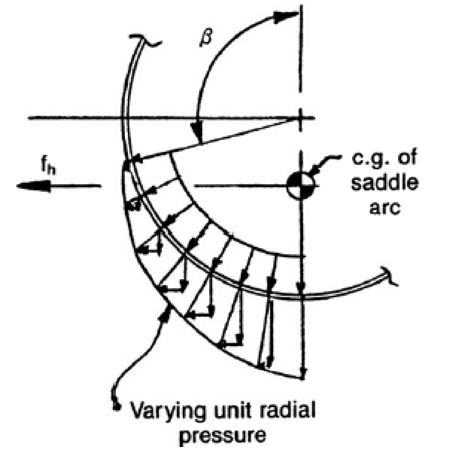
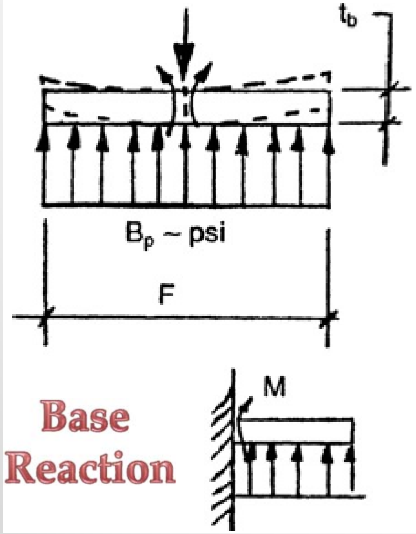
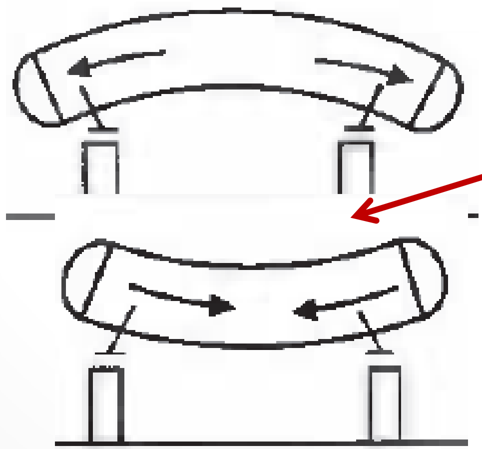


Figure 4-51. Saddle splitting forces.

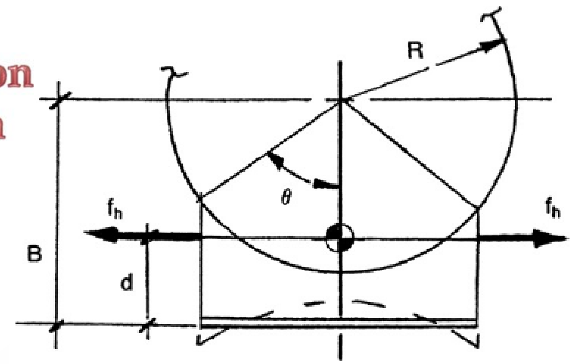
Load acting To Saddle due to Vessel Weight



Base Reaction

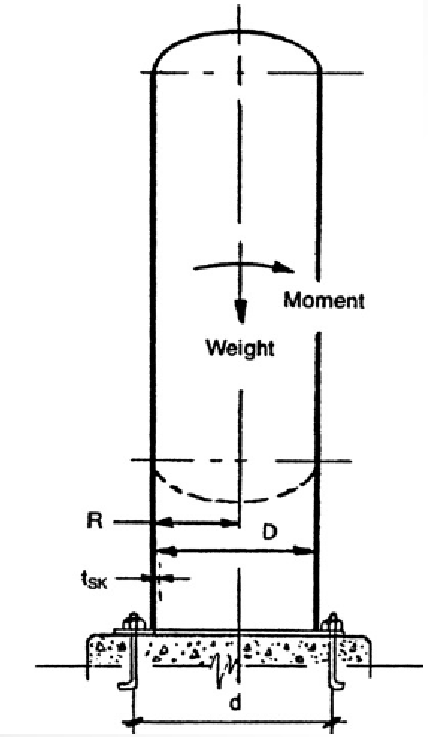


Thermal Expansion and Contraction

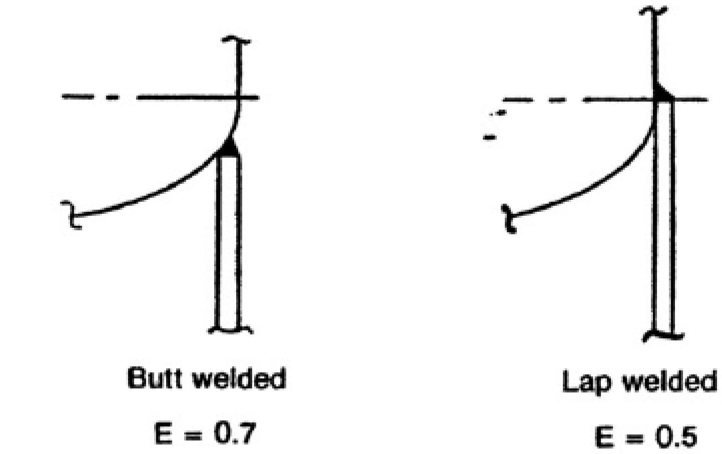


Spilt Force

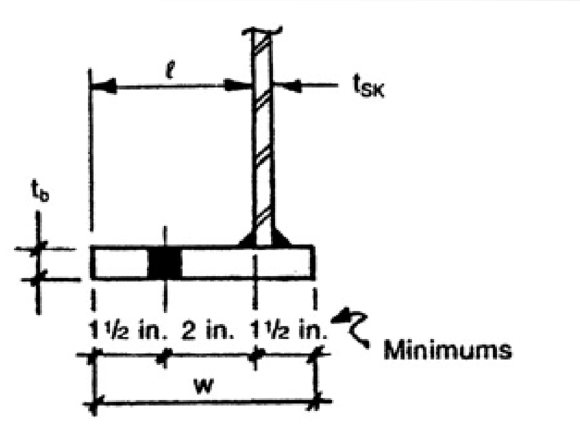
DESIGN : SKIRT



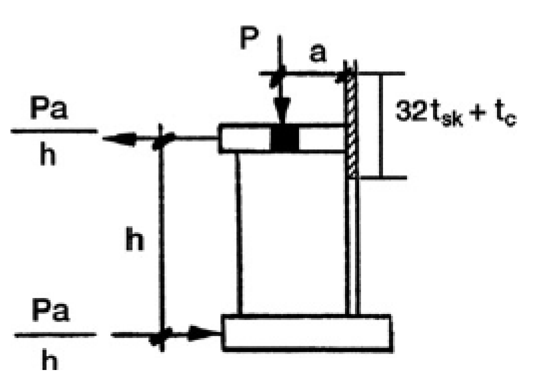
Vessel with Skirt



Weld at Skirt Attached to Vessel Head



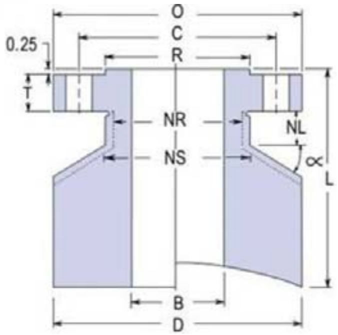
<u>As per common project specification.</u>
**When vessel metal temperature at point of attachment is above 300°C weld shall be designed to be readily inspected by ultrasonic.
**Skirt butt welds shall be full penetration



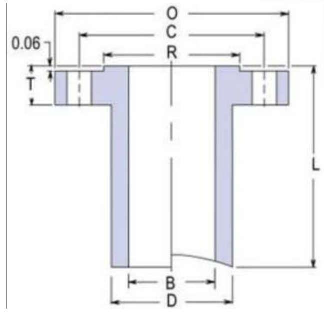
Skirt Base Rings Type

DESIGN : TYPE OF NOZZLES

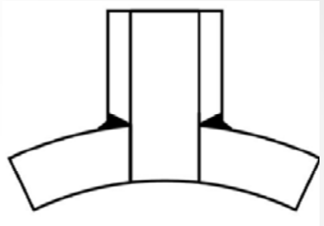
Nozzle with Pad



Self reinforced nozzle

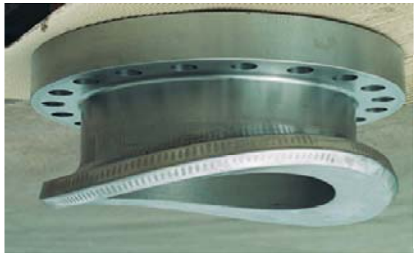


Long weld neck nozzle



Set on nozzle

Coupling on Vessel



1. Wall thickness of shell or head exceeds 50mm.
2. Vessel is in cyclic or thermal shock service.
3. Vessel is in hydrogen, H_2S or HF service.

Integral reinforcement employing butt welds that can be examined by radiography

Criteria for design to be self reinforced nozzle

a. Design Temperature exceed 350° C
b. Vessel is used for Hydrogen charging service.
c. Vessel is used for Hydrogen service.
d. Vessel is in cyclic or thermal shock service.

Note: As per common project spec.
** Nozzles shall not control maximum allowable working pressure
**Pad Thickness shall not exceed 1.5 x shell thickness
** times diameter reinforcing pad

DESIGN : FLANGE TYPE AND RATING

Standard
- Size 24" and lower – ANSI B16.5
- Size 26" and bigger – ANSI B16.47 Series A or Series B

Table 1
(from Table 2-2.2 of ASME B16.5-1996)

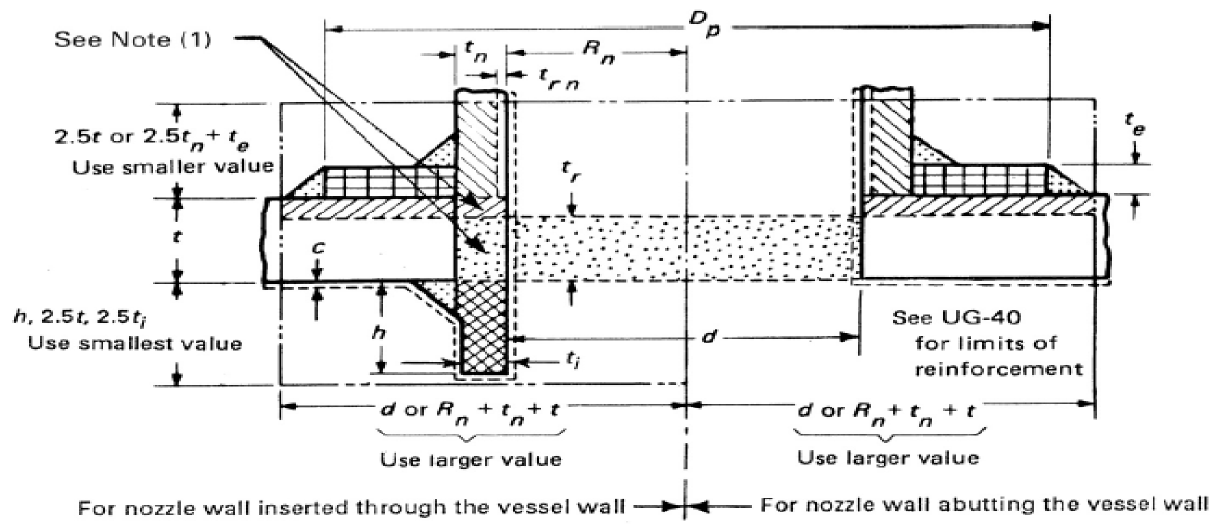
Working Pressures by Classes							
Class	150	300	400	600	900	1500	2500
Temperature	PSIG Values						
-20 to100° F	275	720	960	1440	2160	3600	6000
200° F	235	620	825	1240	1860	3095	5160
300° F	215	560	745	1120	1680	2795	4660
400° F	195	515	685	1025	1540	2570	4280
500° F	170	480	635	955	1435	2390	3980
600° F	140	450	600	900	1355	2255	3760
650° F	125	445	590	890	1330	2220	3700
700° F	110	430	580	870	1305	2170	3620
750° F	95	425	570	855	1280	2135	3560
800° F	80	420	565	845	1265	2110	3520
850° F	65	420	555	835	1255	2090	3480

NOTE: 304L material is limited to 800° F.

Pressure rating for each flange class (#150,#300, #600,…, #2500 Depend on Material & Temperature

DESIGN : NOZZLE REINFORCEMENT

Figure UG-37.1
Nomenclature and Formulas for Reinforced Openings



Sample of Nozzles on Top Head

With Reinforcing Element Added

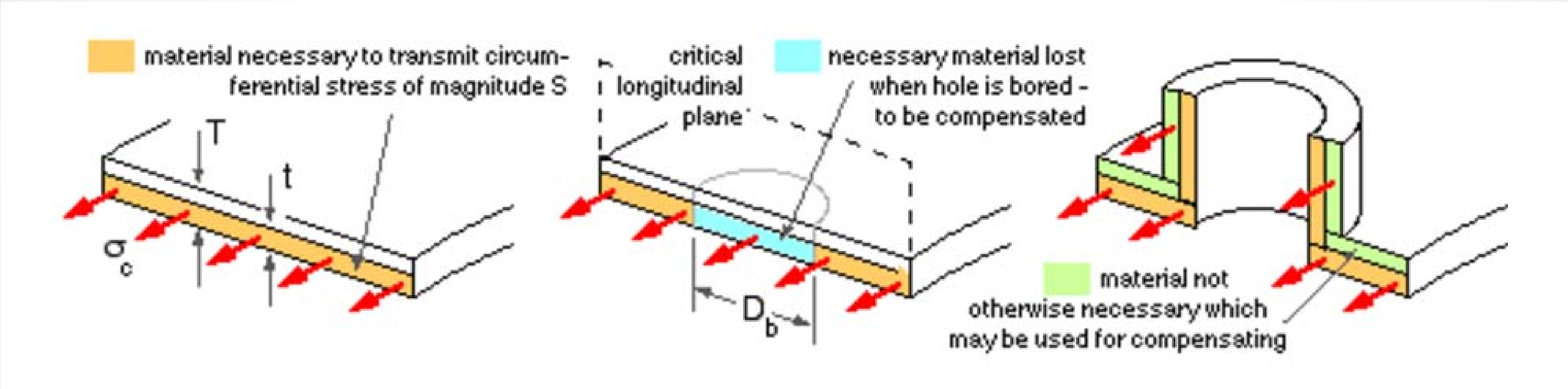
A = same as A, above	Area required
A_1 = same as A_1, above	Area available
A_2 = $5(t_n - t_{rn})f_{r2}t$ or $= 2(t_n - t_{rn})(2.5t_n + t_e)f_{r2}$	Area available in nozzle projecting outward; use smaller area
A_3 = same as A_3, above	Area available in inward nozzle
= A_{41} = outward nozzle weld = $(\text{leg})^2 f_{r3}$	Area available in outward weld
= A_{42} = outer element weld = $(\text{leg})^2 f_{r4}$	Area available in outer weld
= A_{43} = inward nozzle weld = $(\text{leg})^2 f_{r2}$	Area available in inward weld
= A_5 = $(D_p - d - 2t_n)\, t_e\, f_{r4}$ [Note (2)]	Area available in element
If $A_1 + A_2 + A_3 + A_{41} + A_{42} + A_{43} + A_5 \geq A$	Opening is adequately reinforced

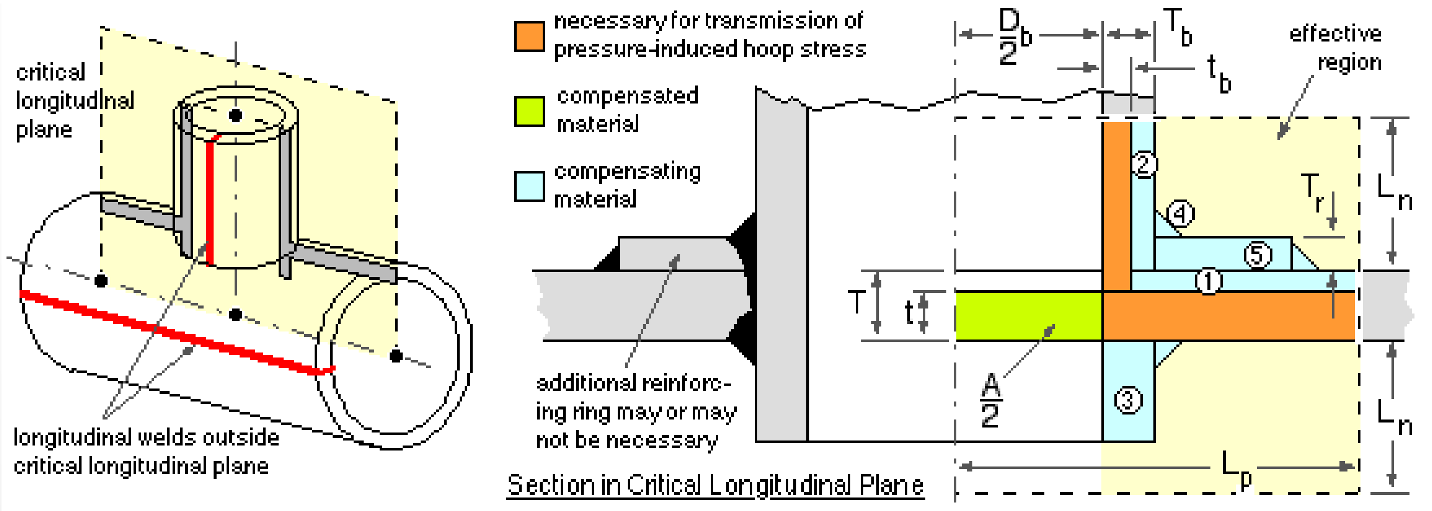
UG-37(g) Shall provide telltale hole ,maximum diameter 7/16 in. (11 mm)]

DESIGN : NOZZLE REINFORCEMENT

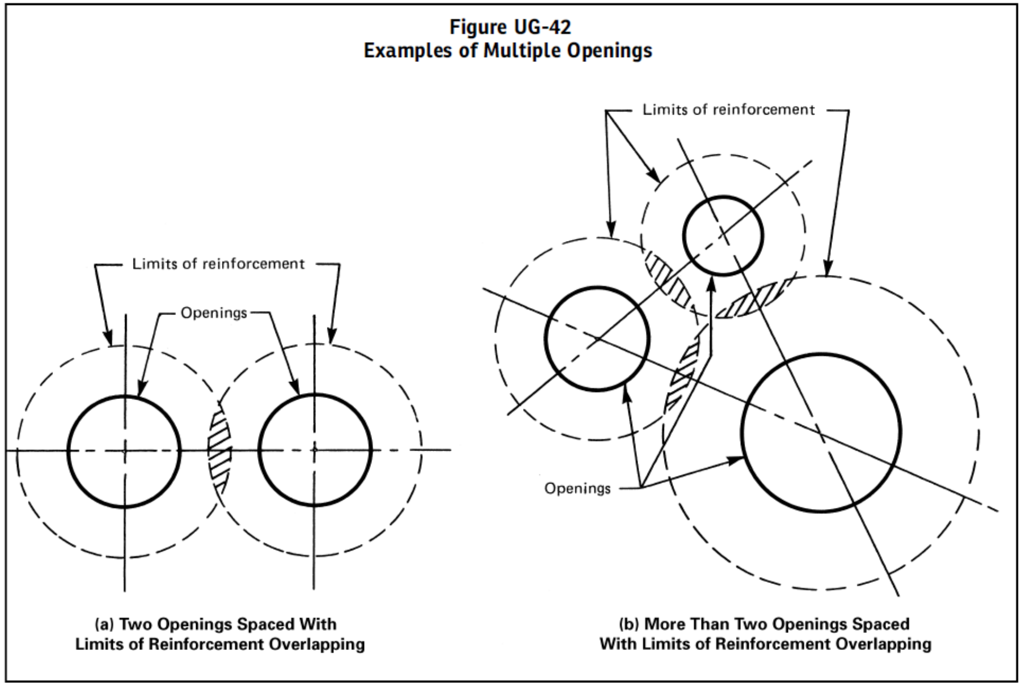
Compensation

Compensation, or *reinforcement*,is the provision of extra stress-transmitting area in the wall of a cylinder or shell when some area is removed by boring a hole for branch attachment.



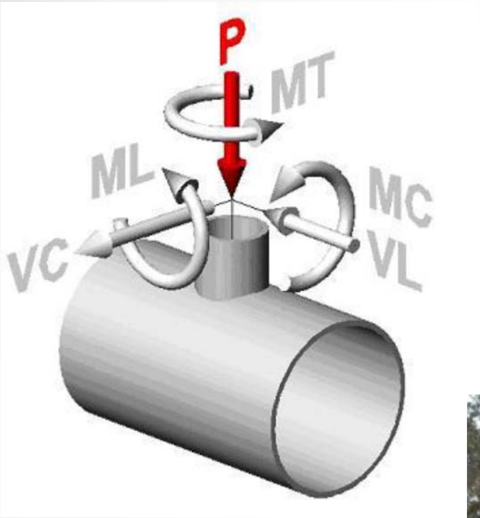


DESIGN : NOZZLE REINFORCEMENT(MULTIPLE OPENINGS)

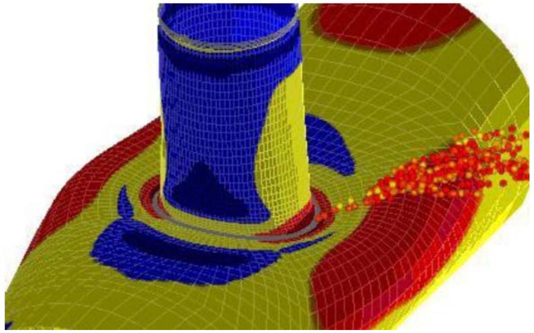


- When any two openings are spaced such that their limits of reinforcement overlap the two openings shall be reinforced in the plane connecting the centers, in accordance with the rules of UG-37, UG-38, UG-40, and UG-41 with a combined reinforcement that has an area not less than the sum of the areas required for each opening. **No portion of the cross section is to be considered as applying to more than one opening, nor to be considered more than once in a combined area.**
  - The available area of the head or shell between openings having an overlap area shall be proportioned between the two openings by the ratio of their diameters.
  - For cylinders and cones, if the area of reinforcement between the two openings is less than 50% of the total required for the two openings, the supplemental rules of 1-7(a) and 1-7(c) shall be used.
  - A series of openings all on the same centerline shall be treated as successive pairs of openings.
- When more than two openings are spaced as figure UG-42 and are to be provided with a combined reinforcement, the minimum distance between centers of any two of these openings shall be 1 1/3 times their average diameter, and the area of reinforcement between any two openings shall be at least equal to 50% of the total required for the two openings. If the distance between centers of two such openings is less than 1 1/3 times their average diameter, no credit for reinforcement shall be taken for any of the material between these openings.

DESIGN : LOCAL STRESS , WRC 107

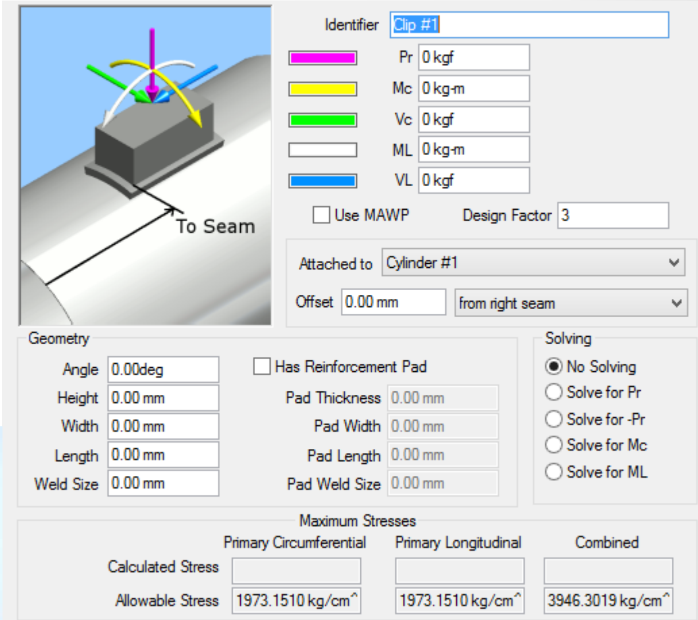


Nozzle load



Stress analysis

Clip on Vessel

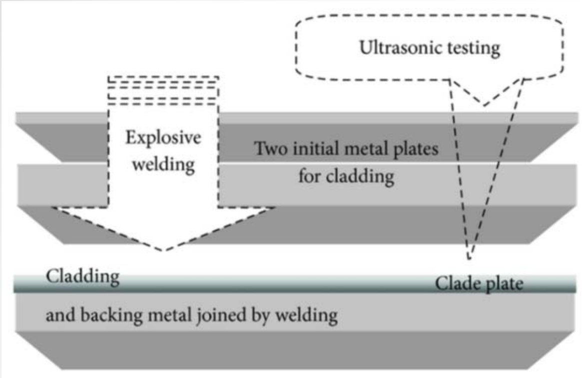


Local stress on clip

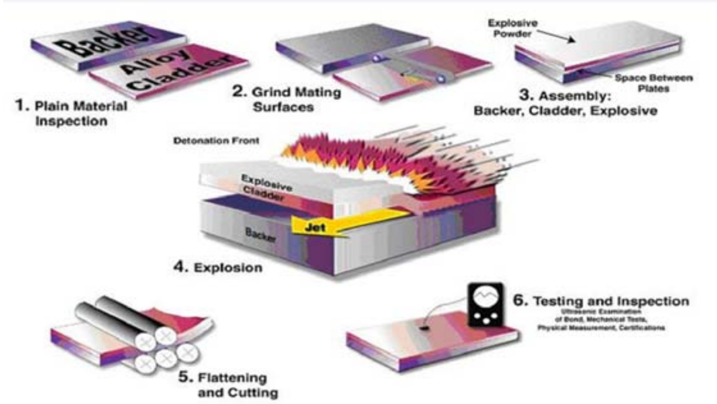
**WRC states that bulletin 537 is a reprint of bulletin 107.

**Supplementary bulletin WRC 297 contains directions to calculate local stresses in nozzle, too.

DESIGN : Corrosion resistance



Cladding



Cladding process

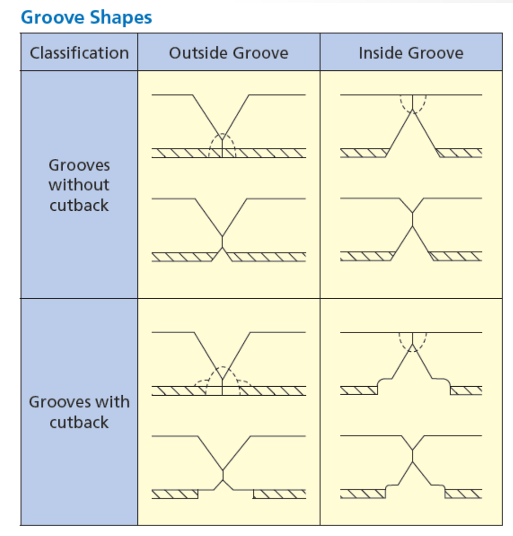

SPECIFICATION FOR STAINLESS CHROMIUM STEEL-CLAD PLATE

SA-263

ASME Code

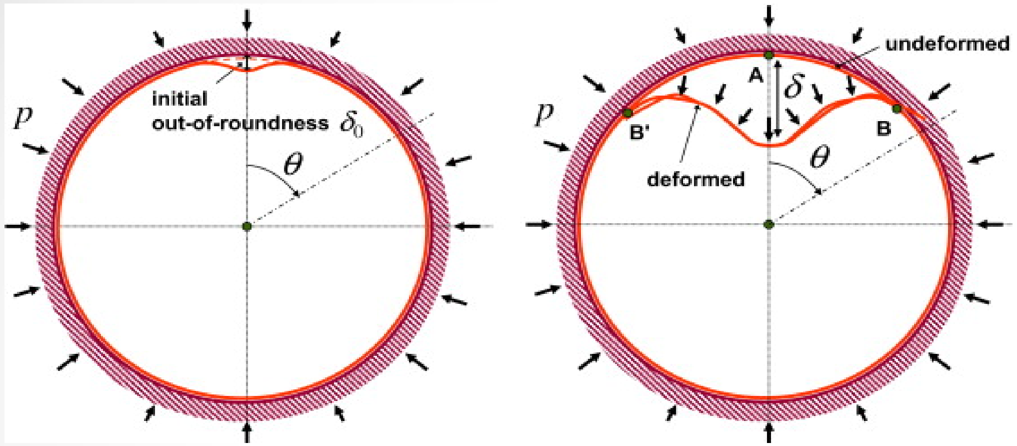
Weld Overlay

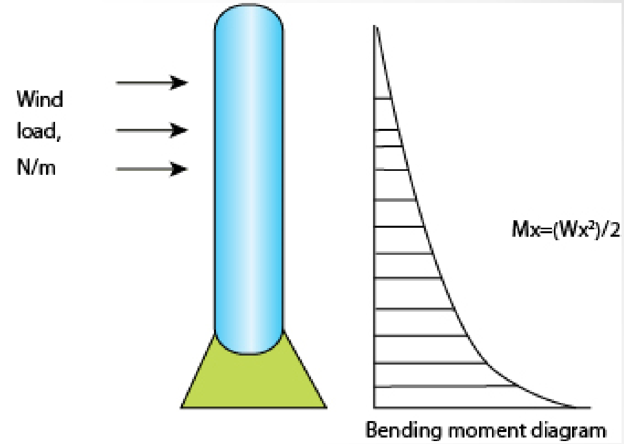
Weld Overlay

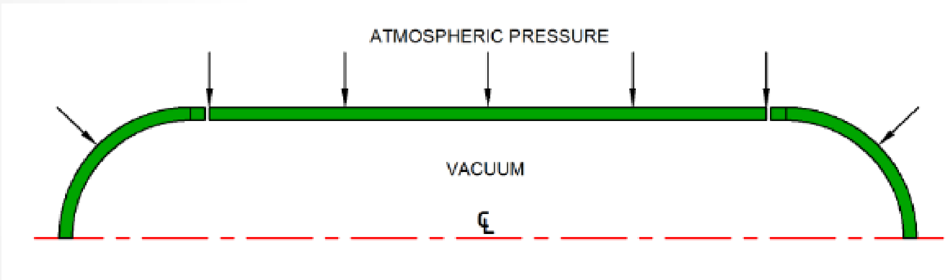


Cladding plate Butt weld

VACUUM DESIGN







Vacuum Load Diagram

Sample of Vessel Collapse Under Vacuum

DESIGN: INSPECTION OPENING (UG-46)

TREAD PIPE PLUG

Sizing	Service	Opening requirement
D≤ 900		Not required if have telltale holes,one hole per 10 ft2 (0.9 m2)
300mm < D	Unde air pressure	Need opening
D≤ 300		No need if having pipe connection not less than 3/4"
300≤ D<450		2 handholes or 2 tread pipe plug not lessthan 1.5"
450≤ D≤900		2 handholes or 2 tread pipe plug not lessthan 2"
900< D		1 Manhole

Sizing	Inspection opening exemption case
All vessel	when telltale holes are used in lieu of inspection openings;
Shell side of Fixed tubesheet heat exchangers or U-tube and floating tubesheet heat exchangers	when inspection openings are omitted in fixed tubesheet heat exchangers or U-tube and floating tubesheet heat exchangers
D≤ 900	have telltale holes ,one hole per 10 ft2 (0.9 m2)
D≤ 300	having pipe connection not less than 3/4" except Under air pressure
All Vessel	Openings with removable heads or cover plates may be used in place of the required inspection openings
All Vessel	Single opening with removable head or cover plate may be used in place of all the smaller inspection Openings
All Vessel	Flanged and/or threaded connections from which piping, instruments, or similar attachments can be removed may be used in place of the required inspection openings

Inspection type	Sizing
Manholes	An elliptical or obround manhole : 12 in. × 16 in. (300 mm × 400 mm). A circular manhole : 16 in. (400 mm) I.D.
Handholds	An elliptical or obround manhole : 2 in. × 3 in. (50 mm × 75 mm), but should be as large as is consistent with the size of the vessel and the location of the opening.

MANHOLE

ELLIPTICAL MANHOLE

DESIGN: STANDARD FLANGES AND PIPE FITTINGS

The following standards covering flanges and pipe fittings are Pressure–
temperature ratings shall be in accordance with the appropriate standard except that the pressure–temperature ratings for ASME B16.9 and ASME B16.11 fittings shall be calculated as for straight seamless pipe in accordance with the rules of this Division including

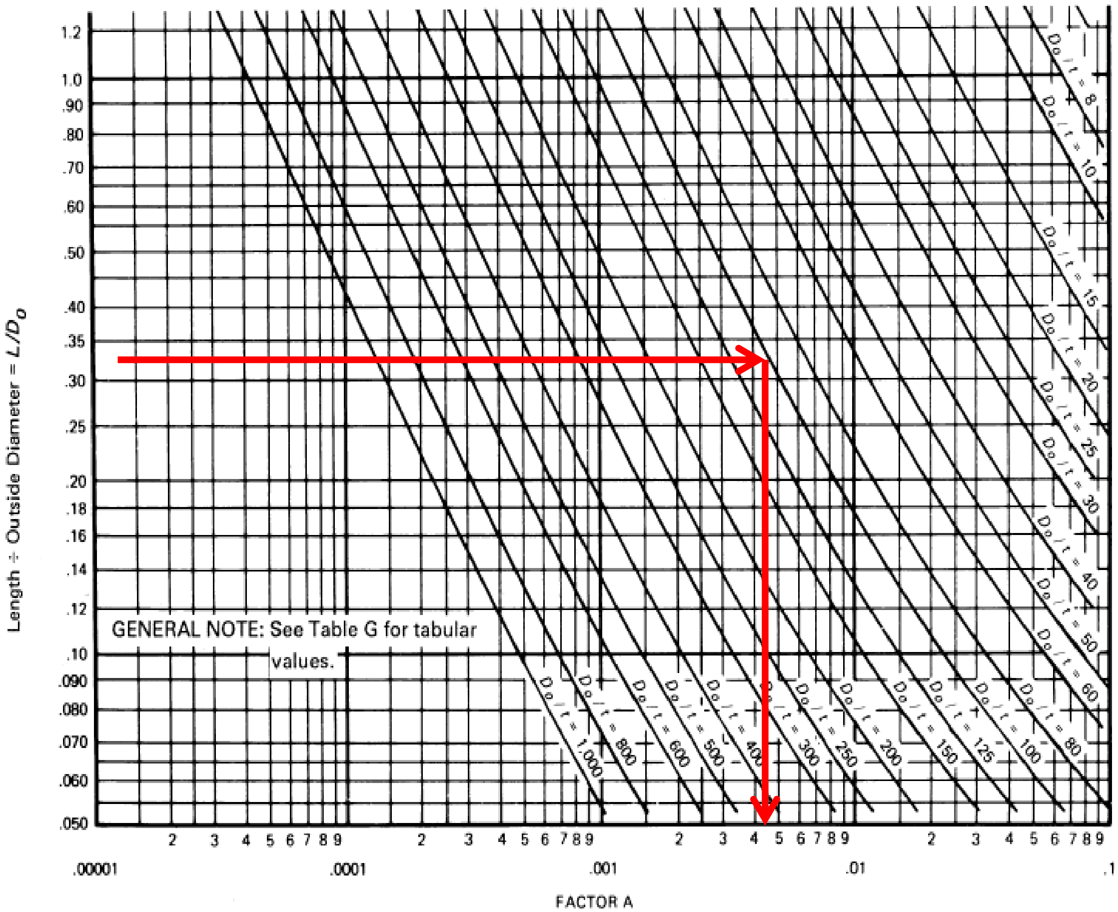
Table U-3
Year of Acceptable Edition of Referenced Standards in This Division

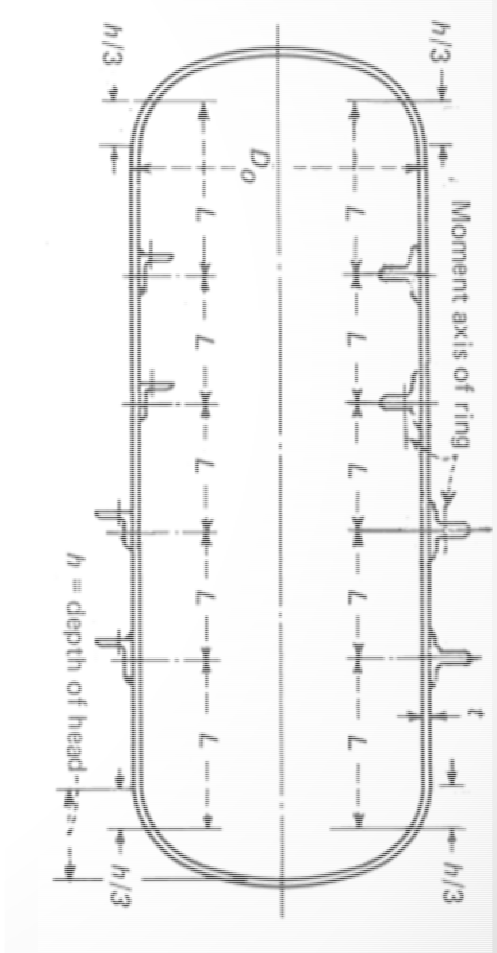
Title	Number	Year
Pressure Relieving and Depressuring Systems	ANSI/API Std. 521	5th Ed., January 2007
Pipe Threads, General Purpose (Inch)	ANSI/ASME B1.20.1	Latest edition
Marking and Labeling Systems	ANSI/UL-969	Latest edition
Seat Tightness of Pressure Relief Valves	API Std. 527	2014, 4th Ed.
Unified Inch Screw Threads (UN and UNR Thread Form)	ASME B1.1	Latest edition
Cast Iron Pipe Flanges and Flanged Fittings, Classes 25, 125, and 250	ASME B16.1	2015
Pipe Flanges and Flanged Fittings, NPS $^1/_2$ Through NPS 24 Metric/Inch Standard	ASME B16.5	2013 [Note (1)]
Factory-Made Wrought Buttwelding Fittings	ASME B16.9	Latest edition
Forged Fittings, Socket-Welding and Threaded	ASME B16.11	Latest edition
Cast Copper Alloy Threaded Fittings, Classes 125 and 250	ASME B16.15	Latest edition
Metallic Gaskets for Pipe Flanges — Ring-Joint, Spiral– Wound, and Jacketed	ASME B16.20	Latest edition
Cast Copper Alloy Pipe Flanges and Flanged Fittings, Class 150, 300, 600, 900, 1500, and 2500	ASME B16.24	2011
Ductile Iron Pipe Flanges and Flanged Fittings, Class 150 and 300	ASME B16.42	2011
Large Diameter Steel Flanges, NPS 26 Through NPS 60 Metric/Inch Standard	ASME B16.47	2011
Nuts for General Applications: Machine Screw Nuts, Hex, Square, Hex Flange, and Coupling Nuts (Inch Series)	ASME B18.2.2	Latest edition
Welded and Seamless Wrought Steel Pipe	ASME B36.10M	Latest edition
Conformity Assessment Requirements	ASME CA-1	Latest edition
Guidelines for Pressure Boundary Bolted Flange Joint Assembly	ASME PCC-1	2013
Repair of Pressure Equipment and Piping	ASME PCC-2	2015
ASME Section VIII - Division 1 Example Problem Manual	ASME PTB-4	Latest edition
Pressure Relief Devices	ASME PTC 25	2014
Qualifications for Authorized Inspection	ASME QAI-1	Latest edition [Note (2)]
Standard Test Method for Flash Point by Tag Closed Tester	ASTM D56	Latest edition
Standard Test Methods for Flash Point by Pensky-Martens Closed Cup Tester	ASTM D93	Latest edition
Standard Guide for Preparation of Metallographic Specimens	ASTM E3	2011
Standard Reference Photographs for Magnetic Particle Indications on Ferrous Castings	ASTM E125	1963 (R2008) [Note (3)]
Standard Hardness Conversion Tables for Metals Relationship Among Brinell Hardness, Vickers Hardness, Rockwell Hardness, Superficial Hardness, Knoop	ASTM E140	Latest edition

VACUUM DESIGN

Step 1. **Assume a value for t and determine the ratios L/Do and Do/t. determine Factor A in Figure G, ASME II D**

Figure G
Geometric Chart for Components Under External or Compressive Loadings (for All Materials) (Cont'd)

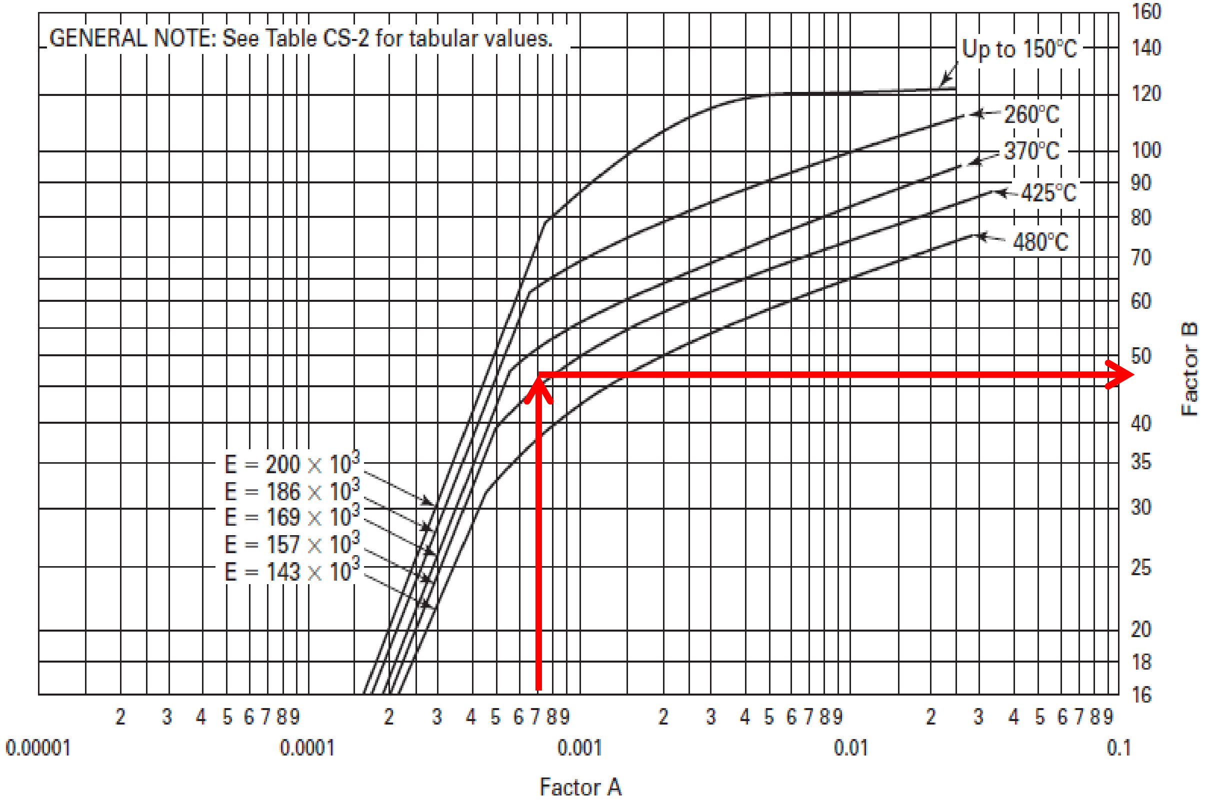




VACUUM DESIGN

Step 2. Use value A to determine ***Factor B*** *in Figure CS-2 , ASME II Part D*

Figure CS-2
Chart for Determining Shell Thickness of Components Under External Pressure Developed for Carbon or Low Alloy Steels With Specified Minimum Yield Strength 207 MPa and Higher



***Using this value of B, calculate the value of the maximum allowable external working pressure Pa using the following equation:

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

VACUUM DESIGN : STIFFENER RING

1. Calculate factor *B*

$$B = \frac{3}{4}\left(\frac{PD_O}{t + A_S/L_S}\right)$$

2. Determine value A
in Subpart 3 of Section II, Part D

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

$$I_S = \left[D_O^2 L_S (t + A_S/L_S) A\right] / 14$$

$$I_S' = \left[D_O^2 L_S (t + A_S/L_S) A\right] / 10.9$$

I = available moment of inertia of the stiffening ring cross section about its neutral axis parallel to the axis of the shell

I s = required moment of inertia of the stiffening ring cross section about its neutral axis parallel to the axis of the shell

I ′ = available moment of inertia of combined ring-shell cross section

I ′s = required moment of inertia of the combined ring shell cross section about its neutral

As = cross-sectional area of the stiffening ring

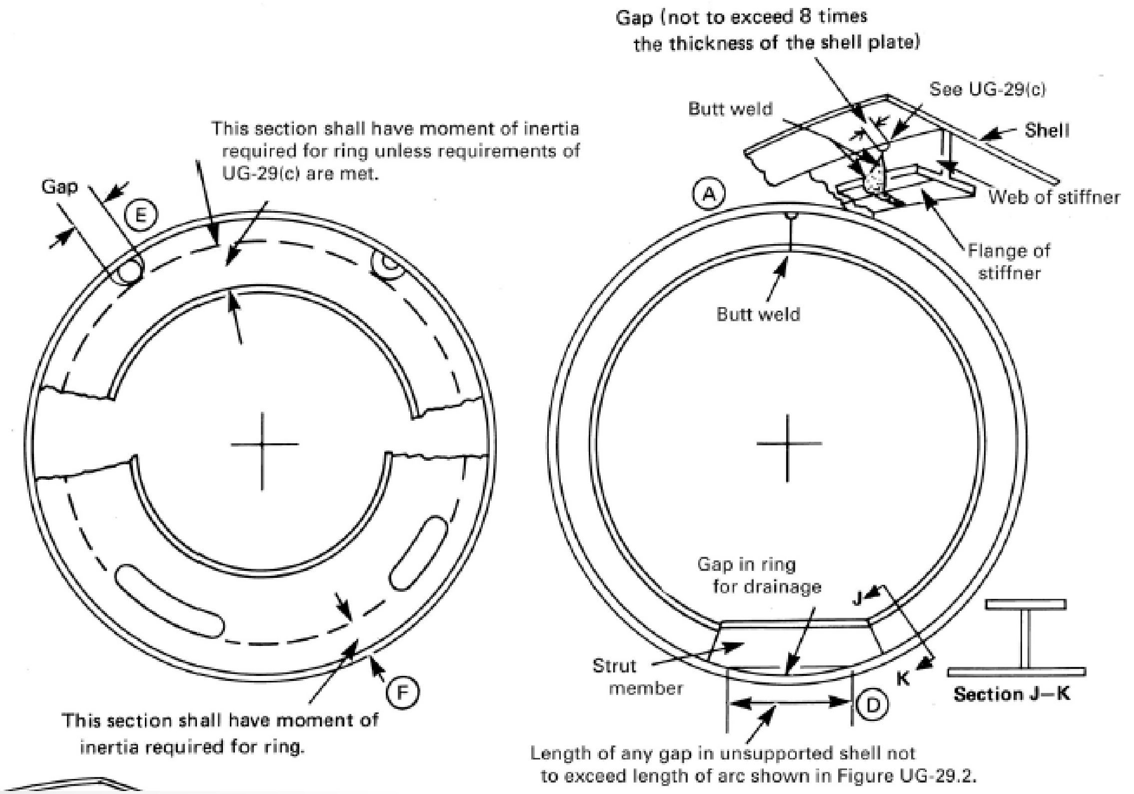
A = factor determined from the applicable chart in Subpart 3 of Section II, Part D

B = factor determined from the applicable chart or table in Subpart 3 of Section II, Part D

Ls = one-half of the distance from the centerline of the stiffening ring to the next line of support on one side, plus one-half of the centerline distance to the next line of support on the other side of the stiffening ring,

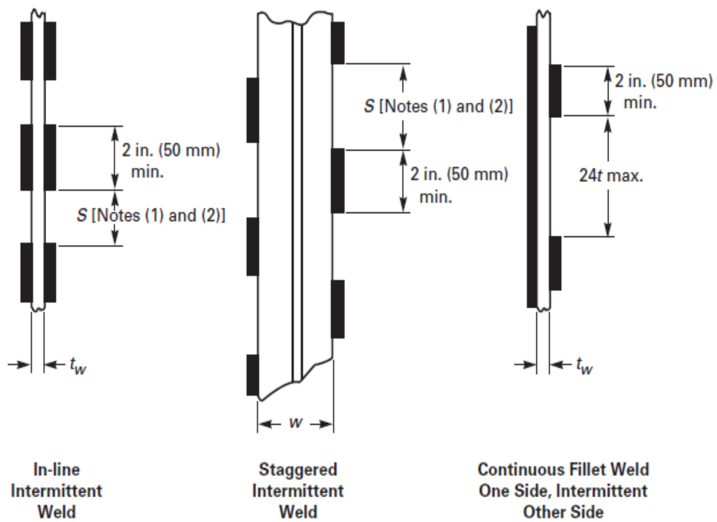
VACUUM DESIGN : STIFFENER RING

Figure UG-29.1
Various Arrangements of Stiffening Rings for Cylindrical Vessels Subjected to External Pressure



Sample of Internal Stiff. Rings

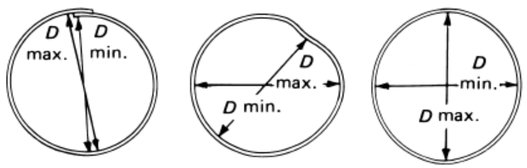
Figure UG-30
Some Acceptable Methods of Attaching Stiffening Rings



NOTES:
(1) For external stiffeners, $S \leq 8t$.
(2) For internal stiffeners, $S \leq 12t$.

ROUNDNESS

Figure UG-80.2
Example of Differences Between Maximum and Minimum Inside Diameters in Cylindrical, Conical, and Spherical Shells



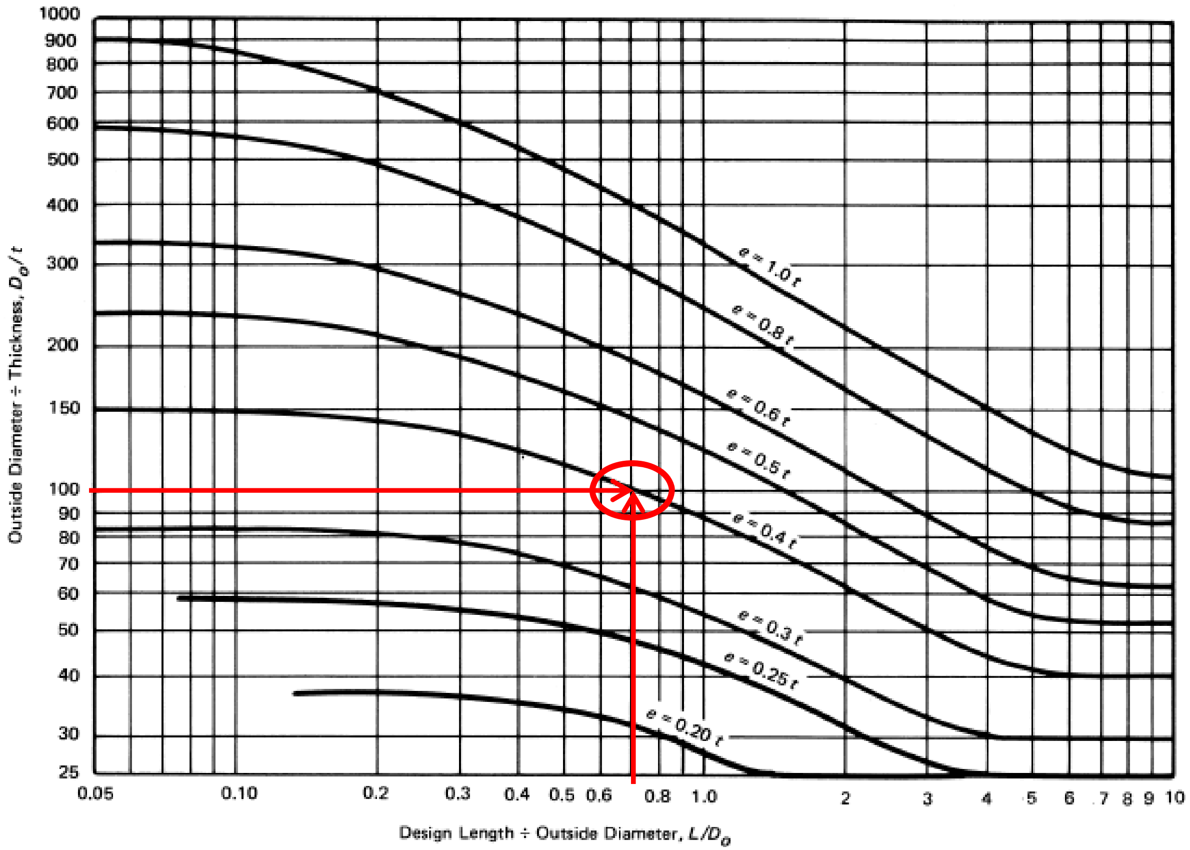
Internal Pressure.

- The difference between the maximum and minimum inside diameters at any cross section shall not exceed 1% of the nominal diameter at the cross section under consideration. The diameters may be measured on the inside or outside of the vessel
- When the cross section passes through an opening, the permissible difference in inside diameters given above may be increased by 2% of the inside diameter of the opening.

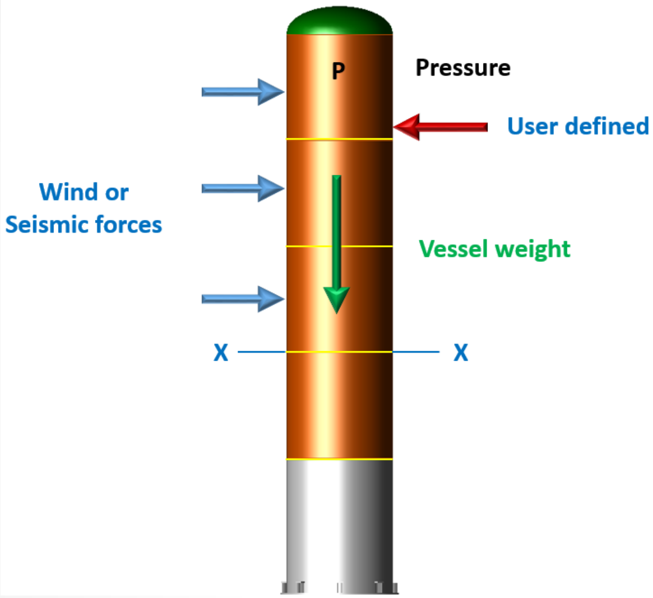
External Pressure

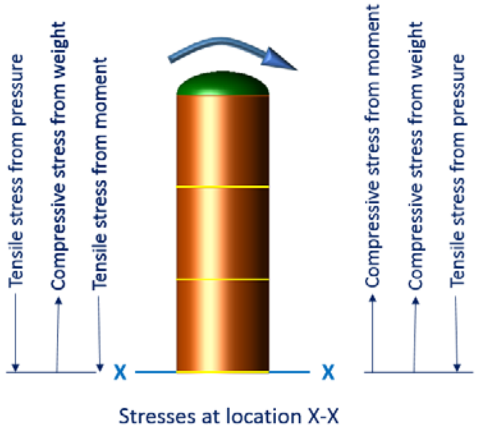
- The maximum plus-or-minus deviation from the true circular form, measured radially on the outside or inside of the vessel, shall not exceed the maximum permissible deviation *e* obtained from Figure UG-80.1

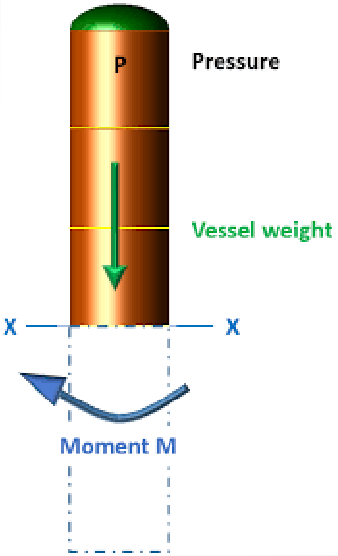
Figure UG-80.1
Maximum Permissible Deviation From a Circular Form *e* for Vessels Under External Pressure



WIND LOAD: VERTICAL PRESSURE VESSEL







WIND LOAD: VERTICAL PRESSURE VESSEL

- *Exposure B:* For buildings with a mean roof height of less than or equal to 30 ft (9.1 m). Urban and suburban areas, towns, city out skirts, wooded areas, or other terrain with numerous closely spaced obstructions having the size of single family dwellings or larger.
- *Exposure C:* For cases where Exposures B and D do not apply. Open terrain with scattered obstructions having heights generally less than 30 ft (9.1 m).
- *Exposure D:* Flat, unobstructed coastal areas directly exposed to wind blowing over open water.

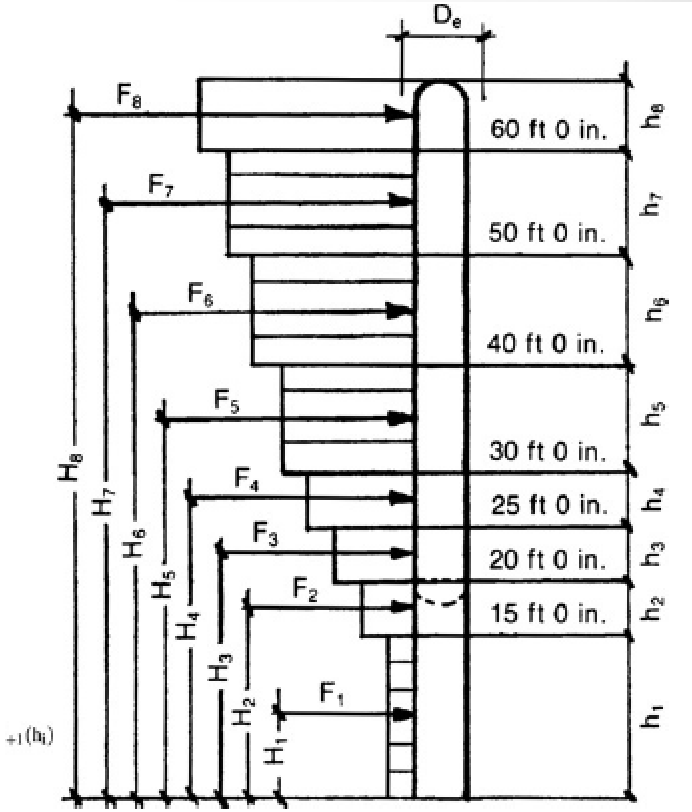


Figure 4-2. Vertical vessels.

$$A_f = h_n D_e$$

$$F_i = q_z G C_f A_f$$

$$M_i = F_i(h_i/2) + V_{i+1}(h_i) + M_{i+1}$$

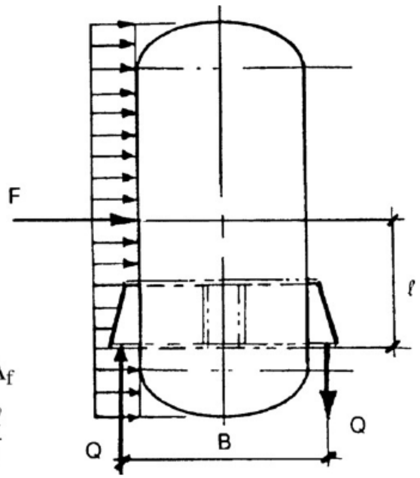
$$M = \Sigma F_i H_i$$

WIND LOAD : DESIGN CONDITION

Condition	S_t	S_c	Internal Design pressure	External design pressure	Wind or Seismic load	Self weight New	Self weight Corroded
Operating, Hot & Corroded	1.2x Sa (ASME II D)@ design temp.	Table CS-2	Yes	No	Yes	-	Yes
Operating, Hot & New	1.2x Sa (ASME II D)@ design temp.	Table CS-2	Yes	No	Yes	Yes	-
Hot Shut Down, Corroded	1.2x Sa (ASME II D)@ design temp.	Table CS-2	No	No	Yes		Yes
Hot Shut Down, New	1.2x Sa (ASME II D)@ design temp.	Table CS-2	No	No	Yes	Yes	
Empty, Corroded	1.2x Sa (ASME II D)@ room temp.	Table CS-2	No	No	Yes		Yes
Empty, New	1.2x Sa (ASME II D)@ room temp.	Table CS-2	No	No	Yes	Yes	
Vacuum	1.2x Sa (ASME II D)@ external temp.	Table CS-2	No	Yes	Yes		Yes
Hot Shut Down, Corroded, Weight & Eccentric Moments Only	1.2x Sa (ASME II D)@ design temp.	Table CS-2	No	No	No		Yes

For Net Tensile stress	Thickness from Design pressure	$t_p = P*R / (2*S_t*K_s*E_c + 0.40*\|P\|)$
	Thickness from bending moment due to wind or seismic	$t_m = M / (p*R_m^2*S_t*K_s*E_c)$
	Thickness from self weight	$t_w = 0.6*W / (2*p*R_m*S_t*K_s*E_c)$
	Net thickness required	$t_t = t_p + t_m - t_w$
For Net Compressive stress	Thickness from Design pressure	$t_p = P*R / (2*S_c*K_s*E_c + 0.40*\|P\|)$
	Thickness from bending moment due to wind or seismic	$t_m = M / (p*R_m^2*S_c*K_s*E_c)$
	Thickness from bending moment due to wind or seismic	$t_w = W / (2*p*R_m*S_c*K_s*E_c)$
	Net thickness required	$t_c = \|t_{mc} + t_{wc} - t_{pc}\|$

WIND LOAD : REACTION ON SUPPORT



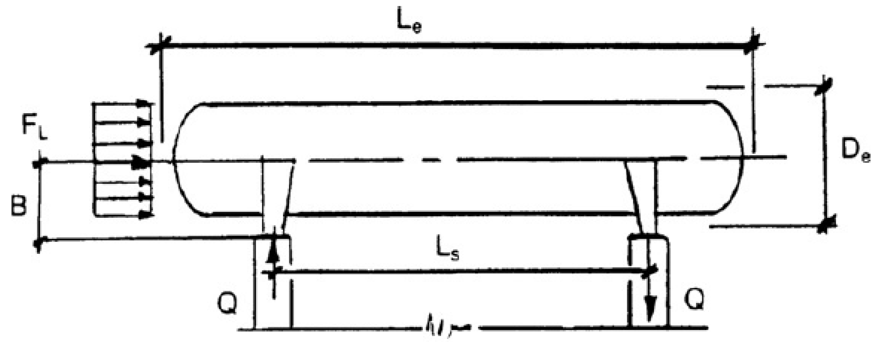
$$A_f = L_e D_e$$

$$F = q_z G C_f A_f$$

$$Q = \frac{W}{N} \pm \frac{F\ell}{B}$$

Figure 4-4. Vessels on lugs or rings.

Support Lugs



Longitudinal

$$A_L = \frac{\pi D_e^2}{4}$$

$$F_L = q_z G C_f A_L$$

$$Q = \frac{W}{2} \pm \frac{F_L B}{L_s}$$

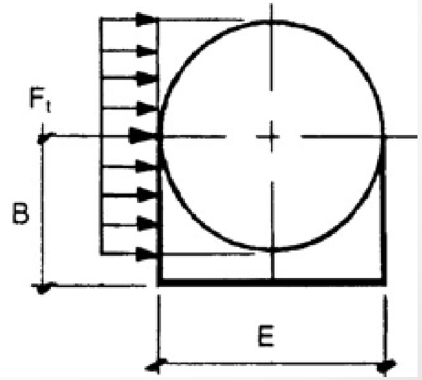
Saddles

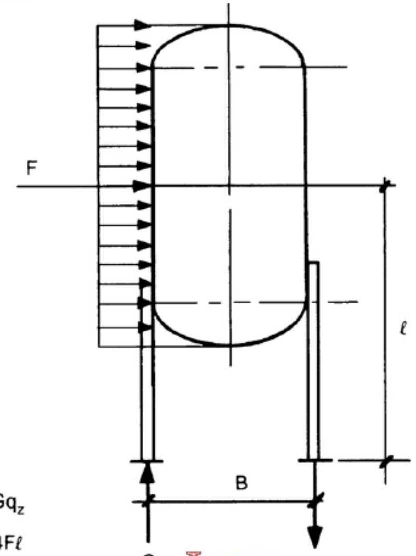
Transverse

$$A_t = L_e D_e$$

$$F_t = 0.5(q_z G C_f A_t)(\text{one support})$$

$$M_t = F_t B(\text{one support})$$





$$A_f = L_e D_e$$

$$F = A_f C_f G q_z$$

$$Q = \frac{W}{N} \pm \frac{4F\ell}{NB}$$

Legs

WINDLOAD : DETERMINE WIND FORCE

$n_1 \geq 1$ Hz,

$$F = q_z G_f C_f A_f$$

$$q_z = 0.00256 K_z K_{zt} K_d V^2$$

0.00256 (0.613), reflects the mass density of air for the standard atmosphere

For 15 ft. $\leq z \leq z_g$

$$K_z = 2.01(z/z_g)^{2/\alpha}$$

For $z <$ 15 ft.

$$K_z = 2.01(15/Z_g)^{2/\alpha}$$

K_d = wind directionality factor, use 0.95 for vessels when using ASCE/SEI 7-10 load combinations

C_f = force coefficient, shape factor 0.7, 0.8, and 0.9 for h/D_e of 1, 7, and 25, respectively (linear interpolation is permitted). See ASCE/SEI 7-10.

$$\bar{z} = \max(0.6h, z_{min})$$

$$I_{\bar{z}} = c\left(\frac{33}{\bar{z}}\right)^{1/6},\ I_{\bar{z}} = c\left(\frac{10}{\bar{z}}\right)^{1/6} \text{(SI)}$$

$$L_{\bar{z}} = \ell\left(\frac{\bar{z}}{33}\right)^{\bar{\epsilon}},\ L_{\bar{z}} = \ell\left(\frac{\bar{z}}{10}\right)^{\bar{\epsilon}} \text{(SI)}$$

$$Q = \sqrt{\frac{1}{1 + 0.63\left(\frac{D_e + h}{L_{\bar{z}}}\right)^{0.63}}}$$

$$G = 0.925\left(\frac{1 + 1.7 g_Q I_{\bar{z}} Q}{1 + 1.7 g_v I_{\bar{z}}}\right)$$

$$g_Q = g_v = 3.4$$

Table 4-3
Miscellaneous coefficients

Expos.	α	z_g (ft/m)	$\bar{\alpha}$	$\bar{b}$	$\bar{c}$	ℓ (ft/m)	$\bar{\epsilon}$	$*z_{min}$ (ft/m)
B	7.0	1200/365.76	1/4.0	0.45	0.30	320/97.54	1/3.0	30/9.14
C	9.5	900/274.32	1/6.5	0.65	0.20	500/152.4	1/5.0	15/4.57
D	11.5	700/213.36	1/9.0	0.80	0.15	650/198.12	1/8.0	7/2.13

*z_{min} = *minimum height used to ensure that the equivalent height* $\bar{z}$ *is the greater of 0.6 h or* z_{min}.

WINDLOAD : DETERMINE WIND FORCE

Risk Category of Buildings and Other Structures for Flood, Wind, Snow, Earthquake, and Ice Loads

Buildings and structures that represent a low risk to human life in the event of failure.	Category I
All buildings and other structures not covered by Risk Categories I, III, and IV.	Category II
Buildings and other structures containing sufficient quantities of toxic or explosive substances to be dangerous to the public if released. Typically, the equipment inside of a refinery falls under this category.	Category III
Schools, non-emergency health care facilities, jails, non-essential power stations	Category III
Essential facilities	Category IV
Buildings and other structures containing sufficient quantities of toxic or explosive substances to be dangerous to the public if released. (Buildings and other structures containing these substances may be eligible to be classified in a lower category if it can be demonstrated to the jurisdictional authority through a special assessment that the lower risk category is acceptable).	Category IV

HYDRO STATIC& PNEUMATIC TEST

UG-99: HYDROSTATIC TEST

UG-99(b): 1.3 times the maximum allowable working pressure multiplied by the lowest stress ratio (LSR) for the materials of which the vessel is constructed.

UG-99(c): Agreement between the user and the Manufacturer. The hydrostatic test calculated by multiplying the basis for calculated test pressure as defined in **3-2** for each pressure element by 1.3 and reducing this value by the hydrostatic head on that element

UG-100 :PNEUMATIC TEST

- that are so designed and/or supported that they cannot safely be filled with water
- Not readily dried that are to be used in services where traces of the testing liquid cannot be tolerated.

UG-100(b) : 1.1 times the maximum allowable working pressure36 multiplied by the lowest stress ratio (LSR) for the materials of which the vessel is constructed.

Note:

- LSR : Lowest stress ratio = Allowable stress at test temp. / Allowable stress at design temp.
- Appendix 3-2

  The basis for calculated test pressure in either of these paragraphs is the highest permissible internal pressure as determined by **the design equations**, for each element of the vessel using nominal thicknesses with corrosion allowances included

- **ENDNOTES -36 (ASME VIII div1)**

"The maximum allowable working pressure may be assumed to be the same as the design pressure when calculations are not made to determine the maximum allowable working pressure."

HYDROSTATIC& PNEUMATIC TEST

Example of Hydrostatic Test Report

Gauge pressure at 32°C = 1.3*MAWP*LSR
= 1.3*6.97*1.0698
= 9.7 bar

Horizontal shop hydrostatic test							
Identifier	**Local test pressure (bar)**	**Test liquid static head (bar)**	**UG-99(b) stress ratio**	**UG-99(b) pressure factor**	**Stress during test (kg_f/cm^2)**	**Allowable test stress (kg_f/cm^2)**	**Stress excessive?**
Ellipsoidal Head	9.76	0.06	1.0698	1.30	1,592.053	2,404.489	No
Cylinder #1	9.76	0.06	1.0698	1.30	763.18	2,404.489	No

(1) Ellipsoidal Head limits the UG-99(b) stress ratio.
(2) Allowable Stress test pressure = 1.5*0.9*Sy
(3) The zero degree angular position is assumed to be up, and the test liquid height is assumed to the top-most flange.

The test temperature of 32°C is warmer than the minimum recommended temperature of -31 °C so the brittle fracture provision of UG-99(h) has been met.

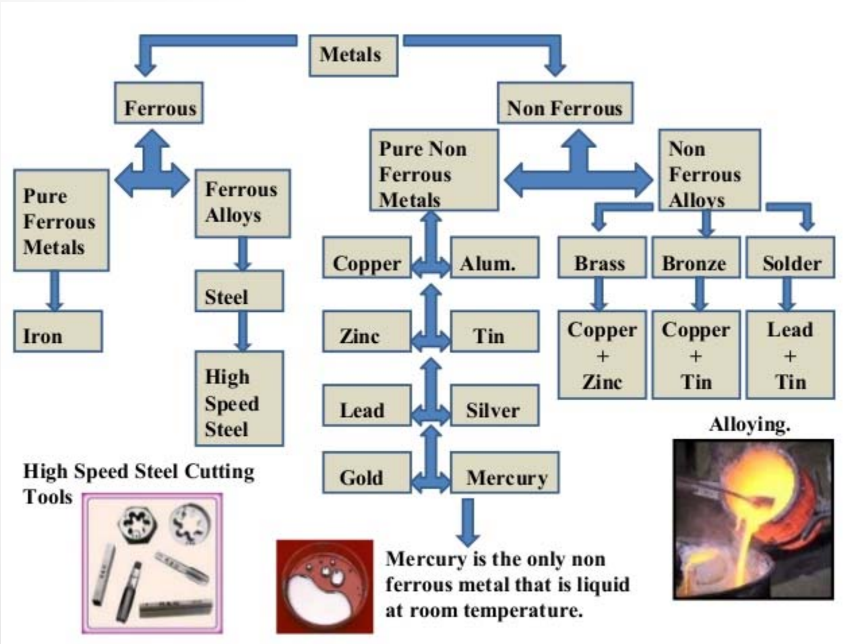
MATERIAL: CLASSIFICATION

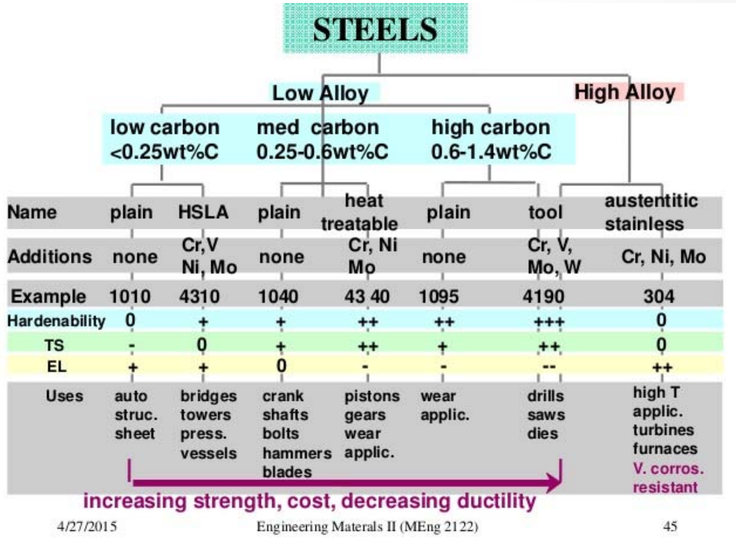
UCS : Carbon and Low Alloy Steels

UHA : High Alloy Steel

UHT : Ferritic Steels

UNF : Nonferrous Materials





	low carbon		med carbon		high carbon		High Alloy
Name	plain	HSLA	plain	heat treatable	plain	tool	austentitic stainless
Additions	none	Cr,V Ni, Mo	none	Cr, Ni Mo	none	Cr, V, Mo, W	Cr, Ni, Mo
Example	1010	4310	1040	43 40	1095	4190	304
Hardenability	0	+	+	++	++	+++	0
TS	-	0	+	++	+	++	0
EL	+	+	0	-	-	--	++
Uses	auto struc. sheet	bridges towers press. vessels	crank shafts bolts hammers blades	pistons gears wear applic.	wear applic.	drills saws dies	high T applic. turbines furnaces V. corros. resistant

MATERIAL: CLASSIFICATION

Austenitic Stainless Steel

- Grade type is 304
- 16 – 26% Cr, 6 – 23% Ni
- Have a face-centered-cubic (fcc) structure
- Nonmagnetic, tough, ductile
- Ex. Type 304 most widely used in the world
- Type 304L is always preferred in more corrosive environments

Applications: domestic kitchen sinks, commerical food processing equipment

Ferritic Stainless Steel

- Grade type is 430
- 12 – 25% Cr
- This simplest form of stainless steel
- Easy to machine
- They are moderate corrosion resistance

Application: automotive trim and inside dishwashers and clothes dryers.

Martensitic Stainless Steel

- Grade type is 410
- 6 – 18% Cr, upto 2% Ni
- Strong, hard and magnetic
- Used for mild corrosive enviornments

Application: knives, razor blades and corrosion resistance bearing

Precipitation Hardening S.S

- Type 17-4
- High strength
- Higher corrosion resistance than martensite stainless steel

Application: they are usually used in aerospace and defense industries.

MATERIAL: SELECTION GUID

	Design Temperature, °F	Material	Plate	Pipe	Forgings	Fittings	Bolting
Cryogenic	−425 to −321	Stainless steel	SA-240-304, 304L, 347, 316, 316L	SA-312-304, 304L, 347, 316, 316L	SA-182-304, 304L, 347, 316, 316L	SA-403-304, 304L, 347, 316, 316L	SA-320-B8 with SA-194-8
	−320 to −151	9 nickel	SA-353	SA-333-8	SA-522-1	SA-420-WPL8	
Low temperature	−150 to −76	3½ nickel	SA-203-D	SA-333-3	SA-350-LF3	SA-420-WPL3	SA-320-L7 with SA-194-4
	−75 to −51	2½ nickel	SA-203-A				
	−50 to −21	Carbon steel	SA-516-55, 60 to SA-20	SA-333-6	SA-350-LF2	SA-420-WPL6	
	−20 to 4		SA-516-All	SA-333-1 or 6			SA-193-B7 with SA-194-2H
	5 to 32		SA-285-C	SA-53-B SA-106-B	SA-105 SA-181-60,70	SA-234-WPB	
Intermediate	33 to 60 61 to 775		SA-516-All SA-515-All SA-455-II				
Elevated temperature	776 to 875	C-½Mo	SA-204-B	SA-335-P1	SA-182-F1	SA-234-WP1	
	876 to 1000	1Cr-½Mo	SA-387-12-1	SA-335-P12	SA-182-F12	SA-234-WP12	
		1-¼Cr-½Mo	SA-387-11-2	SA-335-P11	SA-182-F11	SA-234-WP11	
	1001 to 1100	2¼Cr-1Mo	SA-387-22-1	SA-335-P22	SA-182-F22	SA-234-WP22	with SA-193-B5 SA-194-3
	1101 to 1500	Stainless steel	SA-240-347H	SA-312-347H	SA-182-347H	SA-403-347H	SA-193-BB with SA-194-B
		Incoloy	SB-424	SB-423	SB-425	SB-366	
	Above 1500	Inconel	SB-443	SB-444	SB-446	SB-366	

MATERIAL: ALLOWABLE STRESS AS PER ASME II D

Table 1A (Cont'd)
Section I; Section III, Classes 2 and 3;* Section VIII, Division 1; and Section XII
Maximum Allowable Stress Values *S* for Ferrous Materials
(*See Maximum Temperature Limits for Restrictions on Class)

Page 10, ASME II D

Line No.	Nominal Composition	Product Form	Spec. No.	Type/Grade	Alloy Desig./ UNS No.	Class/ Condition/ Temper	Size/ Thickness, mm	P-No.	Group No.
1	Carbon steel	Wld. pipe	SA–134	A283C	K02401	...	...	1	1
2	Carbon steel	Plate	SA–283	C	K02401	...	...	1	1
3	Carbon steel	Plate	SA–285	C	K02801	...	...	1	1

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Line No.	Min. Tensile Strength, MPa	Min. Yield Strength, MPa	Applicability and Max. Temperature Limits (NP = Not Permitted) (SPT = Supports Only): I	III	VIII-1	XII	External Pressure Chart No.	Notes
1	380	205	NP	149 (Cl. 3 only)	NP	NP	CS–2	W12
2	380	205	NP	149 (Cl. 3 only)	343	343	CS–2	...
3	380	205	482	371	482	343	CS–2	G10, S1, T2

Maximum Allowable Stress, MPa (Multiply by 1000 to Obtain kPa), for Metal Temperature, °C, Not Exceeding

Line No.	−30 to 40	65	100	125	150	200	250	300	325	350	375	400	425	450	475
1	108	108	108	108	108	...	...	...	...	...	...	...	...	...	...
2	108	108	108	108	108	108	108	107	104	101	...	...	...	...	...
3	108	108	108	108	108	108	108	107	104	101	97.8	*89.1*	*75.4*	*62.6*	*45.5*

Page 12, ASME II D

MATERIAL: ALLOWABLE STRESS AS PER ASME II D

Page 150, ASME II D

determined from the flexibility of the flange and bolts and corresponding relaxation properties.

G9 For Section III applications, the use of these materials shall be limited to materials for tanks covered in Subsections NC and ND, component supports, and for nonpressure-retaining attachments (NC/ND-2190).

G10 Upon prolonged exposure to temperatures above 425°C, the carbide phase of carbon steel may be converted to graphite. See Nonmandatory Appendix A, A-201 and A-202.

G11 Upon prolonged exposure to temperatures above 475°C, the carbide phase of carbon-molybdenum steel may be converted to graphite. See Nonmandatory Appendix A, A-201 and A-202.

G12 At temperatures above 550°C, these stress values apply only when the carbon is 0.04% or higher on heat analysis.

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NOTES – SIZE REQUIREMENTS

S1 For Section I applications, stress values at temperatures of 450°C and above are permissible but, except for tubular products 75 mm O.D. or less enclosed within the boiler setting, use of these materials at these temperatures is not current practice.

S2 For Section I applications, stress values at temperatures of 475°C and above are permissible but, except for tubular products 75 mm O.D. or less enclosed within the boiler setting, use of these materials at these temperatures is not current practice.

S3 For Section I applications, stress values at temperatures of 550°C and above are permissible but, except for tubular products 75 mm O.D. or less enclosed within the boiler setting, use of these materials at these temperatures is not current practice.

S4 For Section I applications, stress values at temperatures of 625°C and above are permissible but, except for tubular products 75 mm O.D. or less enclosed within the boiler setting, use of these materials at these temperatures is not current practice.

S5 Material that conforms to Class 10, 11, or 12 is not permitted when the nominal thickness of the material exceeds 19 mm.

S6 Material that conforms to Class 10, 11, or 12 is not permitted when the nominal thickness of the material exceeds 32 mm.

S7 The maximum thickness of unheat-treated forgings shall not exceed 95 mm. The maximum thickness as-heat-treated may be 100 mm.

S8 The maximum section thickness shall not exceed 75 mm for double-normalized-and-tempered forgings, or 125 mm for quenched-and-tempered forgings.

S9 Both DN 200 and larger, and schedule 140 and heavier.

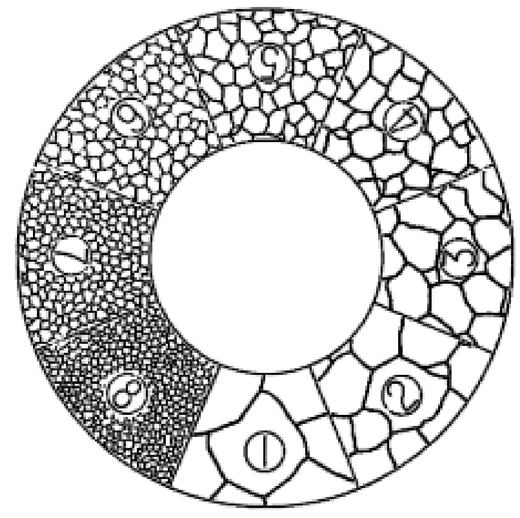
(15) S10 The maximum pipe size shall be DN 100 and the maximum thickness in any pipe size shall be Schedule 80.

S11 Either DN 200 and larger and less than schedule 140 wall, or less than DN 200 and all wall thicknesses.

NOTES – TIME-DEPENDENT PROPERTIES [See General Note (f)]

T1 Allowable stresses for temperatures of 370°C and above are values obtained from time-dependent properties.

MATERIAL: SPACIAL TREATMENT-HIGH TEMP. SERVICE



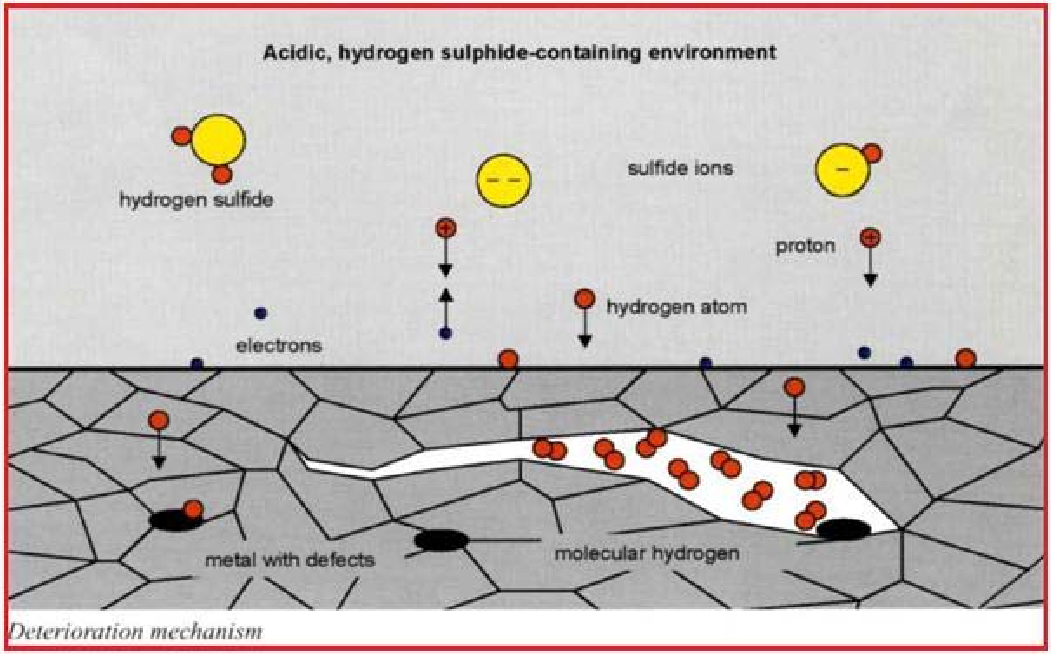
Materials for High-Temperature Service

- The austenitic H Types shall conform to an average grain size of ASTM No. 7 or coarser as measured by Test Methods E112.
- Supplementary Requirement S2 shall be invoked when non-H grade austenitic stainless steels are ordered for ASME Code applications for service above 1000°F [540°C].

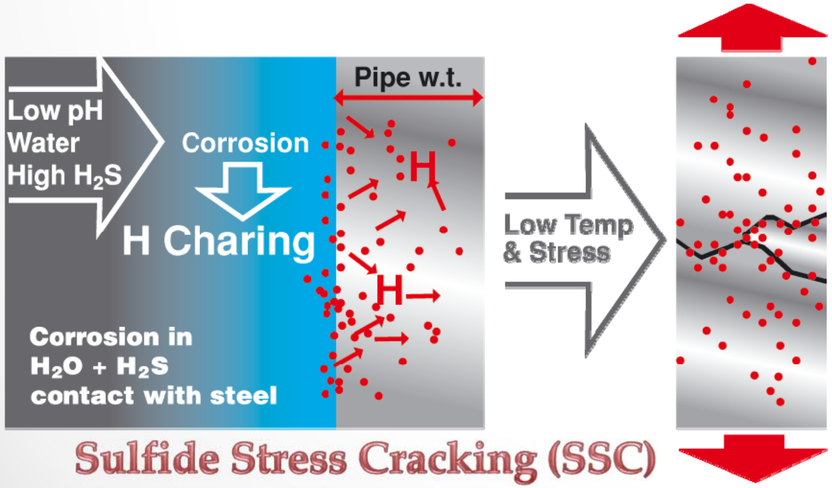
- Unless an H grade has been ordered, this supplementary requirement shall be specified for ASME Code applications for service above 1000°F [540°C].
- The user is permitted to use an austenitic stainless steel as the corresponding H grade when the material meets all requirements of the H grade including chemistry, annealing temperature, and grain size (see Section 6).

- For 304 SS serviced at temperatures above 550°C, the stress values in ASME II D, apply only when the carbon is 0.04% or higher on heat analysis.

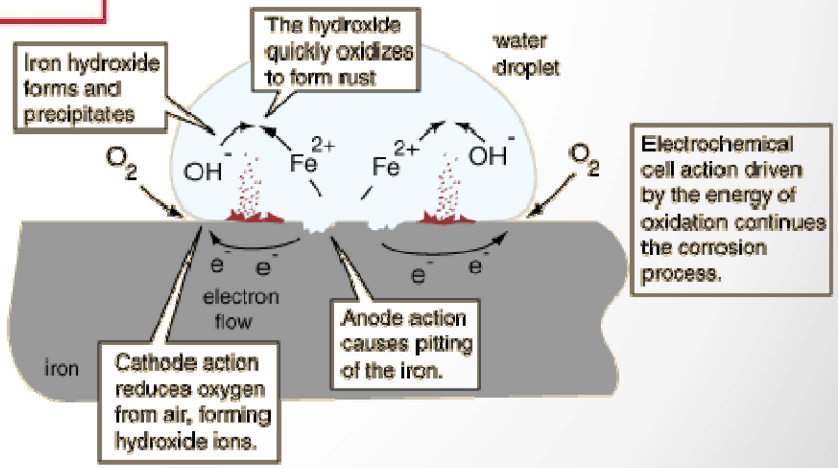
MATERIAL: SPACIAL TREATMENT-SOUR. SERVICE



Hydrogen Induced Cracking (HIC)



Sulfide Stress Cracking (SSC)



Electro Chemical Corrosion

SPACIAL TREATMENT-SOUR. SERVICE

Sour Service (SG) Or Amine Service Requirement

- Pressure parts of carbon steel equipment shall be manufactured from fine- grained and normalized condition

- Carbon content shall not exceed 0.22%, except forgings which shall be limited to 0.25 % maximum

- Carbon equivalent (CE) = C+Mn/6 shall not exceed 0.40 .

- Carbon equivalent (CE) as below formula shall not exceed 0.43

$$CE = \%C + \frac{\%Mn}{6} + \frac{(\%Ni + \%Cu)}{15} + \frac{(\%Cr + \%Mo + \%V)}{5}$$

The chemical composition, product analysis shall be limited as follows.
% Manganese = 1.30 maximum
% Phosphorus = 0.025 maximum
% Sulphur = 0.003 maximum
% V+Nb = 0.03 maximum

- Pressure parts, welded attachments, internal (including bolting) shall fully comply with the requirement of NACE MR 0175.

- All carbon steel and C- Mn steels shall be subject to PHWT

SPACIAL TREATMENT-SOUR. SERVICE

- Hardness requirement

Table 1: Low Alloy Steel Hardness Requirements

P-Number	Maximum Hardness (HBW)
3	225
4	225
5A	235
5B (except 9Cr-1Mo-V grades)	235
5B 9Cr-1Mo-V grades (F91, P91, T91, WP91, Grade 91, C12A)	248
5C	235
6	235
7	235
10A	225
10B	225
10C	225
P-No. 10F	225
P-No. 11	225

Carbon steel materials that are cold worked to produce outer fiber deformation greater than 5%, must be stress relieved to ensure that the material is below 22 HRC.

Composition Requirements for Austenitic Stainless Steels

Element	Weight Percent
C	0.10 max.
Cr	16.0 min.
Ni	8.0 min.
Mn	2.0 max.
Si	2.0 max.
P	0.045 max.
S	0.04 max.

Austenitic stainless steel materials are required to be in the solution-annealed or solution-annealed and thermally stabilized condition, must be free from cold work intended to enhance mechanical properties, and must meet a maximum hardness requirement of 22 HRC

- In addition, HIC resistant material requirements for plate shall be met.

SPACIAL TREATMENT-LETHAL SERVICE

<u>As per ENDNOTES ASME VIII Div.1 2015 Ed.</u>

Poisonous gases or liquids of such a nature that a very small amount of the gas or
of the vapor of the liquid mixed or unmixed with air is dangerous to life when inhaled. For purposes of this Division,
this class includes substances of this nature which are stored under pressure or may generate a pressure if stored in a closed vessel.

<u>As per UW-2(a)</u>

"When a vessel is to contain fluids of such a nature that a very small amount mixed or unmixed with air is dangerous to life when inhaled, it shall be the responsibility of the user and/or his designated agent to determine if it is lethal. If determined as lethal, the user and/or his designated agent [see U-2(a)] shall so advise the designer and/or Manufacturer. It shall be the responsibility of the Manufacturer to comply with the applicable Code provisions"

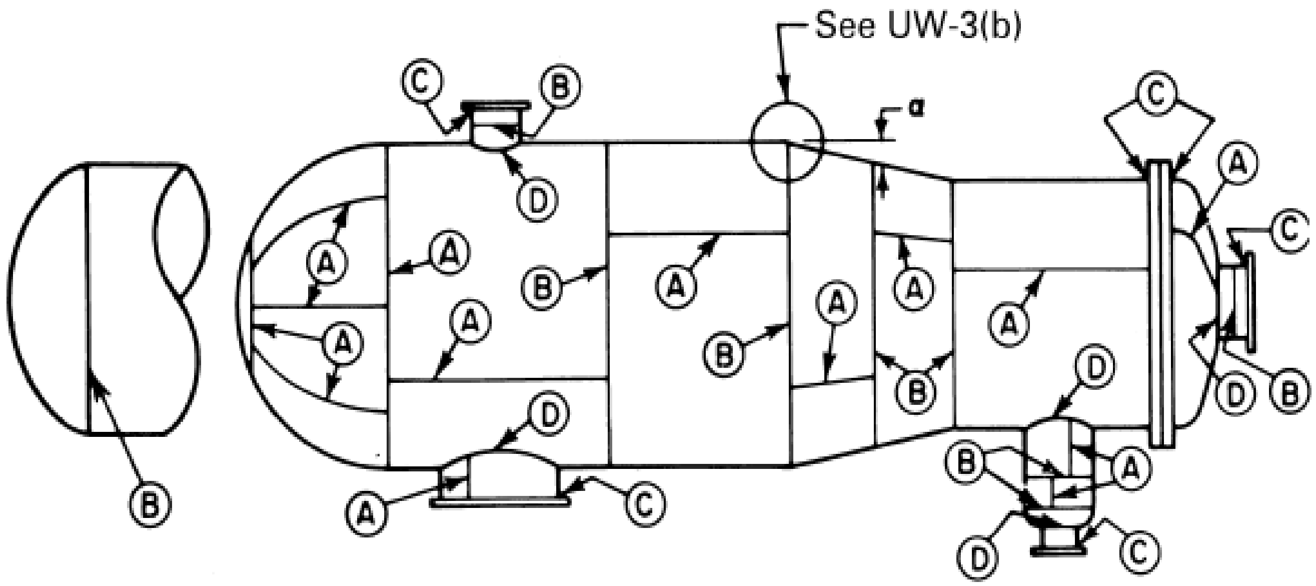
SPACIAL TREATMENT-LETHAL SERVICE

UG-16(5)(a) - Air cooled and cooling tower heat exchanger tube walls to be 1/16" min.
UG-24(b)(5)(a)- Casting RT requirements. **UCI-2, UCD-2** Cast iron and ductile cast iron vessels are not allowed.
UG-99(g),(k) - Hydro test visual leak inspection cannot be waived. Do not paint prior to the hydro test.
UG-100(d)(4) - Pneumatic tests cannot be used for lethal service vessels,
UG-116(c) - "L" stamping must be added to the nameplate. **UG-120(d)(1)** - "lethal service" is added to the data report
UW-2 - Service Restrictions - main source of info on Lethal Service (see lots more from UW-2 below)
UW-11(a)(1) - All shell and head butt welds to be 100% RT
UB-3 - Brazed vessels shall not be used
UCS-6 - Do not use SA-36, 38W or SA-283
UCS-79 - PWHT and extreme fiber elongation - read for rules when heat treatment is required
ULW-1 & ULW-26(b)(4) - Layered vessels lethal restrictions apply to the inner shell and heads only
UHX-19.1(b)- Heat exchanger markings
Appendix 2-5(d) - Maximum Flange Bolt Spacing
Appendix 2-6 - Bolt Spacing Correction
Appendix 7-1, 7-5 - Steel casting examination for 100% quality factor

Appendix 9-8 - if the jacket does not carry lethal substances, lethal service restrictions do not apply to it
Appendix 17-2(a) - Dimple jackets will not contain lethal substances
Appendix W Table W-3 - Filing out the U forms
More from UW-2:
UW-2(a) and UW-11(a)(1) - All butt welds shall be 100% radiographed
UW-2(a) - ERW pipe (like some grades of SA-53) is not permitted but interpretation VIII-1-01-118 says it is acceptable if the long seam is fully radiographed
UW-2(a) - Post weld heat treatment is required for CS and Low Alloy
UW-2(a)(1)(a) - Category A welds shall be type 1 only (butt welded with no permanent backing strip)
UW-2(a)(1)(b&c) &Interpretation VIII-1 92-211 - Category B & C welds shall be type 1 or 2 only (butt welded). No slip on flanges! No Figure UW-13.2 Flange or Head to Shell attachments
Interpretation VIII-I-98-23 - Category D welds (typically nozzles) shall be full penetration.

WELDING : CATEGORIES

Figure UW-3
Illustration of Welded Joint Locations Typical of Categories A, B, C, and D



WELDING : DESIGN AND JOINT EFFICIENCIES

Table UW-12
Maximum Allowable Joint Efficiencies for Arc and Gas Welded Joints

Type No.	Joint Description	Limitations	Joint Category	Degree of Radiographic Examination (a) Full [Note (1)]	(b) Spot [Note (2)]	(c) None
(1)	Butt joints as attained by double-welding or by other means that will obtain the same quality of deposited weld metal on the inside and outside weld surfaces to agree with the requirements of UW-35. Welds using metal backing strips that remain in place are excluded.	None	A, B, C, and D	1.00	0.85	0.70
(2)	Single-welded butt joint with backing strip other than those included under (1)	*(a)* None except as in (b) below	A, B, C, and D	0.90	0.80	0.65
		(b) Circumferential butt joints with one plate offset; see UW-13(b)(4) and Figure UW-13.1, sketch (i)	A, B, and C	0.90	0.80	0.65
(3)	Single-welded butt joint without use of backing strip	Circumferential butt joints only, not over $^5/_8$ in. (16 mm) thick and not over 24 in. (600 mm) outside diameter	A, B, and C	NA	NA	0.60

UW-35

a) Butt welded joints shall have complete penetration and full fusion. Welds shall be sufficiently free from coarse ripples, grooves, overlaps, and abrupt ridges

(b) A reduction in thickness due to the welding process

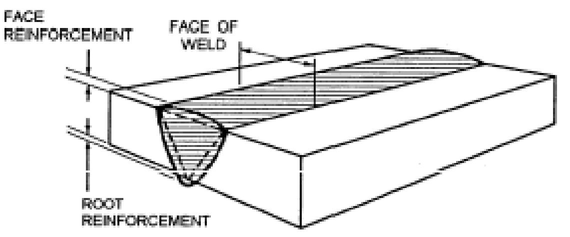
(1) Shall not be lower than the minimum required Thickness

(2) The reduction in thickness shall not exceed 1/32 in. (1 mm) or 10% of the nominal thickness of the adjoining surface, whichever is less.

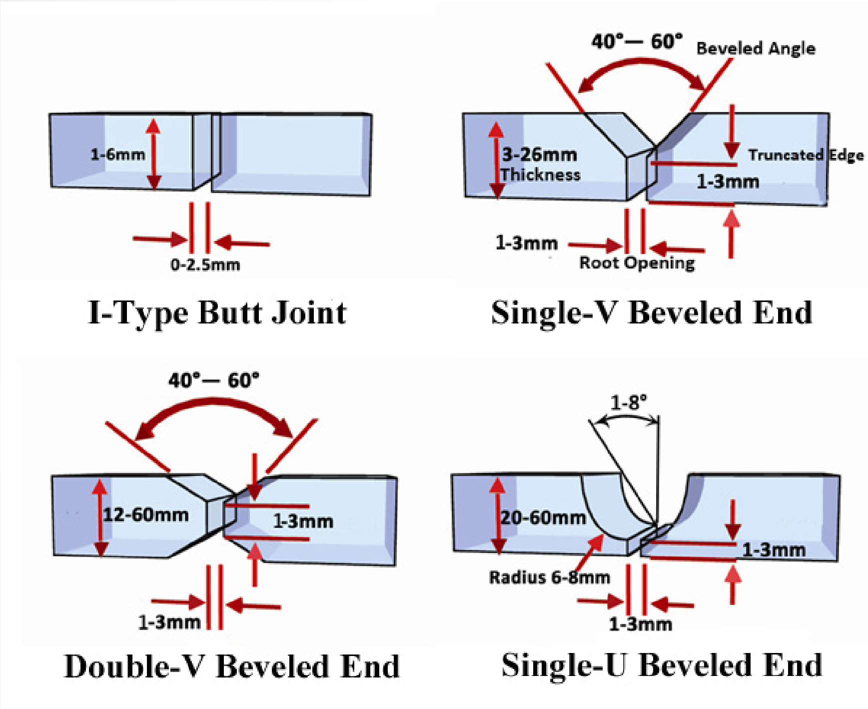
Reinforcement on each face of the weld

SI Units

Material Nominal Thickness, mm	Maximum Reinforcement, mm: Categories B and C Butt Welds	Other Welds
Less than 2.4	2.5	0.8
2.4 to 4.8, incl.	3	1.5
Over 4.8 to 13, incl.	4	2.5
Over 13 to 25, incl.	5	2.5
Over 25 to 51, incl.	6	3
Over 51 to 76, incl.	6	4
Over 76 to 102, incl.	6	5.5
Over 102 to 127, incl.	6	6
Over 127	8	8



WELDING : DESIGN



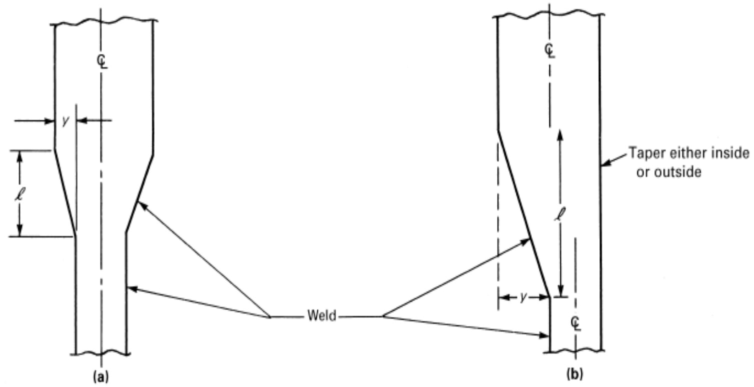
I-Type Butt Joint

Single-V Beveled End

Double-V Beveled End

Single-U Beveled End

Figure UW-9
Butt Welding of Plates of Unequal Thickness



GENERAL NOTES:

(a) $\ell \geq 3y$, where ℓ is the required length of taper and y is the offset between the adjacent surfaces of abutting sections.

(b) Length of required taper, ℓ, may include the width of the weld.

(c) In all cases, ℓ shall be not less than $3y$.

WELDING : DESIGN

Figure UW-13.1
Heads Attached to Shells

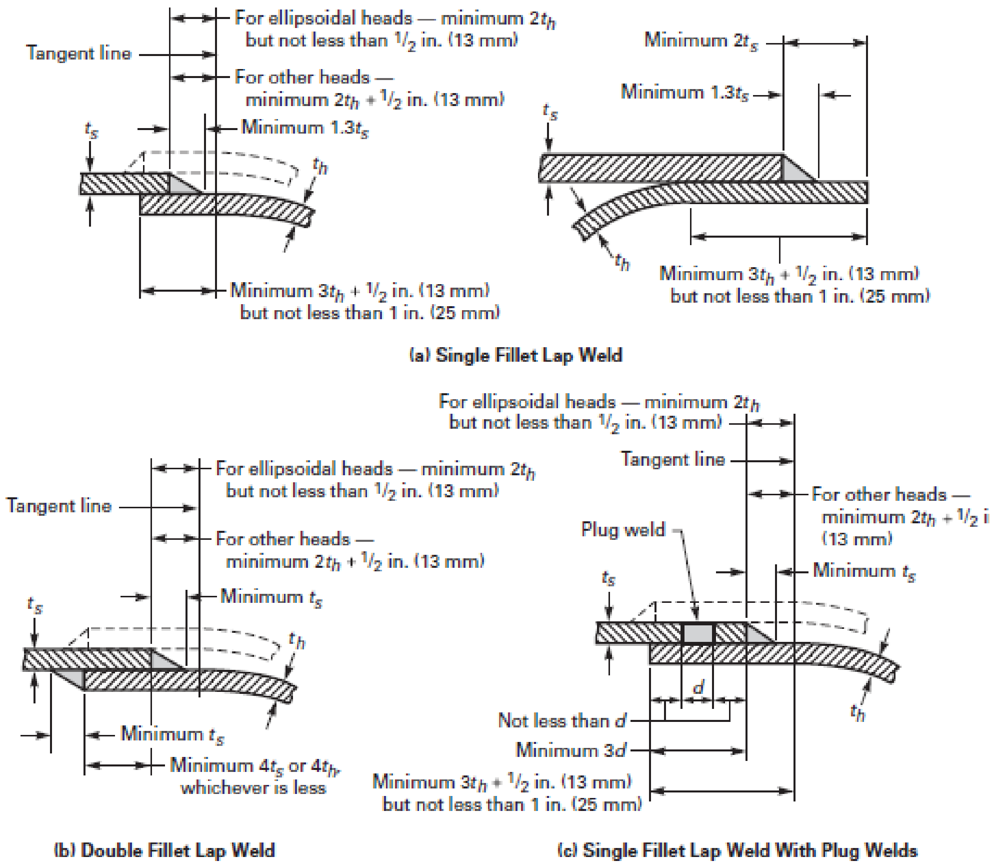
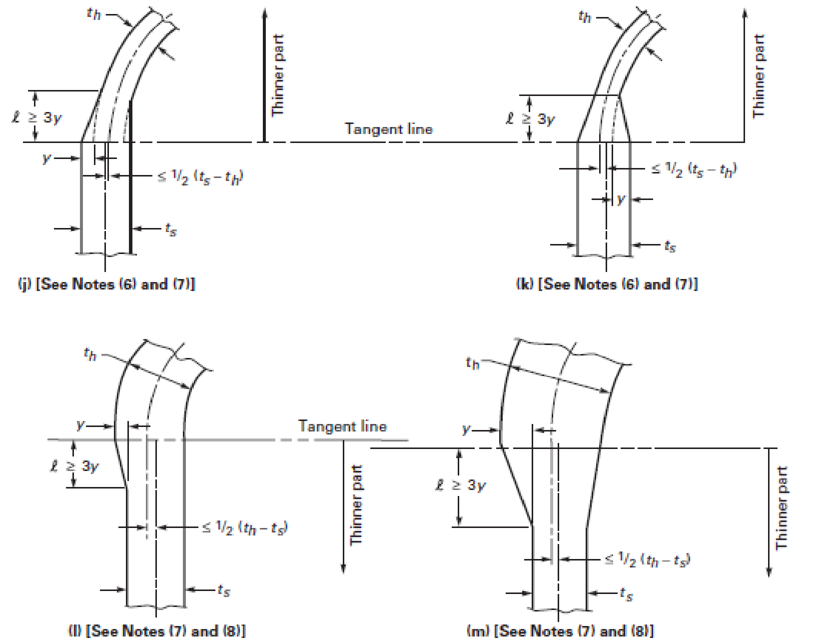
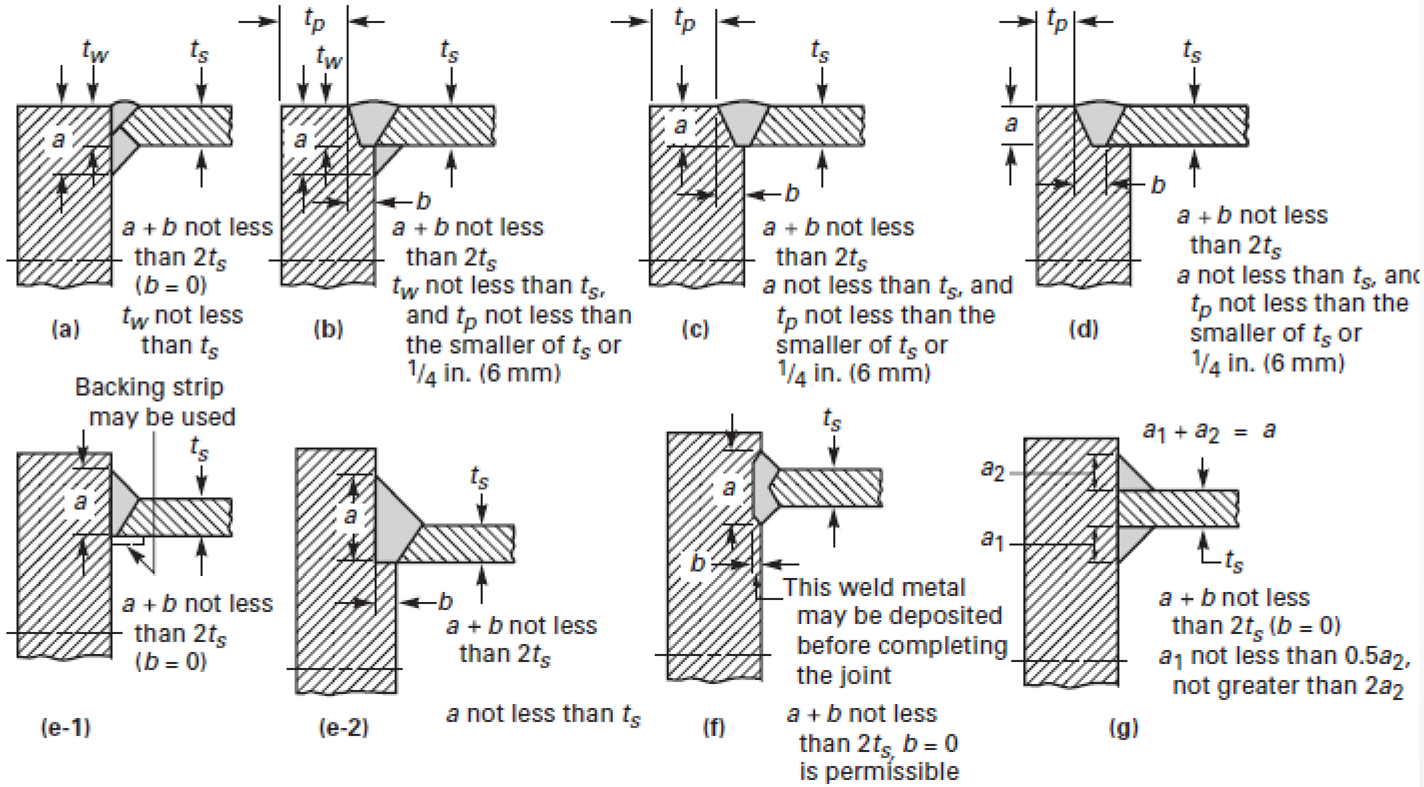


Figure UW-13.1
Heads Attached to Shells (Cont'd)



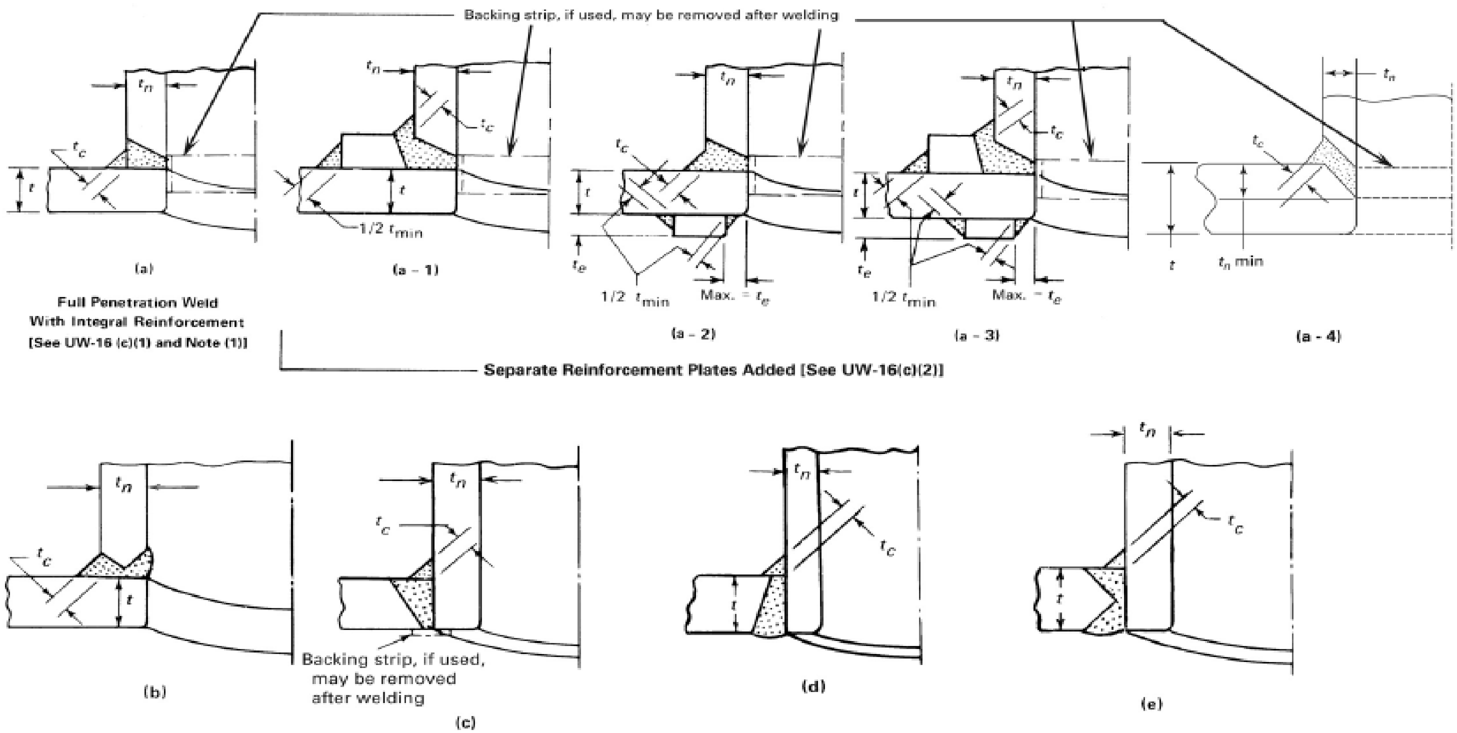
WELDING

Figure UW-13.2
Attachment of Pressure Parts to Flat Plates to Form a Corner Joint



WELDING

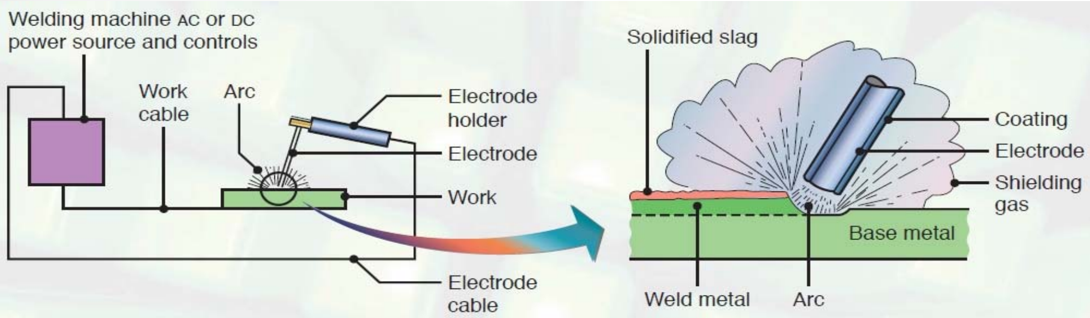
Figure UW-16.1
Some Acceptable Types of Welded Nozzles and Other Connections to Shells, Heads, etc.

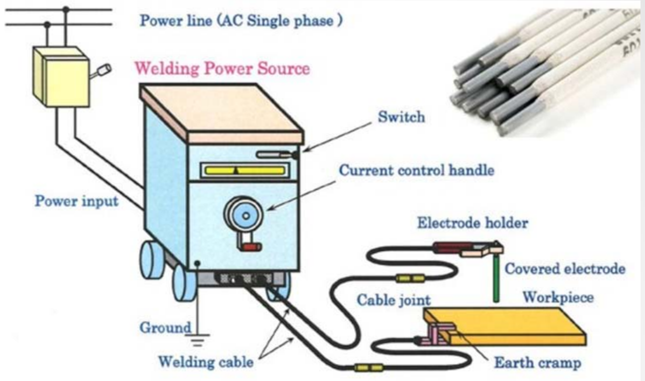


Full Penetration Welds to Which Separate Reinforcement Plates May Be Added [See UW-16(c)(2) and Note (1)]

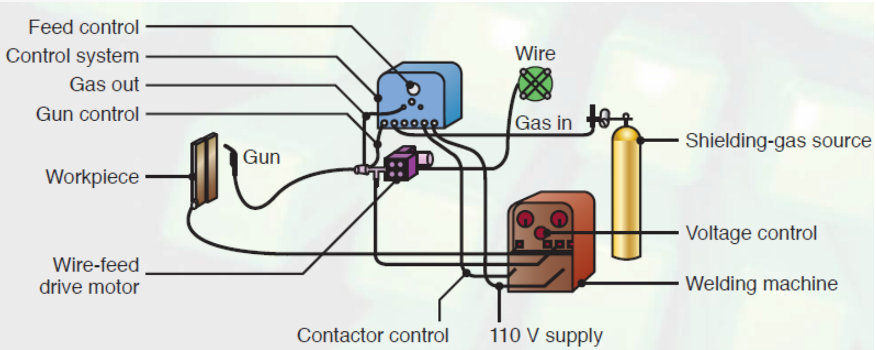
WELDING: SMAW & GMAW

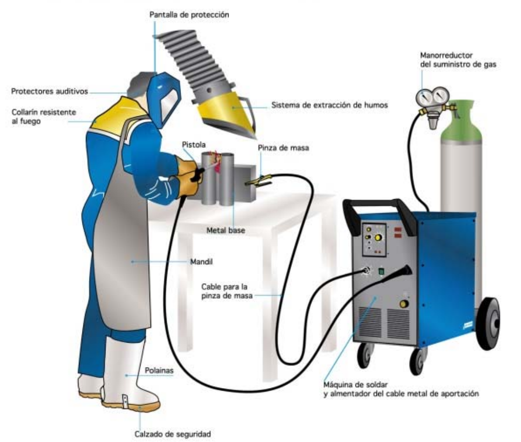
SMAW





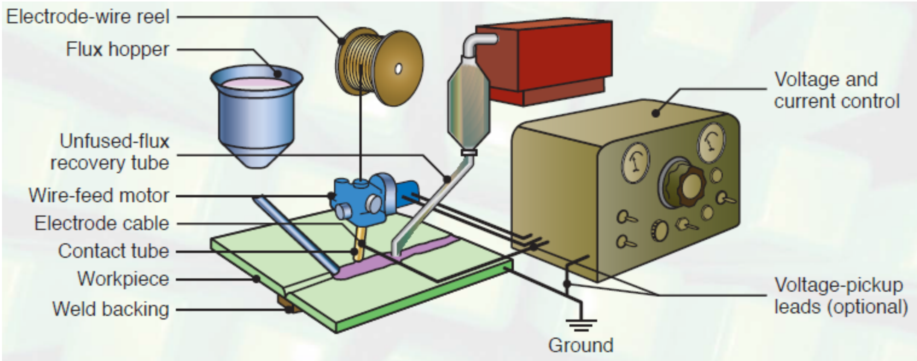
GMAW

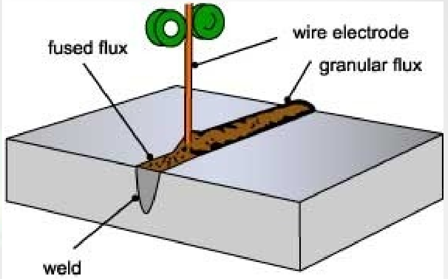




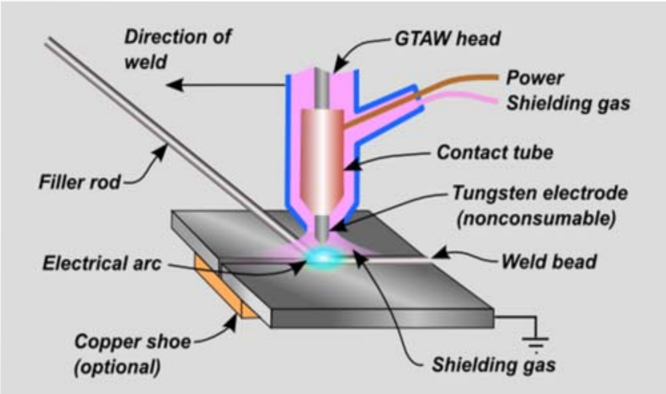
WELDING: SAW & GTAW

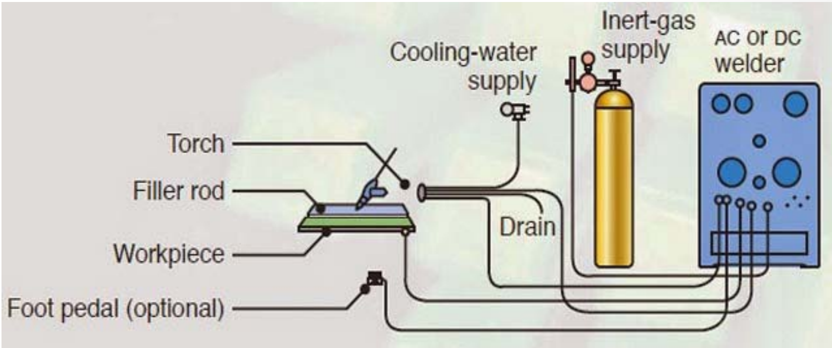
SAW





GTAW





WELDING: WELDING PROCUDURE SPECIFICATION(WPS)

METRODE WELDING CONSUMABLES

Welding Procedure Specification (WPS)

Welding Procedure No: Superduplex TIG/GTAW

Consumables		Base Material	
Welding process (root):	TIG / GTAW	Parent Material:	Superduplex. (UNS S32750 & S32760). ASME IX: P or S number (QW422) = 10H group 1.
- Consumable:	**Zeron 100X**		
- Specification:	BS EN 12072: W 25 9 4 N L		
Welding process (fill):	TIG / GTAW		
- Consumable:	**Zeron 100X**	Thickness:	18.26mm (Schedule 160)
- Specification:	BS EN 12072: W 25 9 4 N L	Outside Diameter:	6 inch NB
Joint Details		**Joint Position**	
Joint Type:	Single side butt	Welding Position:	ASME 6G
Manual/Mechanised:	Manual		
Joint Sketch		**Welding Sequences**	
6" NB Schedule 160; 65°±5°; 18.26mm; 0.5-1.5mm; 2-4mm		Split layers (2 beads per layer) from runs 4/5 onwards.	

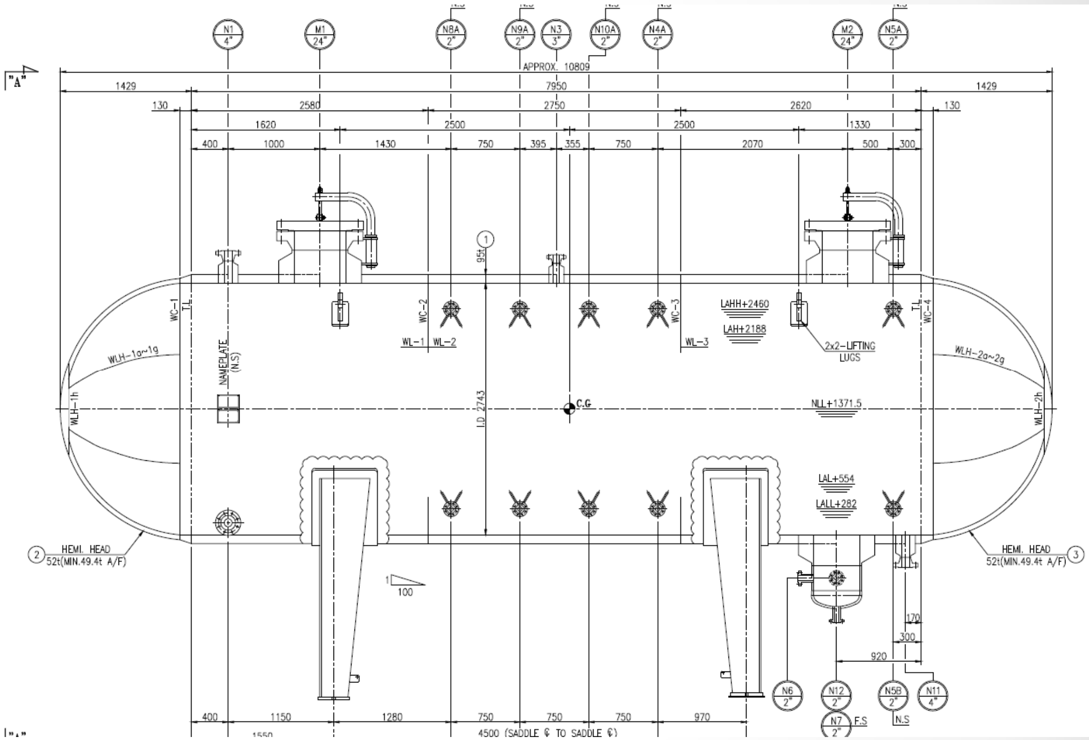
Welding Details

Run	Process	Consumable	Diameter mm	Current A	Voltage V	Travel speed mm/min	Type of current / Polarity	Heat Input kJ/mm
1	TIG	Zeron 100X	2.4	80-100	~12	~50	DC-	~1.2
2	TIG	Zeron 100X	2.4	90-130	~12	~125	DC-	~0.8
Fill	TIG	Zeron 100X	3.2	200-225	~12	100-175	DC-	~1.5

Electrode Baking or Drying:	NA
Gas – root (TIG) shielding:	Ar + 2% N_2
backing:	Ar
Gas - fill/cap (TIG) – Shielding:	Ar
Purge:	Ar
Tungsten Electrode Type/Size:	2%Th/2.4mm
Details of Back Gouging/Backing:	NA
Preheat Temperature:	20°C
Interpass Temperature:	150°C max
Post-Weld Heat Treatment and/or Ageing:	None
Temperature:	
Time:	

Notes:

1. Tack joint securely to prevent root closure using four bridging tacks.
2. Weld pipe in four 90° segments to prevent excessive overheating.
3. Purge to maintain 0.5% oxygen max.
4. Ar + 2%N_2 shielding gas is recommended for the root run to ensure G48A properties.
5. Purging 20-30l/min (reduced to ~10l/min for tie-in). Maintain purge for first two runs.
6. Shielding gas flow rate 8-12l/min.



HEAT TREATMENT : STRESS RELIEVED REQUIREMENT

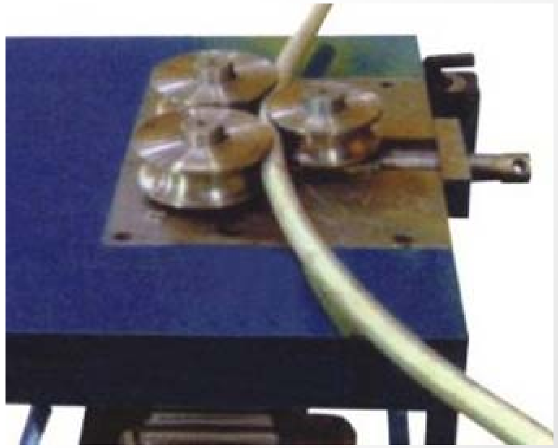
Table UG-79-1
Equations for Calculating Forming Strains

Type of Part Being Formed	Forming Strain
Cylinders formed from plate	$\varepsilon_f = \left(\frac{50t}{R_f}\right)\left(1 - \frac{R_f}{R_o}\right)$
For double curvature (e.g., heads)	$\varepsilon_f = \left(\frac{75t}{R_f}\right)\left(1 - \frac{R_f}{R_o}\right)$
Tube and pipe bends	$\varepsilon_f = \frac{100r}{R}$

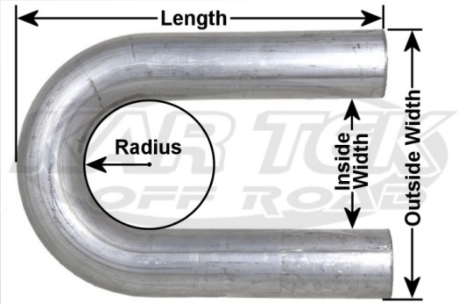
GENERAL NOTE:
- ε_f = calculated forming strain or extreme fiber elongation
- R = nominal bending radius to centerline of pipe or tube
- R_f = final mean radius
- R_o = original mean radius, equal to infinity for a flat plate
- r = nominal outside radius of pipe or tube
- t = nominal thickness of the plate, pipe, or tube before forming

Head Spinning

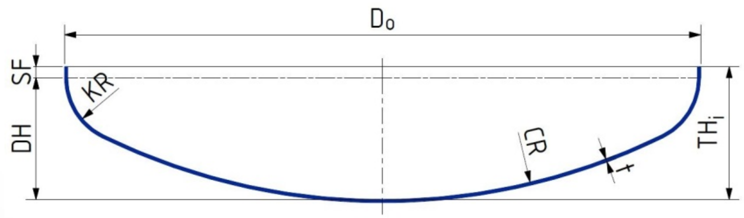
Plate Forming



Tube Bending



Bent Tube



Formed Head

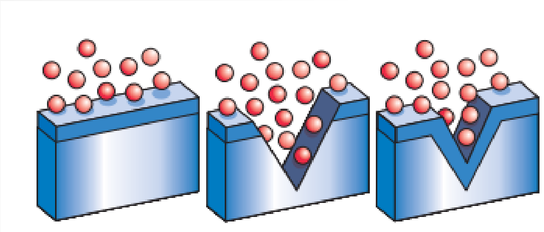
STRESS RELIEVED REQUIREMENT

Table UHA-44
Postfabrication Strain Limits and Required Heat Treatment

		Limitations in Lower Temperature Range			Limitations in Higher Temperature Range		
		For Design Temperature, °F (°C)					
Grade	UNS Number	Exceeding	But Less Than or Equal to	And Forming Strains Exceeding, %	For Design Temperature, °F (°C), Exceeding	And Forming Strains Exceeding, %	Minimum Heat-Treatment Temperature, °F (°C), When Design Temperature and Forming Strain Limits Are Exceeded [Note (1)] and [Note (2)]
201-1	S20100 heads	All	All	All	All	All	1,950 (1 065)
201-1	S20100 all others	All	All	4	All	4	1,950 (1 065)
201-2	S20100 heads	All	All	All	All	All	1,950 (1 065)
201-2	S20100 all others	All	All	4	All	4	1,950 (1 065)
201LN	S20153 heads	All	All	All	All	All	1,950 (1 065)
201LN	S20153 all others	All	All	4	All	4	1,950 (1 065)
204	S20400 heads	All	All	All	All	All	1,950 (1 065)
204	S20400 all others	All	All	4	All	4	1,950 (1 065)
304	S30400	1,075 (580)	1,250 (675)	20	1,250 (675)	10	1,900 (1 040)
304H	S30409	1,075 (580)	1,250 (675)	20	1,250 (675)	10	1,900 (1 040)
304L	S30403	1,075 (580)	1,250 (675)	20	1,250 (675)	10	1,900 (1 040)
304N	S30451	1,075 (580)	1,250 (675)	15	1,250 (675)	10	1,900 (1 040)
309S	S30908	1,075 (580)	1,250 (675)	20	1,250 (675)	10	2,000 (1 095)
310H	S31009	1,075 (580)	1,250 (675)	20	1,250 (675)	10	2,000 (1 095)
310S	S31008	1,075 (580)	1,250 (675)	20	1,250 (675)	10	2,000 (1 095)
316	S31600	1,075 (580)	1,250 (675)	20	1,250 (675)	10	1,900 (1 040)
316H	S31609	1,075 (580)	1,250 (675)	20	1,250 (675)	10	1,900 (1 040)
316N	S31651	1,075 (580)	1,250 (675)	15	1,250 (675)	10	1,900 (1 040)
321	S32100	1,000 (540)	1,250 (675)	15 [Note (3)]	1,250 (675)	10	1,900 (1 040)
321H	S32109	1,000 (540)	1,250 (675)	15 [Note (3)]	1,250 (675)	10	2,000 (1 095)
347	S34700	1,000 (540)	1,250 (675)	15	1,250 (675)	10	1,900 (1 040)
347H	S34709	1,000 (540)	1,250 (675)	15	1,250 (675)	10	2,000 (1 095)
347LN	S34751	1,000 (540)	1,250 (675)	15	1,250 (675)	10	1,900 (1 040)
348	S34800	1,000 (540)	1,250 (675)	15	1,250 (675)	10	1,900 (1 040)
348H	S34809	1,000 (540)	1,250 (675)	15	1,250 (675)	10	2,000 (1 095)

HEAT TREATMENT : PICKLING AND PASSIVATION

solution annealing of SS dissolves any precipitated carbide phase at high temperature, then rapidly cools so that carbides will not be present to lessen corrosion resistance.



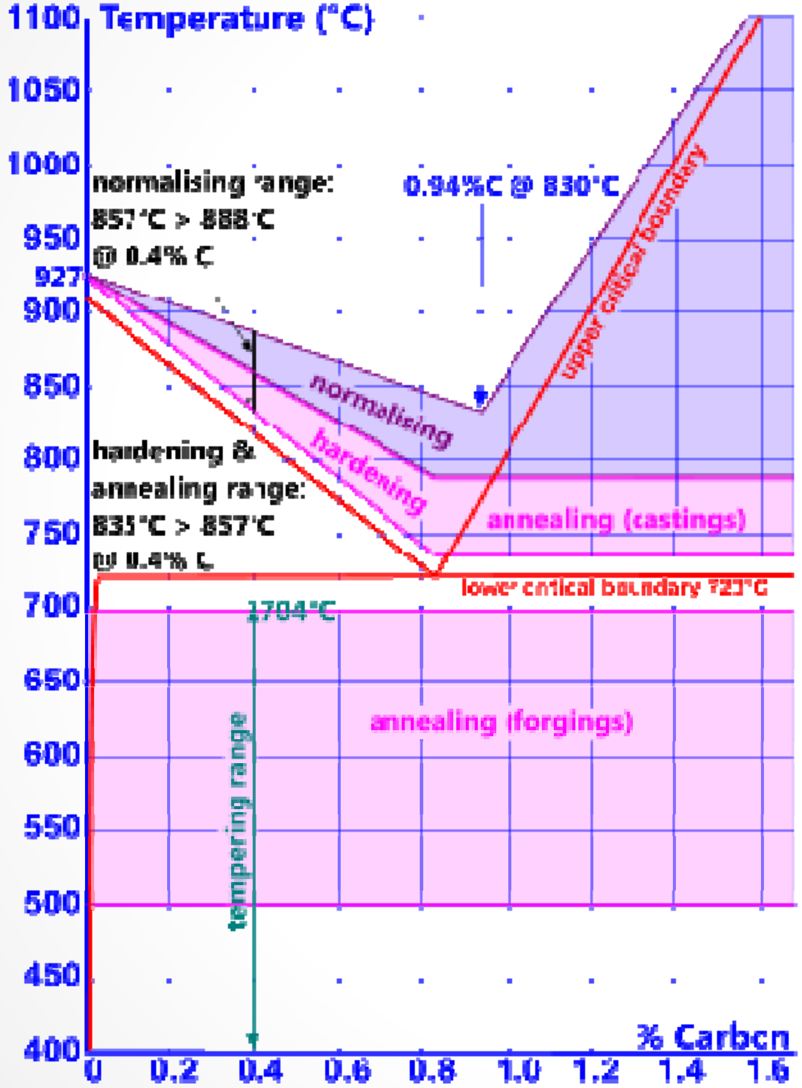
Oxygen to form the chromium-rich oxide surface layer

Tank immersion pickling:

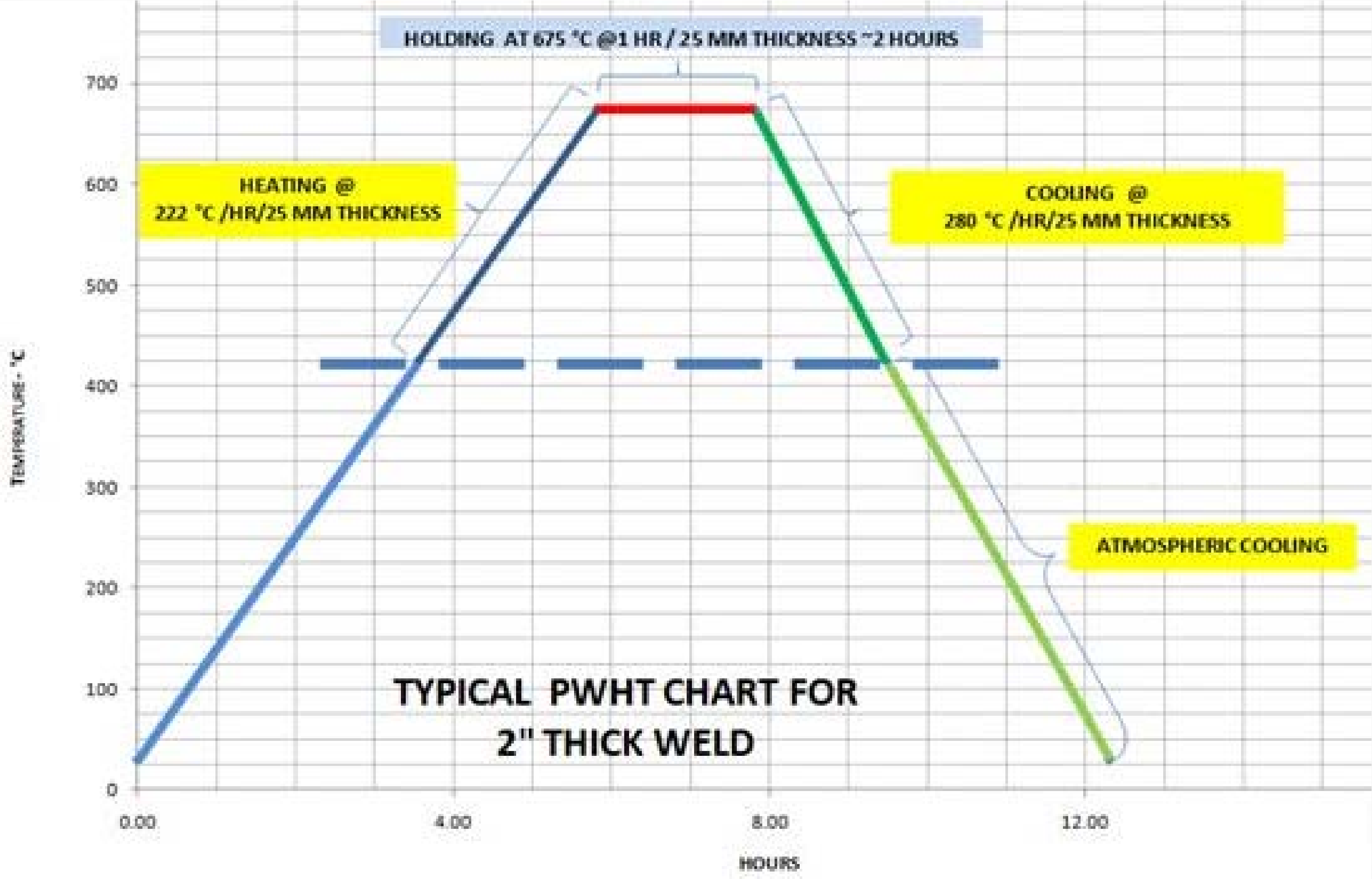
Processing sequence may be:

1) Clean SS of any lubricant which may contaminate surface when heated.
2) Solution anneal.
3) Mechanical descaling (wire brushing, temper rolling of sheet) to fracture & partially remove heat treat scale.
4) Pickle (acidic solution : nitric and Hydrofluoric acid) removes existing surface oxides (as from heat treating or welding), surface contamination such as iron from steel tooling, and removes the near-surface layer of metal which is often depleted in chromium due to prior heating.
5) Mechanically polish.
6) Passivation, nitric acid solutions (or increasingly with heated citric acid solutions)

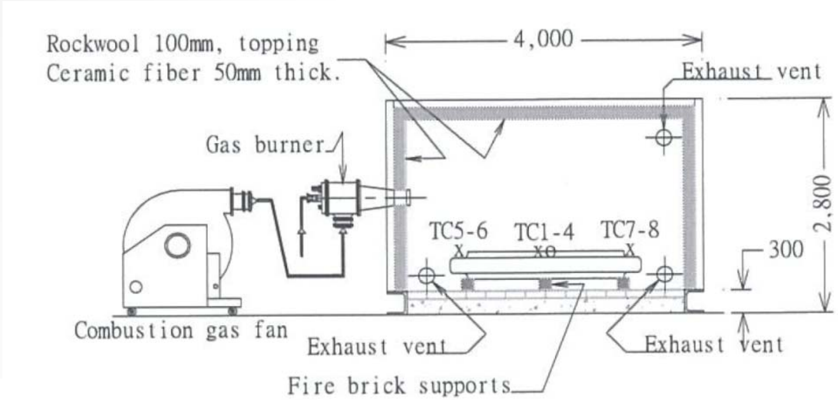
HEAT TREATMENT : HOLDING TEMPERATURE FOR CS

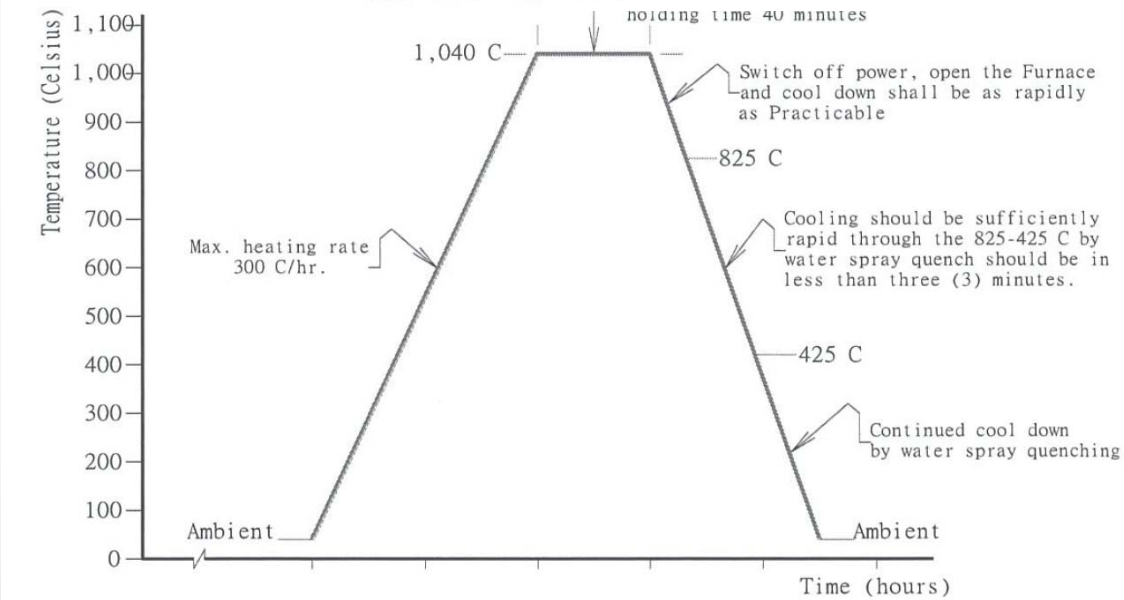


HEAT TREATMENT



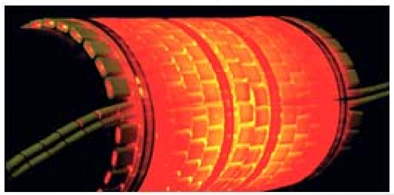
HEAT TREATMENT : SOLUTION ANNEALING FOR SS





Solution Annealing Profile

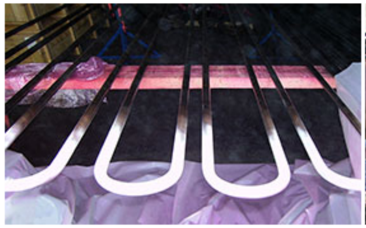
HEAT TREATMENT : PWHT



HEAT TREATMENT : TUBE U-BENDS

U-Tube heat treatment by Electric resistance

Post bending NDT control



– Hydrostatic Test
– Air Underwater Test
– Pulsating Test
– Dye Penetrant Test
– Magnetoscopic test

The Bent portion of the following U-Bend Tubes shall be heat treated after bending.

a. Low Carbon Steel Tubes of which mean bending radius is less than or equal to 5 times of the Tube outside diameter.

b. All Low Alloy Steel and Stainless Steel Tubes.

c. Brass Alloy Steel Tubes.

d. All Tube materials as specified in API 660 paragraph 9.6.3 a) in Hydrogen Charging, Caustic, or Amine Services.

HEAT TREATMENT: PWHT REQUIREMENT

Table UCS-56-1
Postweld Heat Treatment Requirements for Carbon and Low Alloy Steels — P-No. 1

Material	Normal Holding Temperature, °F (°C), Minimum	Minimum Holding Time at Normal Temperature for Nominal Thickness [See UW-40(f)]		
		Up to 2 in. (50 mm)	Over 2 in. to 5 in. (50 mm to 125 mm)	Over 5 in. (125 mm)
P-No. 1 Gr. Nos. 1, 2, 3	1,100 (595)	1 hr/in. (25 mm), 15 min minimum	2 hr plus 15 min for each additional inch (25 mm) over 2 in. (50 mm)	2 hr plus 15 min for each additional inch (25 mm) over 2 in. (50 mm)
Gr. No. 4	NA	None	None	None

GENERAL NOTES:

(a) When it is impractical to postweld heat treat at the temperature specified in this Table, it is permissible to carry out the postweld heat treatment at lower temperatures for longer periods of time in accordance with Table UCS-56.1.

(b) Postweld heat treatment is mandatory under the following conditions:

(1) for welded joints over $1\frac{1}{2}$ in. (38 mm) nominal thickness;

(2) for welded joints over $1\frac{1}{4}$ in. (32 mm) nominal thickness through $1\frac{1}{2}$ in. (38 mm) nominal thickness unless preheat is applied at a minimum temperature of 200°F (95°C) during welding. This preheat need not be applied to SA-841 Grades A and B, provided that the carbon content and carbon equivalent (CE) for the plate material, by heat analysis, do not exceed 0.14% and 0.40%, respectively, where

$$CE = C + \frac{Mn}{6} + \frac{Cr + Mo + V}{5} + \frac{Cu + Ni}{15}$$

SIMULATION HEAT TREATMENT

Supplementary: Simulated Post-Weld Heat Treatment of Mechanical Test Coupons

Prior to testing, the test coupons representing the plate for acceptance purposes for mechanical properties shall be thermally treated to simulate a post-weld heat treatment below the critical temperature (Ac3), using the heat treatment parameters
(such as temperature range, time, and cooling rates) specified in the purchase order. For tests using specimens taken from such heat treated test coupons, the test results shall meet the requirements of the applicable product specification.

IMPACT TEST : DETERMINE IMPACT TEST REQUIREMENT

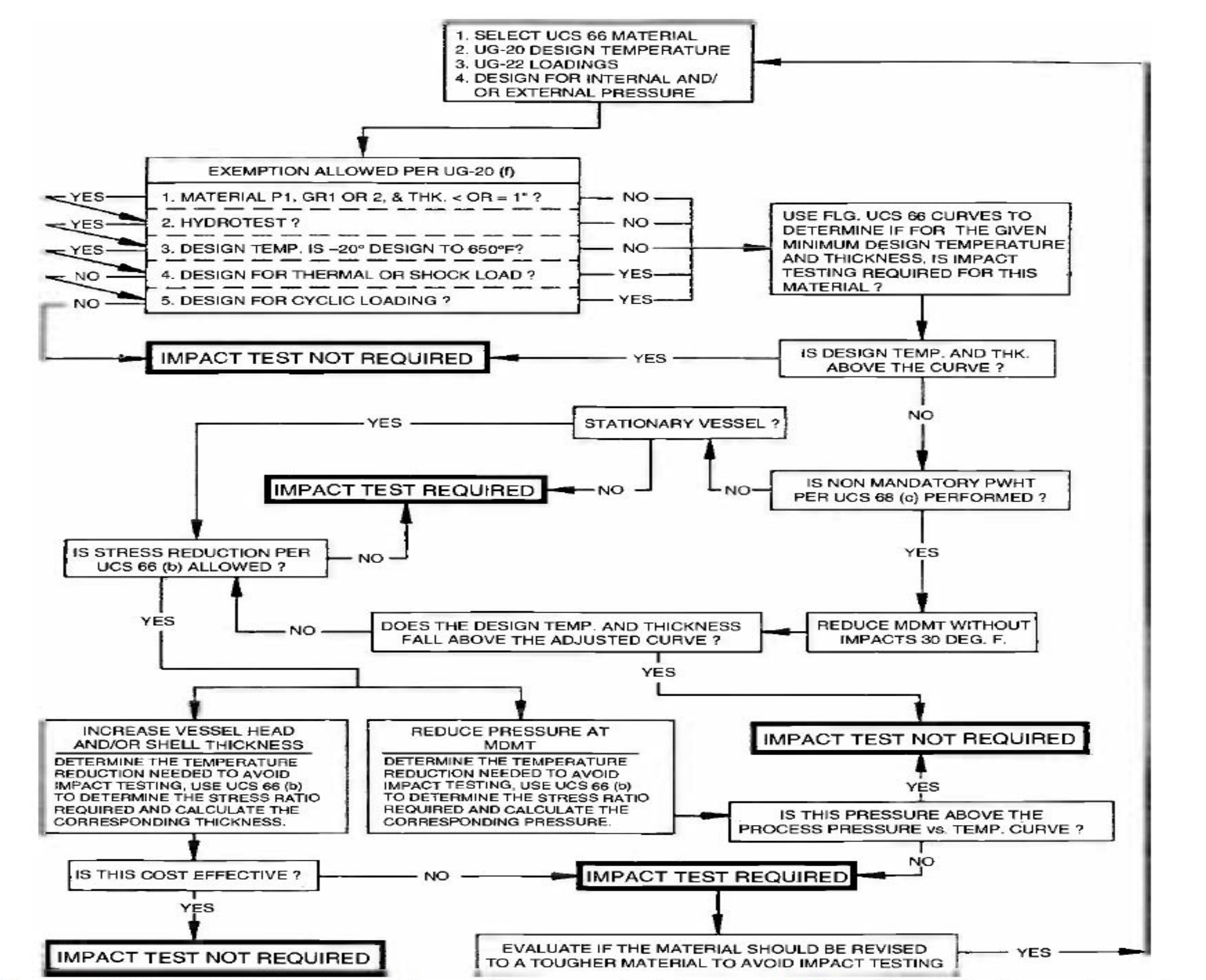


Figure 2-44. Flow chart showing decision-making process to determine MDMT and impact-testing requirements.

IMPACT TEST : EXCEPTION AND REDUCTION CURVES

Figure UCS-66M
Impact Test Exemption Curves

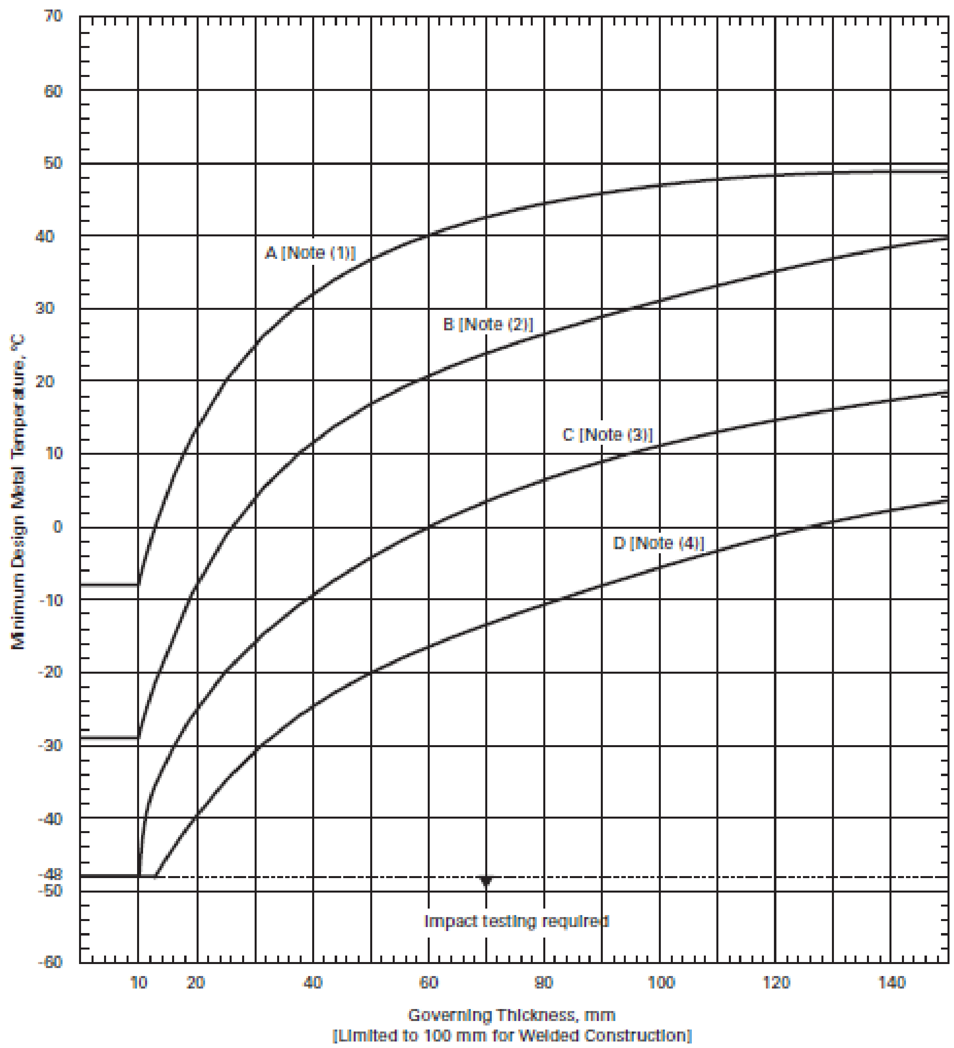
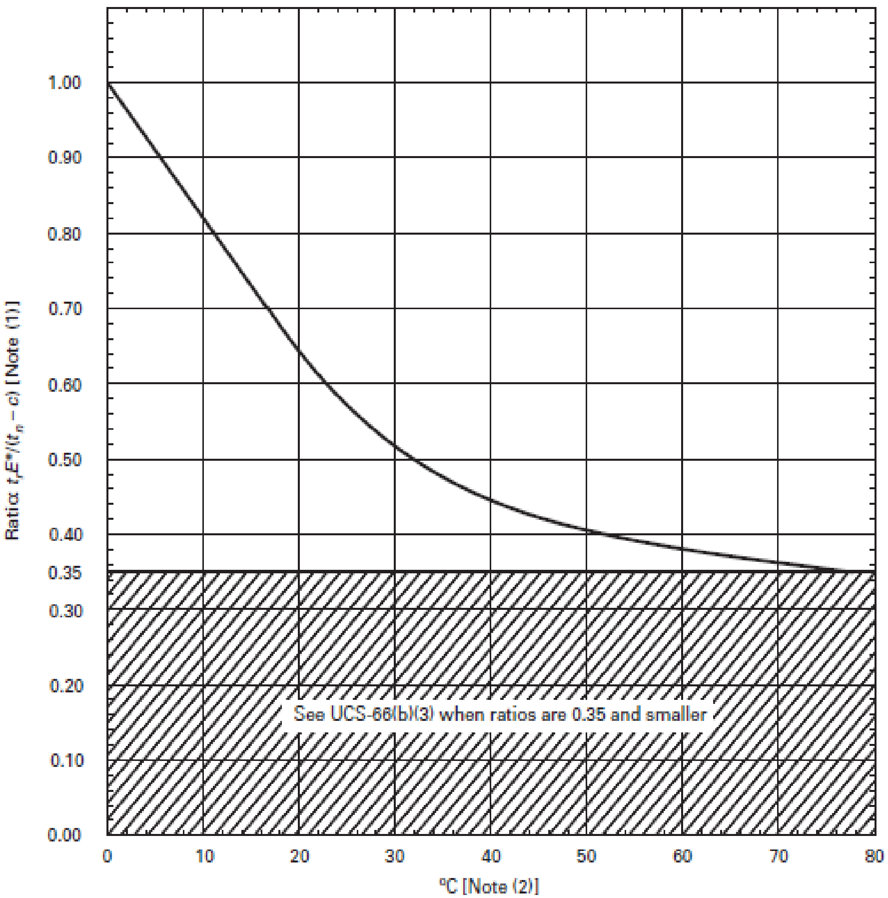


Figure UCS-66.1M
Reduction in Minimum Design Metal Temperature Without Impact Testing



IMPACT TEST : MATERIAL CLASIFICATION CURVE

1) Curve A applies to:

a) all carbon and all low alloy steel plates, structural shapes, and bars not listed in Curves B, C, and D below;

b) SA-216 Grades WCB and WCC if normalized and tempered or water-quenched and tempered; SA-217 Grade WC6 if normalized and tempered or water-quenched and tempered.

(2) Curve B applies to:

a) see below:

SA-216 Grade WCA if normalized and tempered or water-quenched and tempered
SA-216 Grades WCB and WCC for thicknesses not exceeding 2 in. (50 mm) , if produced to fine grain practice and water-quenched
and tempered
SA-217 Grade WC9 if normalized and tempered
SA-285 Grades A and B
SA-414 Grade A
SA-515 Grade 60
SA-516 Grades 65 and 70 if not normalized
SA-612 if not normalized
SA-662 Grade B if not normalized
SA/EN 10028-2 Grades P235GH, P265GH, P295GH, and P355GH as rolled
SA/AS 1548 Grades PT430NR and PT460NR

(b)except for cast steels, all materials of Curve A, if produced to fine grain practice and normalized, that are not listed in Curves C and D below;

(c) all pipe, fittings, forgings and tubing not listed for Curves C and D below;

(d)parts permitted under UG-11 shall be included in Curve B even when fabricated from plate that otherwise would be assigned to a different curve.

(

(3) Curve C applies to:

(a) see below:

SA-182 Grades F21 and F22 if normalized and tempered
SA-302 Grades C and D
SA-336 F21 and F22 if normalized and tempered, or liquid quenched and tempered
SA-387 Grades 21 and 22 if normalized and tempered, or liquid quenched and tempered
SA-516 Grades 55 and 60 if not normalized
SA-533 Types B and C Class 1
SA-662 Grade A
SA/EN 10028-2 Grade 10CrMo 9–10 if normalized and tempered

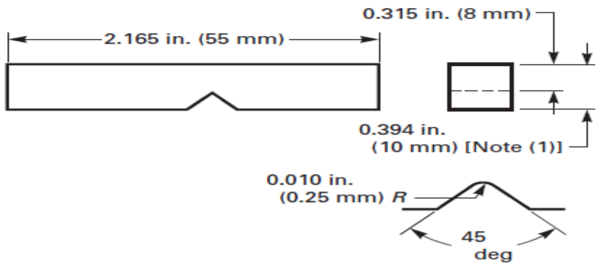
(b) all materials listed in 2(a) and 2(c) for Curve B if produced to fine grain practice and normalized, normalized and tempered, or liquid quenched and tempered as permitted in the material specification, and not listed for Curve D below.

(4) Curve D applies to:

SA-203
SA-508 Grade 1
SA-516 if normalized or quenched and tempered
SA-524 Classes 1 and 2
SA-537 Classes 1, 2, and 3
SA-612 if normalized
SA-662 if normalized
SA-738 Grade A
SA-738 Grade A with Cb and V deliberately added in accordance with the provisions of the material specification, not colder than −20°F (−29°C)
SA-738 Grade B not colder than −20°F (−29°C)
SA/AS 1548 Grades PT430N and PT460N
SA/EN 10028-2 Grades P235GH, P265GH, P295GH, and P355GH if normalized
SA/EN 10028-3 Grade P275NH

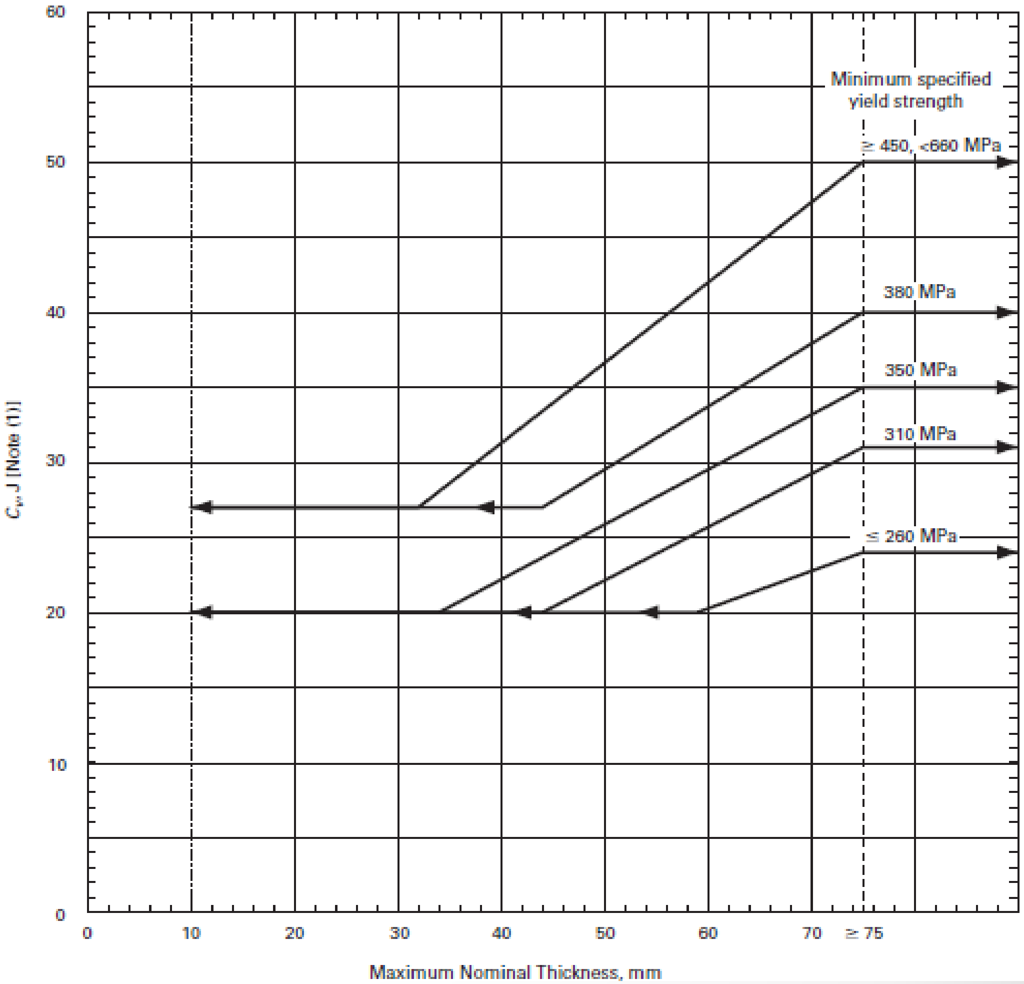
IMPACT TEST : IMPACT ENERGY VALUE

Figure UG-84
Simple Beam Impact Test Specimens (Charpy Type Test)



NOTE:
(1) See UG-84(c) for thickness of reduced size specimen.

Figure UG-84.1M
Charpy V-Notch Impact Test Requirements for Full-Size Specimens for Carbon and Low Alloy Steels, Having a Specified Minimum Tensile Strength of Less Than 655 MPa, Listed in Table UCS-23



IMPACT TEST: DETERMINE GOVERNING THICKNESS

Figure UCS-66.3
Some Typical Vessel Details Showing the Governing Thicknesses as Defined in UCS-66

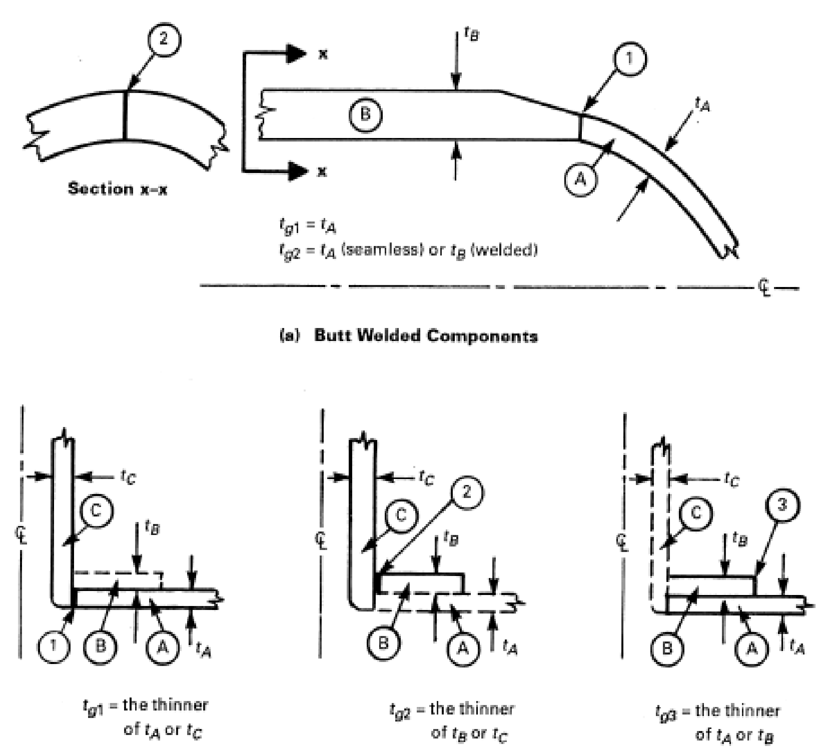
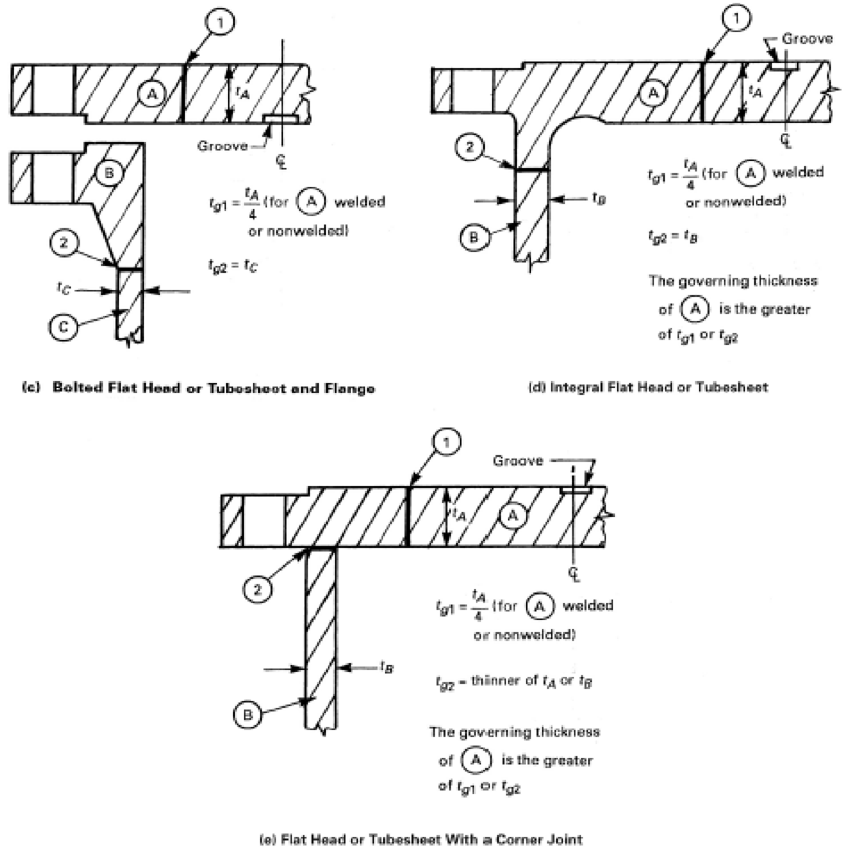
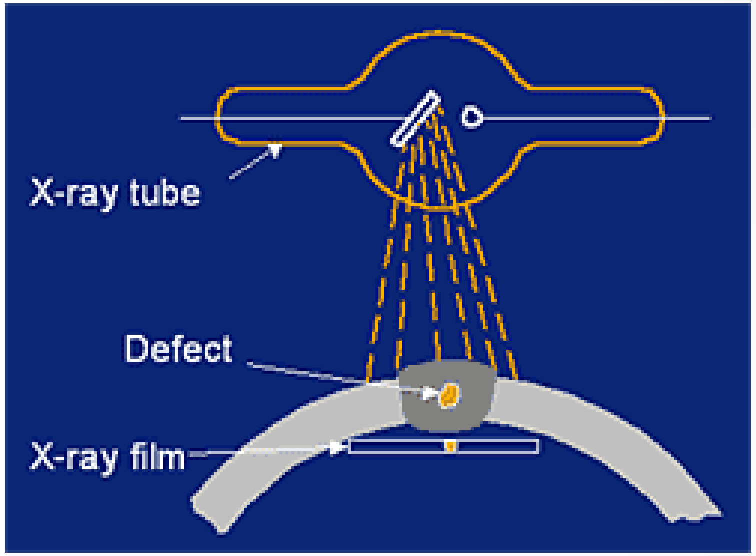
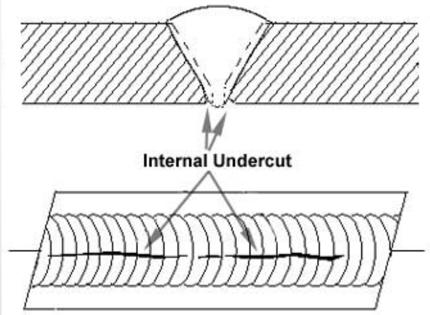


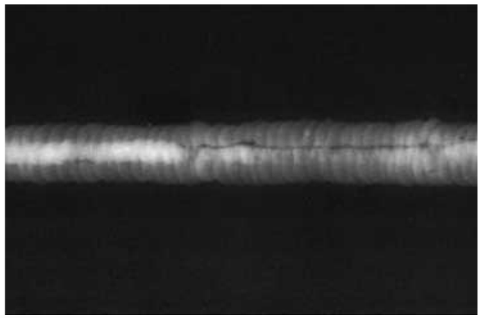
Figure UCS-66.3
Some Typical Vessel Details Showing the Governing Thicknesses as Defined in UCS-66 (Cont'd)

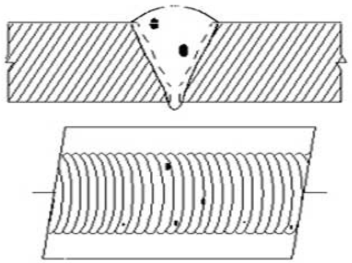


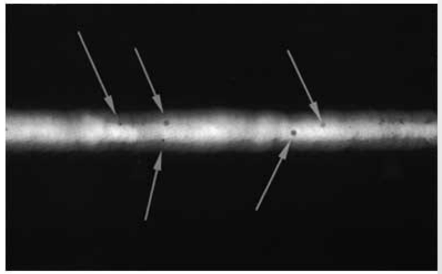
RADIOGRAPHIC EXAMINATION











RADIOGRAPHIC EXAMINATION

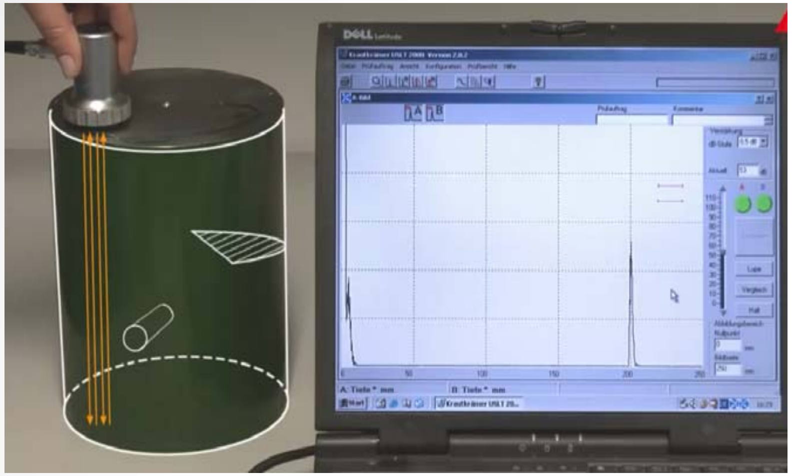
FULL RT MANDATORY

- Lethal substances
- The welded joint exceeds 11/2 in. (38 mm), or exceeds the lesser thicknesses prescribed in UCS-57(See table), UNF-57, UHA-33, UCL-35, or UCL-36
- Unfired Steam Boiler having design pressures *(-a)* exceeding 50 psi (350 kPa) [see UW-2(c)];
- Categories B and C butt welds in nozzles and communicating chambers that neither exceed NPS 10 (DN 250) nor 11/8 in. (29 mm) wall thickness do not require any radiographic examination;
- UT in accordance with UW-53 may be substituted for radiography for the final closure seam of a pressure vessel if the construction of the vessel does not permit interpretable radiographs in accordance with Code requirements.

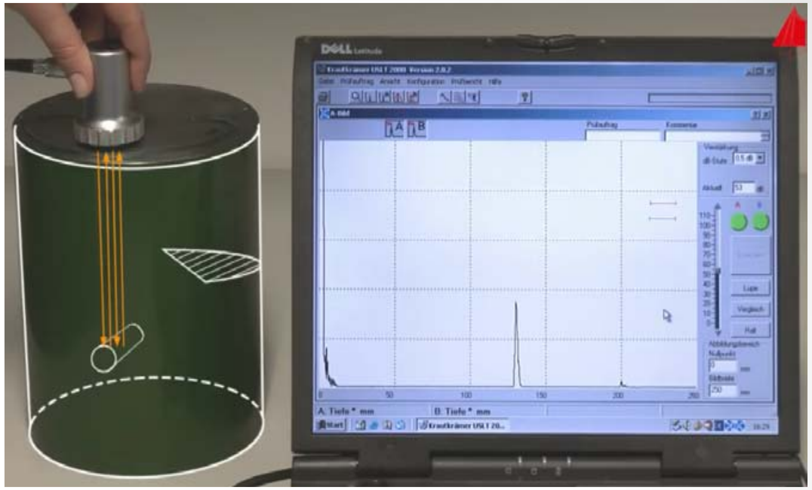
Table UCS-57
Thickness Above Which Full Radiographic Examination of Butt Welded Joints Is Mandatory

P-No. and Group No. Classification of Material	Nominal Thickness Above Which Butt Welded Joints Shall Be Fully Radiographed, in. (mm)
1 Gr. 1, 2, 3	$1\frac{1}{4}$ (32)
3 Gr. 1, 2, 3	$\frac{3}{4}$ (19)
4 Gr. 1, 2	$\frac{5}{8}$ (16)
5A Gr. 1, 2	0 (0)
5B Gr. 1	0 (0)
5C Gr. 1	0 (0)
15E, Gr. 1	0 (0)
9A Gr. 1	$\frac{5}{8}$ (16)
9B Gr. 1	$\frac{5}{8}$ (16)
10A Gr. 1	$\frac{3}{4}$ (19)
10B Gr. 1	$\frac{5}{8}$ (16)
10C Gr. 1	$\frac{5}{8}$ (16)
10F Gr. 1	$\frac{3}{4}$ (19)

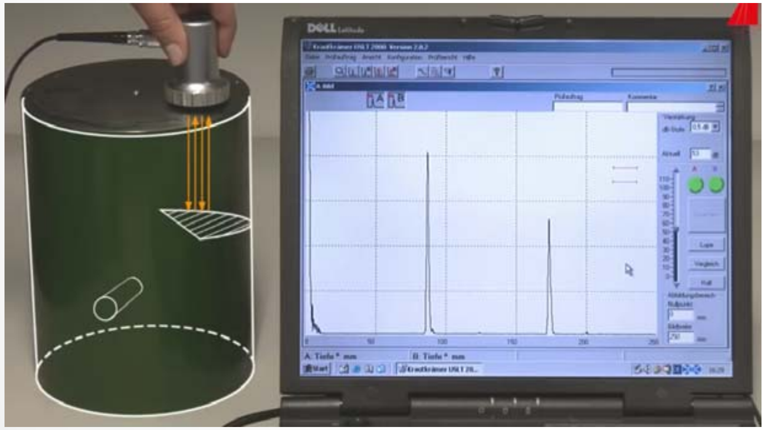
ULTRASONIC EXAMINATION (UT)



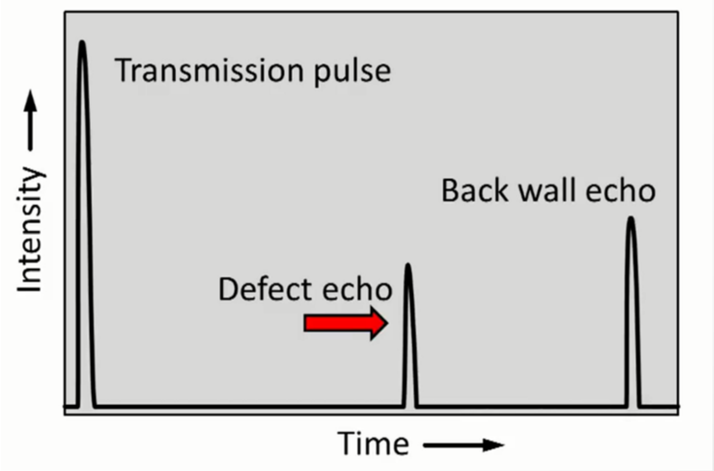
UT , No defect



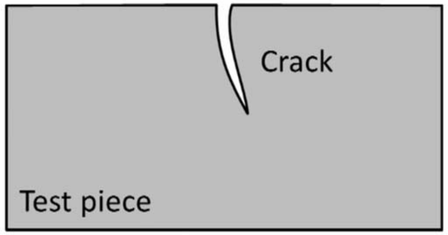
UT , found defect



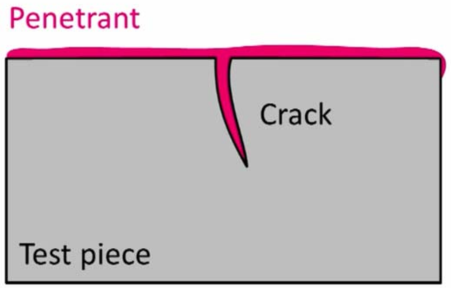
UT , found defect



DYE PENETRANT INSPECTION (PT)

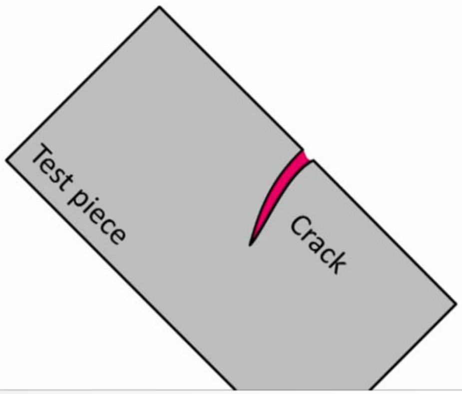


1. Pre-clean the test piece



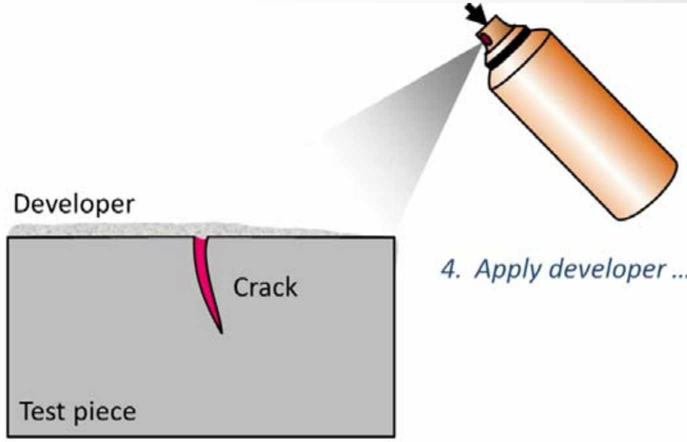
2. Apply penetrant ...

... and allow to soak

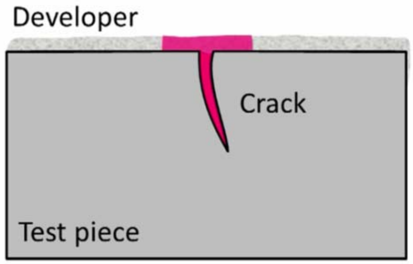


3. Rinse the test piece ...

... and let it dry

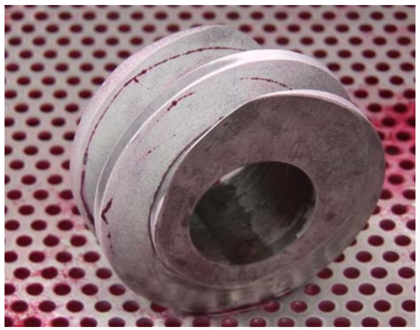


4. Apply developer ...



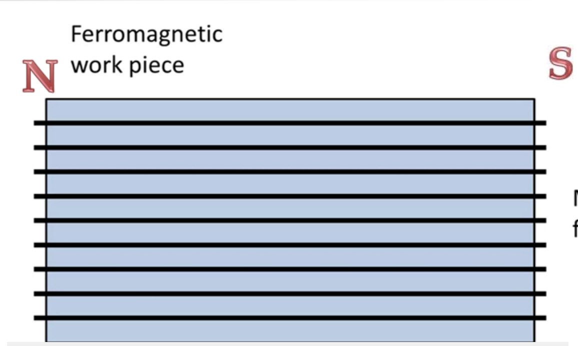
4. Apply developer...

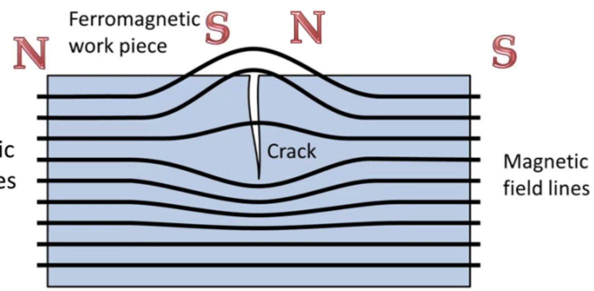
... and wait

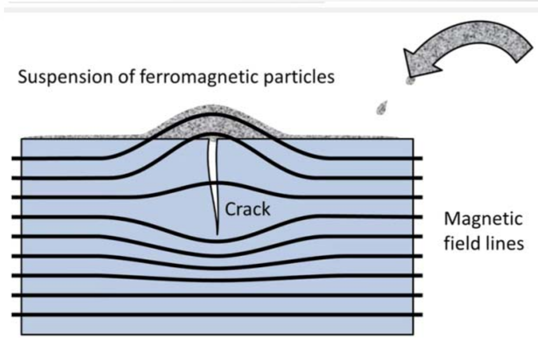


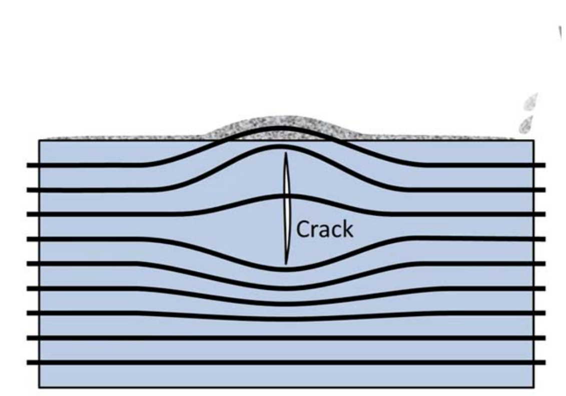
Advantages	Disadvantages
• Almost all materials can be tested	• Only suitable for surface defects
• Simple and low-cost for a single inspection	• No information about the depth of flaws can be gained
	• Rough surfaces are difficult to test

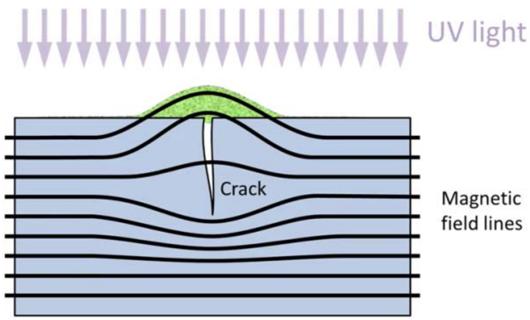
MAGNETIC PARTICLE TESTING (MT)

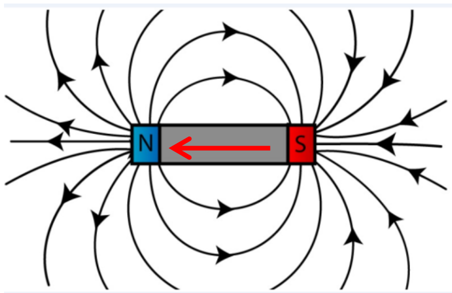






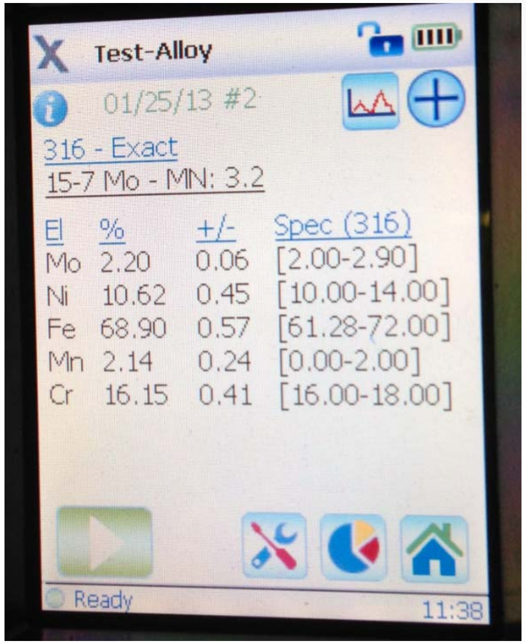






Magnetic Field Lines

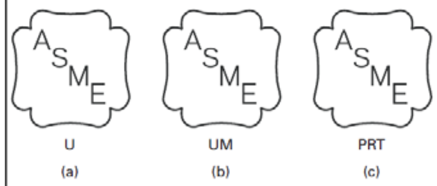
POSITIVE MATERIAL IDENTIFICATION (PMI)



****To identify the alloy composition of material**

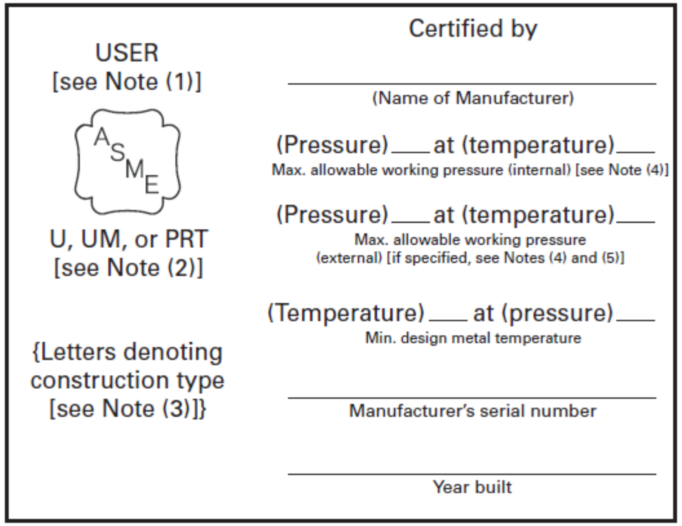
ASME NAME PLATE

Figure UG-116
Official Certification Mark to Denote the American Society of Mechanical Engineers' Standard



Type of Construction	Letter(s)
Arc or gas welded	W
Pressure welded (except resistance)	P
Brazed	B
Resistance welded	RES
Graphite	G

Lethal service	L
Unfired steam boiler	UB
Direct firing	DF



GENERAL NOTE: Information within parentheses, brackets, or braces is not part of the required marking. Phrases identifying data may be abbreviated; minimum abbreviations shall be MAWP, MDMT, S/N, FV, and year, respectively. See ASME PTB-4 for sample Nameplate markings.

NOTES:

(1) "USER" shall be included when the vessel is inspected by a user's Inspector as provided in UG-91.

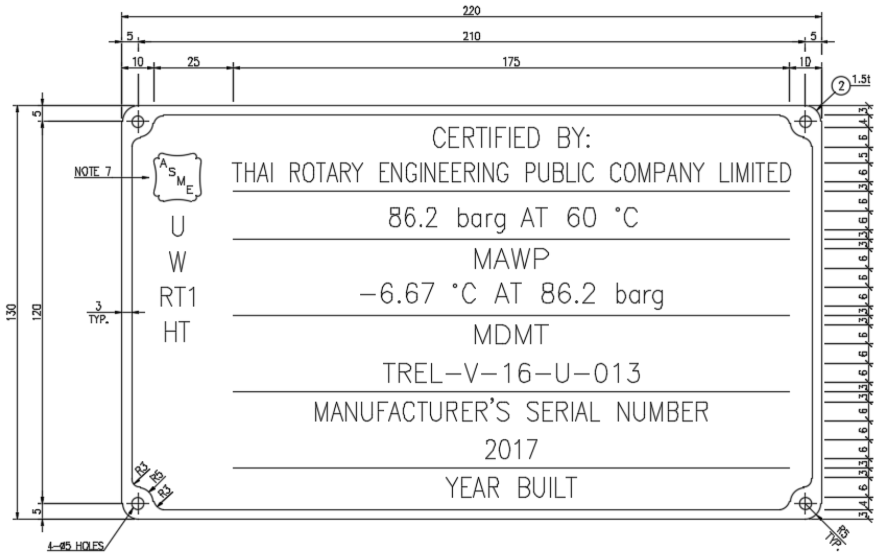
(2) See UG-116(a)(1)(-a), UG-116(a)(1)(-b), and UG-116(a)(1)(-c).

(3) See UG-116(b)(1), UG-116(c), UG-116(e), UG-116(f), and UG-116(h)(1)(-a).

(4) For cases where the MAWP (internal) and MAWP (external) values have the same designated coincident temperature, the values may be combined on a single line as follows:

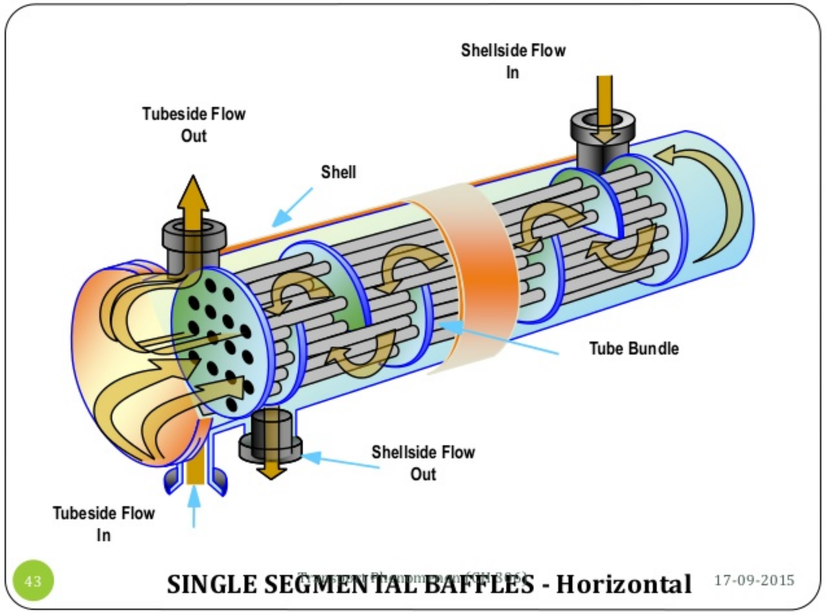
$$P_{int}/FV \text{ (psi) at Temp (°F)}$$

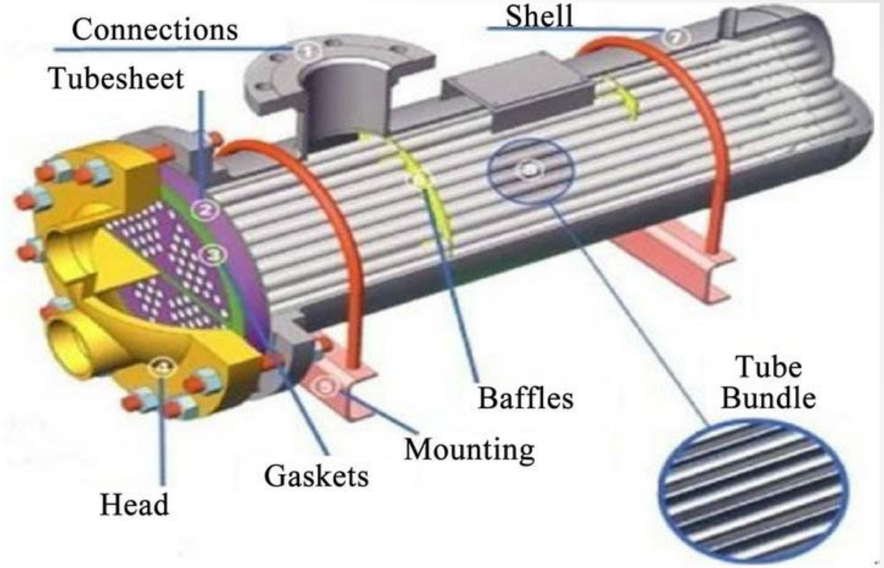
(5) The maximum allowable working pressure (external) is required only when specified as a design condition.



DETAIL OF ASME CERTIFICATION NAMEPLATE
(NOTE 4 & 5) SCALE 1:1

HEAT EXCHANGER DESIGN : COMPONENTS





HEAT EXCHANGER DESIGN : TEMA CLASSES

TEMA : Standards Of The Tubular Exchanger Manufacturers Association
Latest Edition : Ninth

TEMA CLASSES

Heat exchangers specify design and fabrication of unfired shell and tube heat exchangers for the below criteria and related processing applications.

CLASS “R”

Unfired shell and tube heat exchangers for the generally severe requirements of petroleum

CLASS “C”

Chemical process service

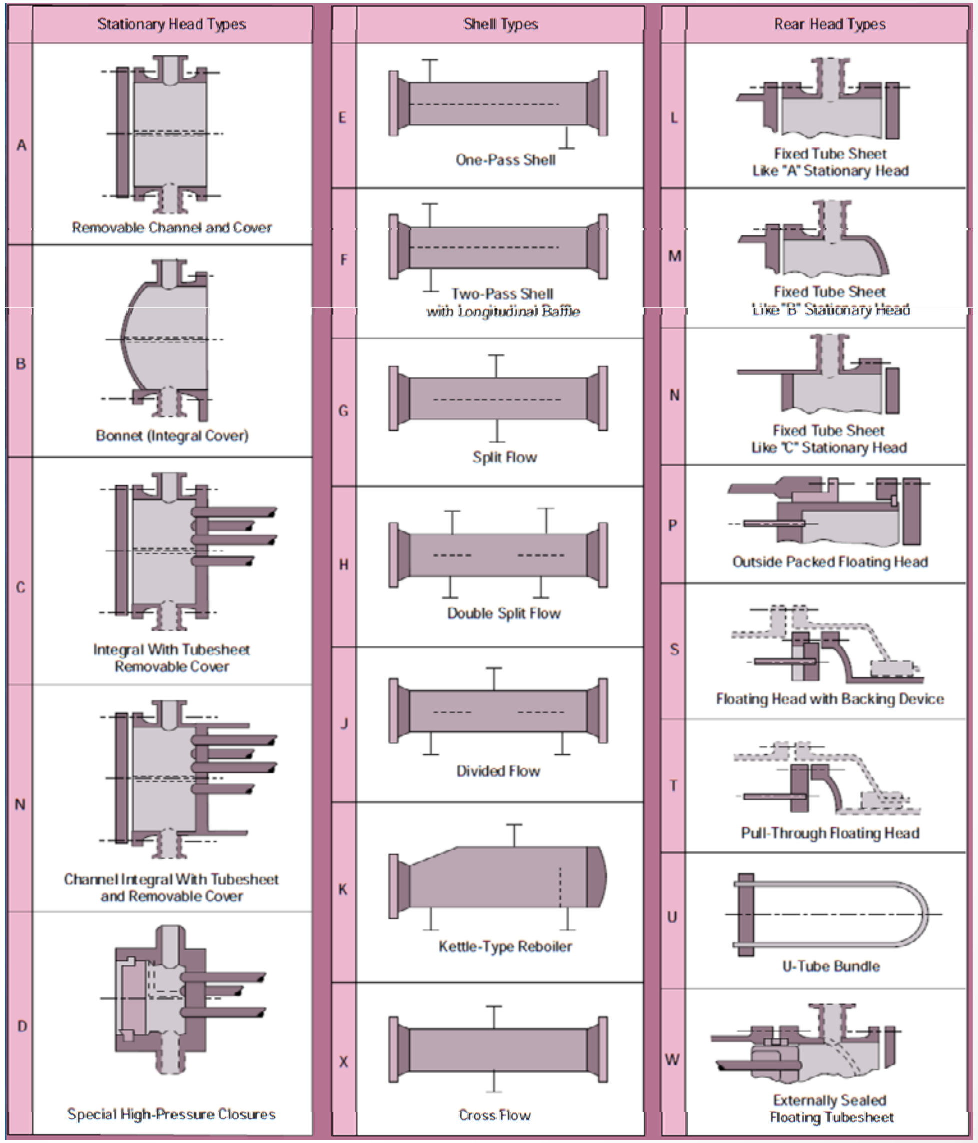
CLASS “B”

Generally moderate requirements of commercial

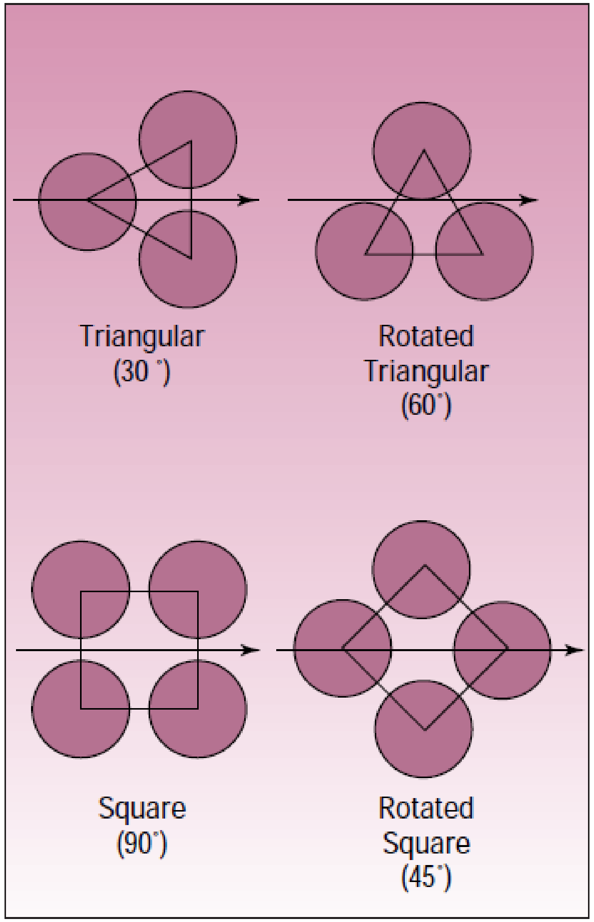
HEAT EXCHANGER DESIGN : TYPE







HEAT EXCHANGER DESIGN : TUBE PATTERN



**The typical tube pitch of 1.25 times the tube O.D

HEAT EXCHANGER DESIGN : MIN. SHELL THICKNESS

TABLE R-3.13
MINIMUM SHELL THICKNESS
Dimensions in Inches (mm)

Nominal Shell Diameter		Minimum Thickness				
		Carbon Steel			Alloy *	
		Pipe	Plate			
6	(152)	SCH. 40	-		1/8	(3.2)
8-12	(203-305)	SCH. 30	-		1/8	(3.2)
13-29	(330-737)	SCH. STD	3/8	(9.5)	3/16	(4.8)
30-39	(762-991)	-	7/16	(11.1)	1/4	(6.4)
40-60	(1016-1524)	-	1/2	(12.7)	5/16	(7.9)
61-80	(1549-2032)	-	1/2	(12.7)	5/16	(7.9)
81-100	(2057-2540)	-	1/2	(12.7)	3/8	(9.5)

TABLE CB-3.13
MINIMUM SHELL THICKNESS
Dimensions in Inches (mm)

Nominal Shell Diameter		Minimum Thickness				
		Carbon Steel			Alloy *	
		Pipe	Plate			
6	(152)	SCH. 40	-		1/8	(3.2)
8-12	(203-205)	SCH. 30	-		1/8	(3.2)
13-23	(330-584)	SCH. 20	5/16	(7.9)	1/8	(3.2)
24-29	(610-737)	-	5/16	(7.9)	3/16	(4.8)
30-39	(762-991)	-	3/8	(9.5)	1/4	(6.4)
40-60	(1016-1524)	-	7/16	(11.1)	1/4	(6.4)
61-80	(1549-2032)	-	1/2	(12.7)	5/16	(7.9)
81-100	(2057-2540)	-	1/2	(12.7)	3/8	(9.5)

*Schedule 5S is permissible for 6 inch (152 mm) and 8 inch (203 mm) shell diameters.

HEAT EXCHANGER DESIGN : BAFFLES

TABLE R-4.41

BAFFLE OR SUPPORT PLATE THICKNESS
Dimensions in Inches (mm)

Nominal Shell ID		Plate Thickness — Unsupported tube length between central baffles. End spaces between tubesheets and baffles are not a consideration.									
		24 (610) and Under		Over 24 (610) to 36 (914) Inclusive		Over 36 (914) to 48 (1219) Inclusive		Over 48 (1219) to 60 (1524) Inclusive		Over 60 (1524)	
6-14	(152-356)	1/8	(3.2)	3/16	(4.8)	1/4	(6.4)	3/8	(9.5)	3/8	(9.5)
15-28	(381-711)	3/16	(4.8)	1/4	(6.4)	3/8	(9.5)	3/8	(9.5)	1/2	(12.7)
29-38	(737-965)	1/4	(6.4)	5/16	(7.5)	3/8	(9.5)	1/2	(12.7)	5/8	(15.9)
39-60	(991-1524)	1/4	(6.4)	3/8	(9.5)	1/2	(12.7)	5/8	(15.9)	5/8	(15.9)
61-100	(1549-2540)	3/8	(9.5)	1/2	(12.7)	5/8	(15.9)	3/4	(19.1)	3/4	(19.1)

TABLE RCB-4.3

Standard Cross Baffle and Support Plate Clearances
Dimensions In Inches (mm)

Nominal Shell ID		Design ID of Shell Minus Baffle OD	
6-17	(152-432)	1/8	(3.2)
18-39	(457-991)	3/16	(4.8)
40-54	(1016-1372)	1/4	(6.4)
55-69	(1397-1753)	5/16	(7.9)
70-84	(1778-2134)	3/8	(9.5)
85-100	(2159-2540)	7/16	(11.1)

TABLE CB-4.41

BAFFLE OR SUPPORT PLATE THICKNESS
Dimensions in Inches (mm)

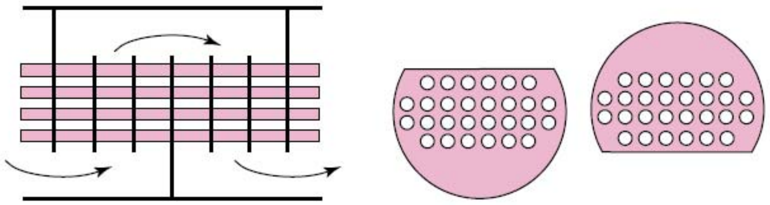
Nominal Shell ID		Plate Thickness — Unsupported tube length between central baffles. End spaces between tubesheets and baffles are not a consideration.											
		12 (305) and Under		Over 12 (305) to 24 (610) Inclusive		Over 24 (610) to 36 (914) Inclusive		Over 36 (914) to 48 (1219) Inclusive		Over 48 (1219) to 60 (1524) Inclusive		Over 60 (1524)	
6-14	(152-356)	1/16	(1.6)	1/8	(3.2)	3/16	(4.8)	1/4	(6.4)	3/8	(9.5)	3/8	(9.5)
15-28	(381-711)	1/8	(3.2)	3/16	(4.8)	1/4	(6.4)	3/8	(9.5)	3/8	(9.5)	1/2	(12.7)
29-38	(737-965)	3/16	(4.8)	1/4	(6.4)	5/16	(7.5)	3/8	(9.5)	1/2	(12.7)	5/8	(15.9)
39-60	(991-1524)	1/4	(6.4)	1/4	(6.4)	3/8	(9.5)	1/2	(12.7)	5/8	(15.9)	5/8	(15.9)
61-100	(1549-2540)	1/4	(6.4)	3/8	(9.5)	1/2	(12.7)	5/8	(12.7)	3/4	(19.1)	3/4	(19.1)

TABLE RCB-4.52

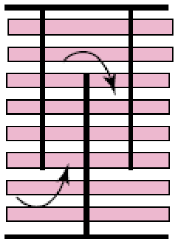
MAXIMUM UNSUPPORTED STRAIGHT TUBE SPANS
Dimensions in Inches (mm)

Tube OD		Tube Materials and Temperature Limits ° F (° C) — Carbon Steel & High Alloy Steel, 750 (399); Low Alloy Steel, 850 (454); Nickel-Copper, 600 (316); Nickel, 850 (454); Nickel-Chromium-Iron, 1000 (538)		Aluminum & Aluminum Alloys, Copper & Copper Alloys, Titanium Alloys At Code Maximum Allowable Temperature	
1/4	(6.4)	26	(660)	22	(559)
3/8	(9.5)	35	(889)	30	(762)
1/2	(12.7)	44	(1118)	38	(965)
5/8	(15.9)	52	(1321)	45	(1143)
3/4	(19.1)	60	(1524)	52	(1321)
7/8	(22.2)	69	(1753)	60	(1524)
1	(25.4)	74	(1880)	64	(1626)
1-1/4	(31.8)	88	(2235)	76	(1930)
1-1/2	(38.1)	100	(2540)	87	(2210)
2	(50.8)	125	(3175)	110	(2794)
2-1/2	(63.5)	125	(3175)	110	(2794)
3	(76.2)	125	(3175)	110	(2794)

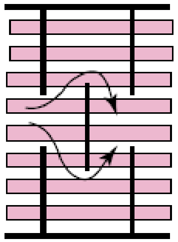
HEAT EXCHANGER DESIGN : BAFFLES



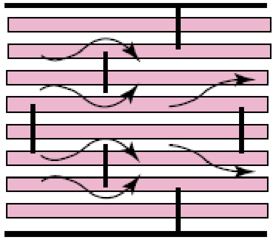
No-Tubes-in-Window Segmental Baffles



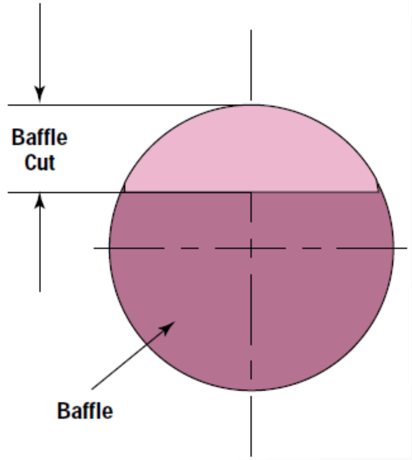
Single Segmental Baffles

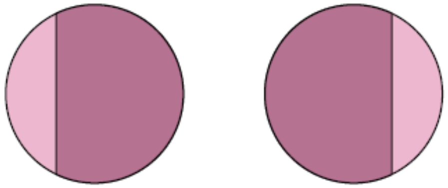


Double Segmental Baffles

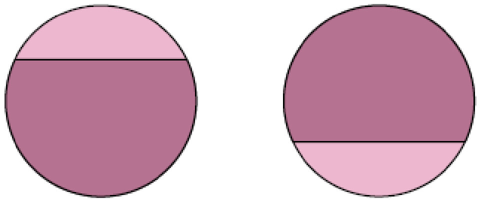


Triple Segmental Baffles





Vertical Cut



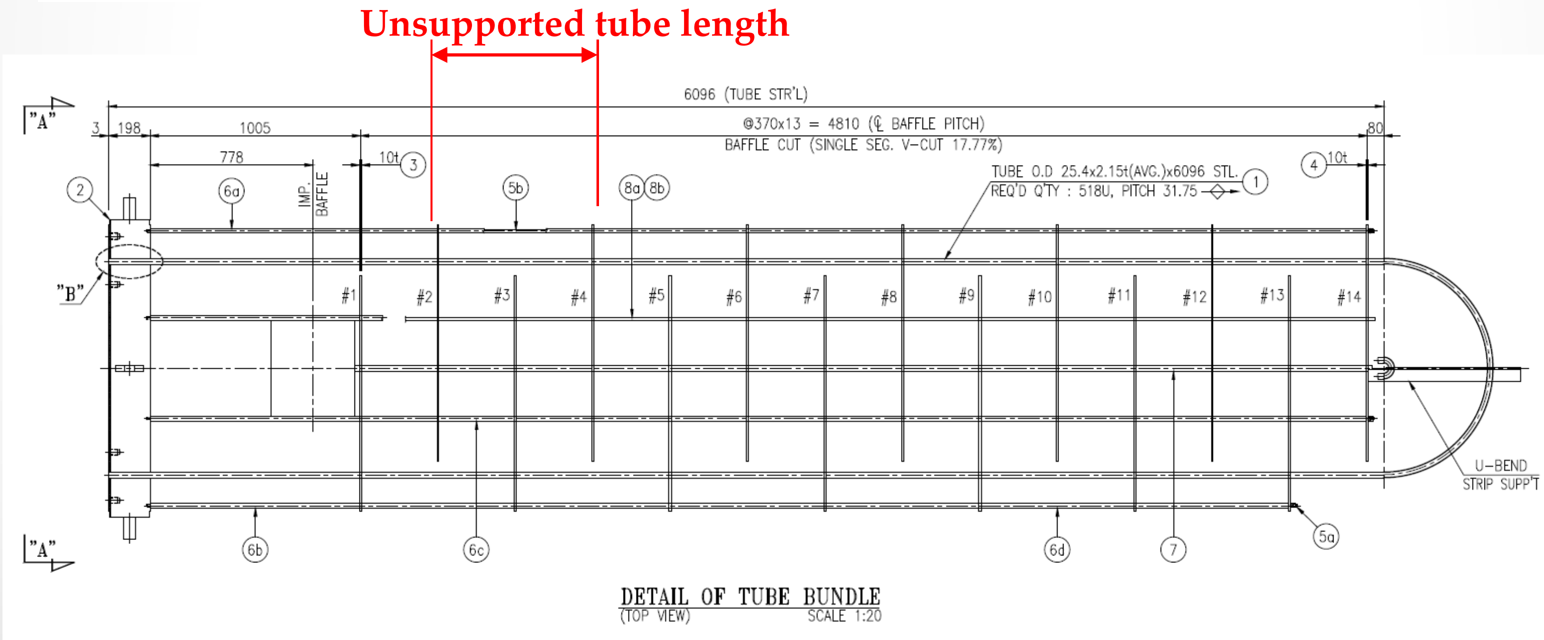
Horizontal Cut

HEAT EXCHANGER DESIGN : BAFFLES THICKNESS AND UNSUPPORT TUBE LENGTH

TABLE R-4.41

BAFFLE OR SUPPORT PLATE THICKNESS
Dimensions in Inches (mm)

Nominal Shell ID		Plate Thickness									
		Unsupported tube length between central baffles. End spaces between tubesheets and baffles are not a consideration.									
		24 (610) and Under		Over 24 (610) to 36 (914) Inclusive		Over 36 (914) to 48 (1219) Inclusive		Over 48 (1219) to 60 (1524) Inclusive		Over 60 (1524)	
6-14	(152-356)	1/8	(3.2)	3/16	(4.8)	1/4	(6.4)	3/8	(9.5)	3/8	(9.5)
15-28	(381-711)	3/16	(4.8)	1/4	(6.4)	3/8	(9.5)	3/8	(9.5)	1/2	(12.7)
29-38	(737-965)	1/4	(6.4)	5/16	(7.5)	3/8	(9.5)	1/2	(12.7)	5/8	(15.9)
39-60	(991-1524)	1/4	(6.4)	3/8	(9.5)	1/2	(12.7)	5/8	(15.9)	5/8	(15.9)
61-100	(1549-2540)	3/8	(9.5)	1/2	(12.7)	5/8	(15.9)	3/4	(19.1)	3/4	(19.1)



HEAT EXCHANGER DESIGN : DESIGN CONDITION

TYPE	DESIGN CONDITION	OPERATING CONDITION
U-TUBE	Table UHX-12.4-1	N/A
FIXED TUBE SHEET	Table UHX-13.4-1	Table UHX-13.4-2
FLOATING HEAD	Table UHX-14.4-1	Table UHX-14.6.4-1

U-TUBE

Table UHX-12.4-1

Design Loading Case	Shell Side Design Pressure, P_s	Tube Side Design Pressure, P_t
1	$P_{sd,min}$	$P_{td,max}$
2	$P_{sd,max}$	$P_{td,min}$
3	$P_{sd,max}$	$P_{td,max}$
4	$P_{sd,min}$	$P_{td,min}$

N/A

FIXED TUBE SHEET

Table UHX-13.4-1

Design Loading Case	Shell Side Design Pressure, P_s	Tube Side Design Pressure, P_t
1	$P_{sd,min}$	$P_{td,max}$
2	$P_{sd,max}$	$P_{td,min}$
3	$P_{sd,max}$	$P_{td,max}$
4	$P_{sd,min}$	$P_{td,min}$

Table UHX-13.4-2

Operating Loading Case	Operating Pressure		Axial Mean Metal Temperature	
	Shell Side, P_s	Tube Side, P_t	Tubes, $T_{t,m}$	Shell, $T_{s,m}$
1	$P_{sox,min}$	$P_{tox,max}$	$T_{t,mx}$	$T_{s,mx}$
2	$P_{sox,max}$	$P_{tox,min}$	$T_{t,mx}$	$T_{s,mx}$
3	$P_{sox,max}$	$P_{tox,max}$	$T_{t,mx}$	$T_{s,mx}$
4	$P_{sox,min}$	$P_{tox,min}$	$T_{t,mx}$	$T_{s,mx}$

FLOATING HEAD

Table UHX-14.4-1

Design Loading Case	Shell Side Design Pressure, P_s	Tube Side Design Pressure, P_t
1	$P_{sd,min}$	$P_{td,max}$
2	$P_{sd,max}$	$P_{td,min}$
3	$P_{sd,max}$	$P_{td,max}$
4	$P_{sd,min}$	$P_{td,min}$

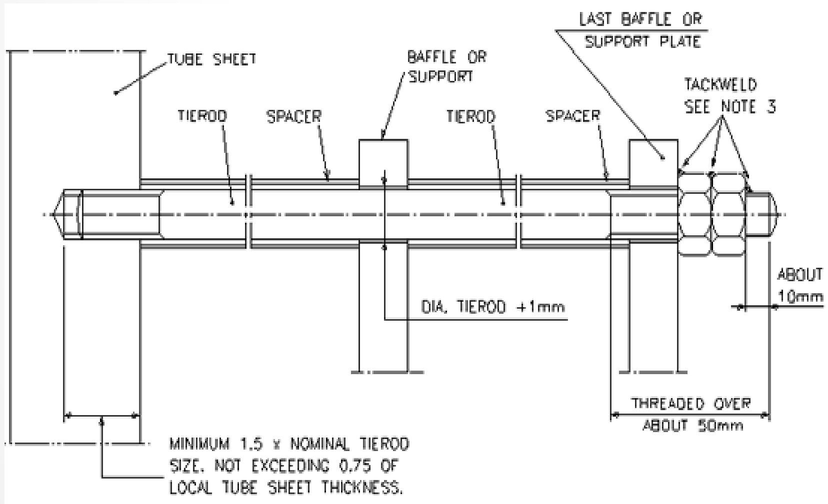
Table UHX-14.6.4-1

Operating Loading Case	Operating Pressure		Metal Temperature		
	Shell Side, P_s	Tube Side, P_t	Tubesheet at the Rim, T'	Channel at Tubesheet, T'_c	Shell at Tubesheet, T'_s
1	$P_{sox,min}$	$P_{tox,max}$	T'_x	T'_{cx}	T'_{sx}
2	$P_{sox,max}$	$P_{tox,min}$	T'_x	T'_{cx}	T'_{sx}
3	$P_{sox,max}$	$P_{tox,max}$	T'_x	T'_{cx}	T'_{sx}
4	$P_{sox,min}$	$P_{tox,min}$	T'_x	T'_{cx}	T'_{sx}

HEAT EXCHANGER DESIGN : TIE RODS, SELING STRIP

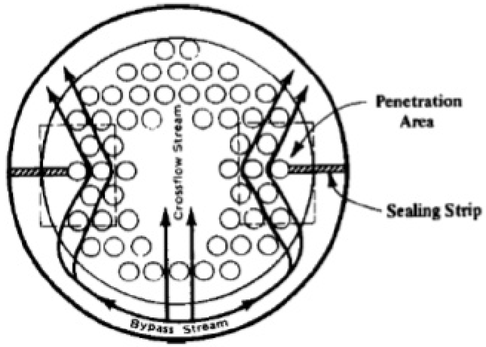
TIE ROD STANDARDS
Dimensions in Inches (mm)

Nominal Shell Diameter		Tie Rod Diameter		Minimum Number of Tie Rods
6 - 15	(152-381)	3/8	(9.5)	4
16 – 27	(406-686)	3/8	(9.5)	6
28 – 33	(711-838)	1/2	(12.7)	6
34 – 48	(864-1219)	1/2	(12.7)	8
49 – 60	(1245-1524)	1/2	(12.7)	10
61 – 100	(1549-2540)	5/8	(15.9)	12



TIE ROD ASSEMBLY

Sealing Strip

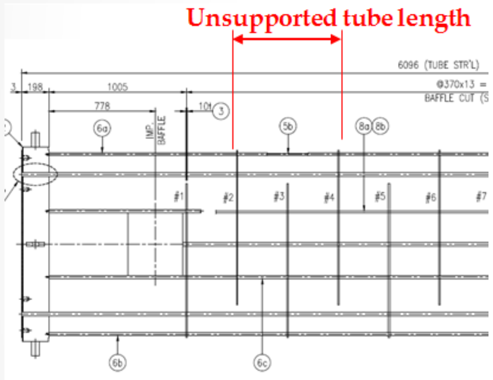


- They are placed in pairs on opposite sides of the baffles running lengthwise along the bundle. Sealing strips are mainly used in floating-head exchangers, where the clearance between the shell and tube bundle is relatively large.
- Typically, one pair is used for every four to ten rows of tubes between the baffle tips. Increasing the number of sealing strips tends to increase the shell side heat-transfer coefficient at the expense of a somewhat larger pressure drop.

HEAT EXCHANGER DESIGN : TUBE HOLE DIAMETER

For tube holes in Baffles

Standard Tube Over the OD of tube	Unsupported tube length (mm)	Tube in diameter (mm)
0.4mm	>914	≤ 31.8
0.8mm	All case except the above Item.	



For tube holes in Tubesheets

RCB-4.2 TUBE HOLES

TABLE RCB-7.21

TUBE HOLE DIAMETERS AND TOLERANCES
(All Dimensions in Inches)

Nominal Tube OD	Nominal Tube Hole Diameter and Under Tolerance: For CS Standard Fit (a) Nominal Diameter	For CS Standard Fit (a) Under Tolerance	For SS Special Close Fit (b) Nominal Diameter	For SS Special Close Fit (b) Under Tolerance	Over Tolerance; 96% of tube holes must meet value in column (c). Remainder may not exceed value in column (d) (c)	(d)
1/4	0.259	0.004	0.257	0.002	0.002	0.007
3/8	0.384	0.004	0.382	0.002	0.002	0.007
1/2	0.510	0.004	0.508	0.002	0.002	0.008
5/8	0.635	0.004	0.633	0.002	0.002	0.010
3/4	0.760	0.004	0.758	0.002	0.002	0.010
7/8	0.885	0.004	0.883	0.002	0.002	0.010
1	1.012	0.004	1.010	0.002	0.002	0.010
1 1/4	1.264	0.006	1.261	0.003	0.003	0.010
1 1/2	1.518	0.007	1.514	0.003	0.003	0.010
2	2.022	0.007	2.018	0.003	0.003	0.010
2 1/2	2.528	0.010	2.523	0.004	0.004	0.010
3	3.033	0.012	3.027	0.004	0.004	0.010

HEAT EXCHANGER DESIGN : EXPANSION JOINT

FIGURE RCB-8.41

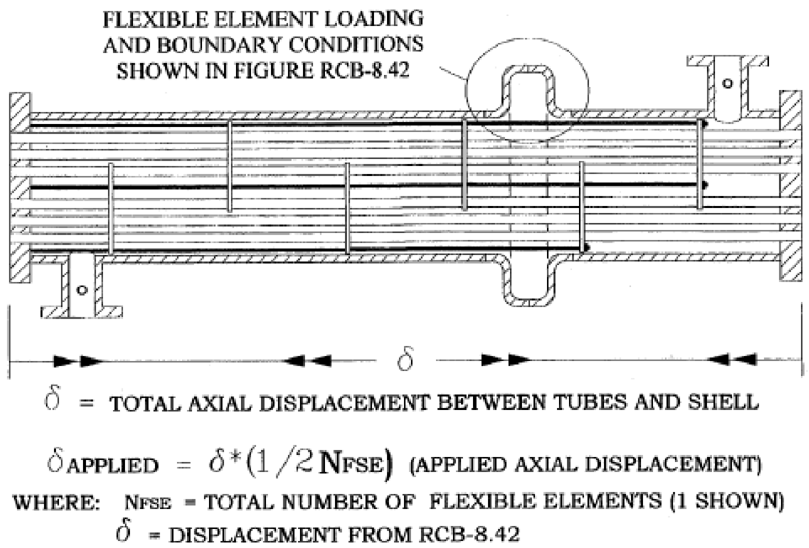


FIGURE RCB-8.42

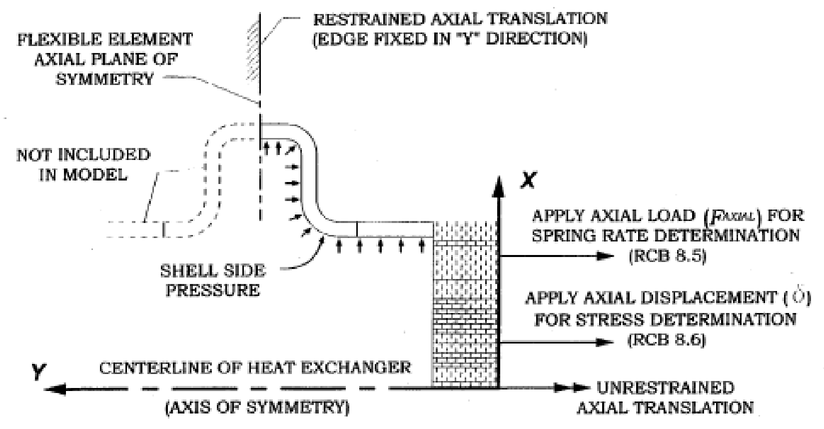
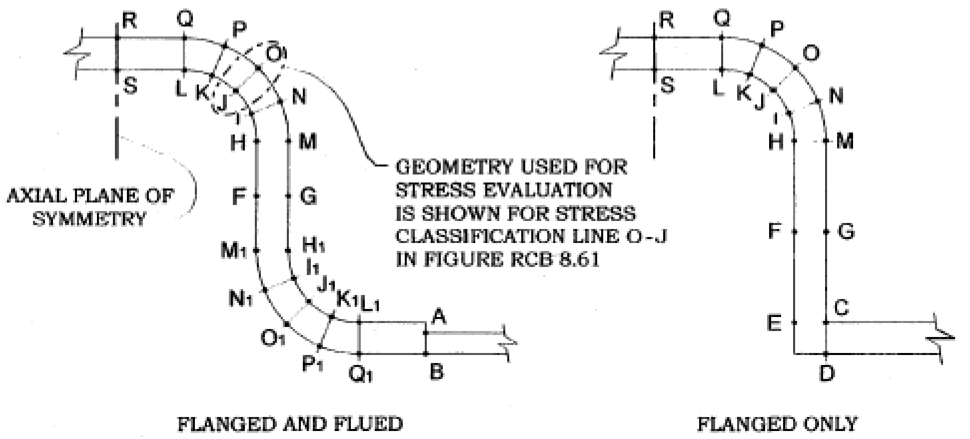


FIGURE RCB-8.62



HEAT EXCHANGER DESIGN : PASS PARTITION

TABLE RCB-9.131

NOMINAL PASS PARTITION PLATE THICKNESS
Dimensions are in Inches (mm)

Nominal Size	Carbon Steel	Alloy Material
Less than 24 (610)	3/8 (9.5)	1/4 (6.4)
24 to 60 (610-1524)	1/2 (12.7)	3/8 (9.5)
61 to 100 (1549-2540)	5/8 (15.9)	1/2 (12.7)

RCB-9.132 PASS PARTITION PLATE FORMULA

$$t = b\sqrt{\frac{qB}{1.5S}}$$

where

t = Minimum pass partition plate thickness, in. (mm)

B = Table value (linear interpolation may be used)

q = Pressure drop across plate, psi (kPA)

S = Code allowable stress in tension, at design metal temperature, psi (kPa)

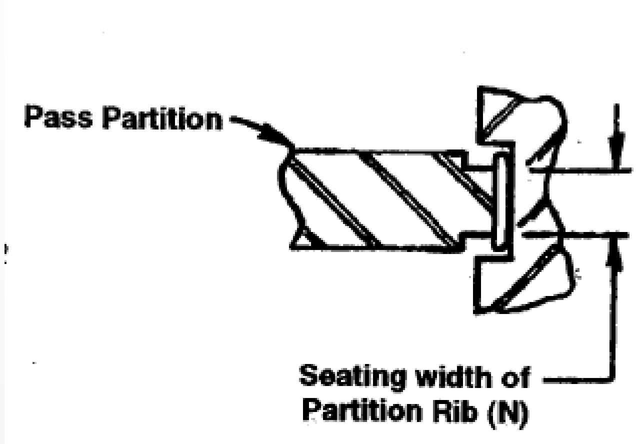
b = Plate dimension. See Table RCB-9.132, in. (mm)

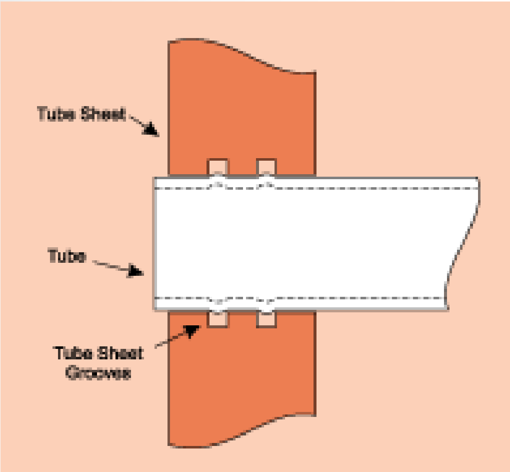
HEAT EXCHANGER DESIGN : PASS PARTITION

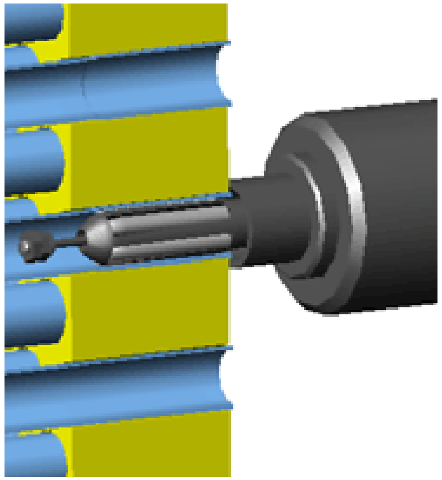
TABLE RCB-9.132

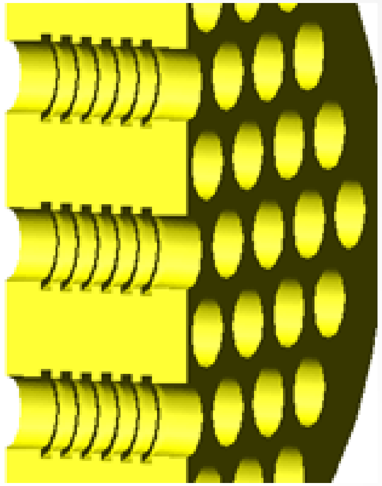
PASS PARTITION DIMENSION FACTORS

Three sides fixed One side simply supported		Long sides fixed Short sides simply supported		Short sides fixed Long sides simply supported	
a/b	B	a/b	B	a/b	B
0.25	0.020	1.0	0.4182	1.0	0.4182
0.50	0.081	1.2	0.4626	1.2	0.5208
0.75	0.173	1.4	0.4860	1.4	0.5988
1.0	0.307	1.6	0.4968	1.6	0.6540
1.5	0.539	1.8	0.4971	1.8	0.6912
2.0	0.657	2.0	0.4973	2.0	0.7146
3.0	0.718	∞	0.5000	∞	0.7500









Cross Section Details of Tube Hole in Tube Sheet

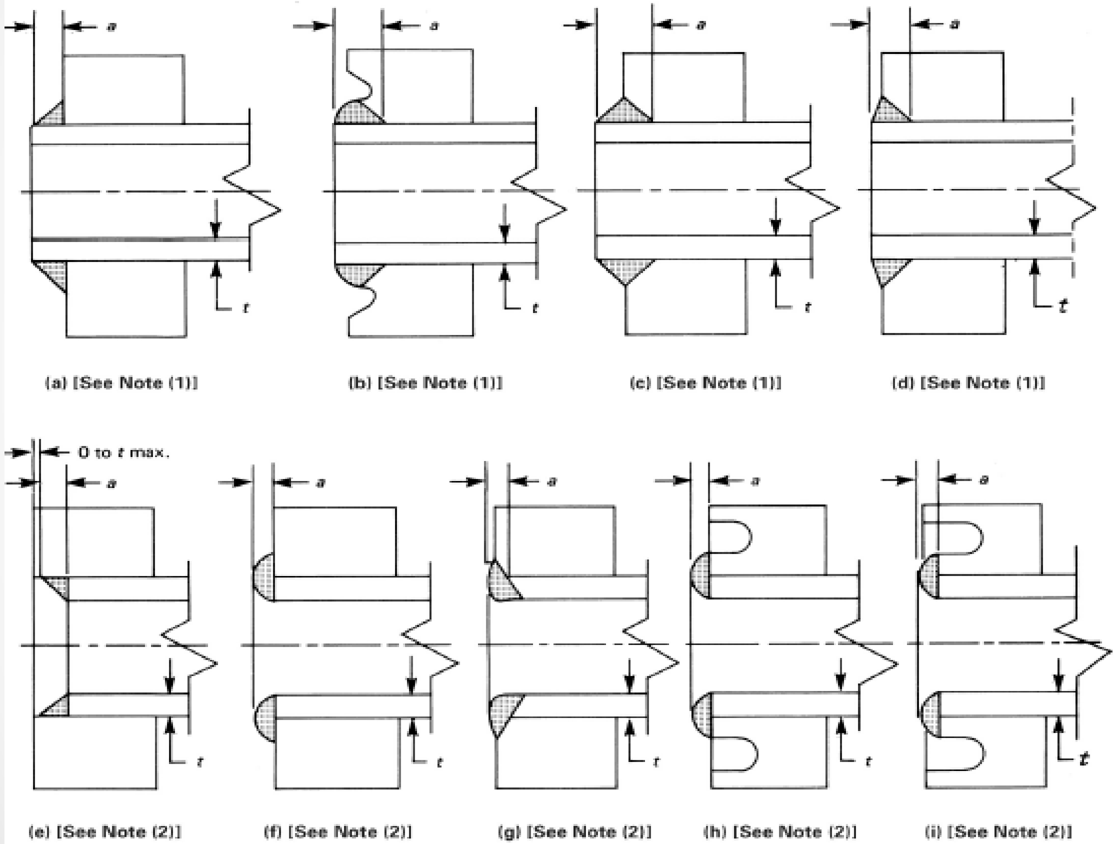
If roller-expanded joints are utilized, the tube wall thickness reduction shall be in accordance with Table 4.

Table 4 — Allowable tube wall thickness reduction for roller-expanded tube-to-tubesheet joints

Material	Tube wall thickness reduction %
Carbon steel and low alloy steel	4 to 6 [a]
Stainless and high alloy steel	6 to 8 [a]
Non-ferrous	4 to 5 [a]

[a] The upper limit may be increased by a further 2 %, if approved by the purchaser.

Figure A-2
Some Acceptable Types of Tube-to-Tubesheet Welds



NOTES:
(1) Sketches (a) through (d) show some acceptable weld geometries where a is not less than $1.4t$.
(2) Sketches (e) through (i) show some acceptable weld geometries where a is less than $1.4t$.

MAXIMUM AXIAL LOADINGS

For joint types a, b, b-1, c, d, e,

$$L_{max} = A_t S_a f_r$$

For joint types f, g, h,

$$L_{max} = A_t S_a f_e f_r f_y$$

For joint types i, j, k,

$$L_{max} = A_t S_a f_e f_r f_y f_T$$

HEAT EXCHANGER DESIGN : TUBE TO TUBE SHEET JOINT

Table A-2
Efficiencies f_r

Type Joint	Description [Note (1)]	Notes	f_r (Test) [Note (2)]	f_r (No Test)
a	Welded only, $a \geq 1.4t$	(3)	1.00	0.80
b	Welded only, $t \leq a < 1.4t$	(3)	0.70	0.55
b-1	Welded only, $a < t$	(4)	0.70	. . .
c	Brazed, examined	(5)	1.00	0.80
d	Brazed, not fully examined	(6)	0.50	0.40
e	Welded, $a \geq 1.4t$, and expanded	(3)	1.00	0.80
f	Welded, $a < 1.4t$, and expanded, enhanced with two or more grooves	(3) (7) (8) (9)	0.95	0.75
g	Welded, $a < 1.4t$, and expanded, enhanced with single groove	(3) (7) (8) (9)	0.85	0.65
h	Welded, $a < 1.4t$, and expanded, not enhanced	(3) (7) (8)	0.70	0.50
i	Expanded, enhanced with two or more grooves	(7) (8) (9)	0.90	0.70
j	Expanded, enhanced with single groove	(7) (8) (9)	0.80	0.65
k	Expanded, not enhanced	(7) (8)	0.60	0.50

NOTES:

(1) For joint types involving more than one fastening method, the sequence used in the joint description does not necessarily indicate the order in which the operations are performed.

(2) The use of the f_r (test) factor requires qualification in accordance with A-3 and A-4.

(3) The value of f_r (no test) applies only to material combinations as provided for under Section IX. For material combinations not provided for under Section IX, f_r shall be determined by test in accordance with A-3 and A-4.

(4) For f_r (no test), refer to UW-20.2(b).

(5) A value of 1.00 for f_r (test) or 0.80 for f_r (no test) can be applied only to joints in which visual examination assures that the brazing filler metal has penetrated the entire joint [see UB-14(a)] and the depth of penetration is not less than three times the nominal thickness of the tube wall.

(6) A value of 0.50 for f_r (test) or 0.40 for f_r (no test) shall be used for joints in which visual examination will not provide proof that the brazing filler metal has penetrated the entire joint [see UB-14(b)].

(7) When $d_o/(d_o - 2t)$ is less than 1.05 or greater than 1.410, f_r shall be determined by test in accordance with A-3 and A-4.

(8) When the nominal pitch (center-to-center distance of adjacent tube holes) is less than $d_o + 2t$, f_r shall be determined by test in accordance with A-3 and A-4.

(9) The Manufacturer may use other means to enhance the strength of expanded joints, provided, however, that the joints are tested in accordance with A-3 and A-4.