Lesson 2

Head and Shell Calculation

Objectives

Learn to Calculate:

The required thickness of a cylindrical shell based on circumferential stress given a pressure (UG-27(c)(1).

The vessel part Maximum Allowable Working Pressure (MAWP) for a cylindrical shell based on circumferential stress given a metal thickness (UG-27(c)(1).

The required thickness of a head (ellipsoidal, Torispherical and hemispherical) given a pressure. (UG-32 (d), (e), (f))

The vessel part MAWP for a head (ellipsoidal, Torispherical and hemispherical) given a metal thickness using paragraphs UG-32 (d), (e) & (f).

Whether a head (ellipsoidal, Torispherical or hemispherical) meets Code requirements given pressure and metal thickness UG 32(d), (e), and (f).

In any of the above you must also be able to:

Compensate for the corrosion allowance: add or subtract based on requirements of the exam problem. The Appendix 1* formula for cylinders, which is based on outside diameter, can be used.

Overview

This lesson will start with straight forward new construction calculations from Section VIII Div.1 for internal dimension (I.D.) and progress on to consider;

Corrosion Allowances

Outside dimension calculation of cylindrical shells.

O.D. calculations will come from Appendix 1 formula 1-1 this is only issue from Appendix 1 on the exam.

UG-27

Thickness of Shells under Internal Pressure

Here we find the formulae and definitions for calculation of cylindrical shells under internal pressure. The paragraph begins as follows;

The thickness of shells under internal pressure shall be not less than that computed by the following formulas. In addition, provision shall be made for any of the other loadings listed in UG - 22, when such loadings are expected. The provided thickness of shells shall also meet UG - 16 (addresses minimum thickness allowed).

The symbols defined below are used in the formulas of this paragraph.

t = minimum required thickness of shell, in.

P = internal design pressure (see UG-21), psi

R = inside radius of the shell course under consideration

S = maximum allowable stress value, psi

E = joint efficiency for, or the efficiency of, appropriate joint in cylindrical or spherical shells, or efficiency of ligaments are not on the exam.

For welded vessels, use the efficiency specified in UW-12.

For ligaments between openings, ...are not on the exam.

(c) Cylindrical Shells. The minimum thickness or maximum allowable working pressure of cylindrical shells shall be the greater thickness or lesser pressure as given by (1) or (2) below.

(1) Circumferential Stress Longitudinal Joints. When the thickness does not exceed one-half of the inside radius, or P does not exceed 0.385SE, the following formulas shall apply: '(The above is a test to see if these formulae apply, they always do on this examination)

With the exception of Appendix 1 formulae, all cylindrical shell calculations on the exam will use one of these two formulae! • Highlight these two!

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

Longitudinal Stress (Circumferential Joints). When the thickness does not exceed one-half of the inside radius, or *P* does not exceed 1.25SE the following formulas shall apply:

These formulas are not used on the exam.
* DO NOT USE or highlight them!

$$t = \frac{PR}{2SE - 0.2P} \quad \text{Not on the Exam} \quad P = \frac{2SEt}{R + 0.2t}$$

Foot Note

Formulas in terms of the outside radius and for thicknesses and pressures beyond the limits fixed in this

paragraph we given in 1-1 to 1-3.

Of Appendix 1, only the first two shell formulas from paragraph 1-1 (a) (1) are on the Body of Knowledge!

Lees have a look at those.

Appendix 1 Supplementary Design Formulas

1-1 THICKNESS OF CYLINDRICAL AND SPHERICAL SHELLS

(a) The following formulas, in terms of the outside radius, are equivalent to and may be used instead

of those given in U G-27 (c) and (d).

For cylindrical shells (circumferential stress),

OR

$$t = \frac{PRo}{SE + 0.4P} \qquad \text{OR} \qquad P = \frac{SEt}{Ro - 0.4t} \quad (1)$$

Longitudinal stress NOT ON EXAM cross out.

Example: Given a cylindrical shell with the following variables, solve for the MAWP of the cylinder using both formulas.

P = ? * The question mark defines what is being solved for.

t= 0.500"

S = 15,000 psi

E =1.0

R = 18.0" and R $_{\text{outside}}$ = 18.5"

$$\text{UG-27(c)(1)} \quad P = \frac{SEt}{R + 0.6t} = \frac{15{,}000 \times 1.0 \times 0.500}{18.0 + (0.6 \times 0.500)} = \frac{7500}{18.3} = 409.8\ psi$$

$$\text{App 1(1-1)} \quad P = \frac{SEt}{R_o - 0.4t} = \frac{15{,}000 \times 1.0 \times 0.500}{18.5 - (0.4 \times 0.500)} = \frac{7500}{18.3} = 409.8\ psi$$

Which formula you use is determined by how the question is asked.

Example 1:

Internal Formula

A vessel shell has corroded to an inside radius of 23.58" its working pressure is 500 psi and its stress allowed is 17,500 psi. What is the required thickness?

Other terms sometimes used:

Corroded internally, found to have an inside diameter/radius, etc.

In these cases, we must use the inside formula of UG-27

Example 2:

External Formula

A vessel shell has corroded to an outside diameter of 23.58" its working pressure is 500 psi and stress allowed is - what is the required thickness?

Other terms sometimes used:

found externally corroded, attacked by corrosion under insulation (CUI) etc.

Here we would have to use the formula of Appendix 1.

You can use either formula in some situations.

Example 3:

Internal Formula or External Formula

A vessel shell has corroded to an inside radius of 23.58 " its working pressure is 500 psi and its stress allowed is its original thickness was 0.500" and the original inside radius was 24.0 ' ** for inside calculations use R = 23.58 (actual)

To use the outside formula, we can add the original thickness to the original inside radius.

24" + 0.500 = 24.5" = Ro Original radius outside

Now we can use the formula of Appendix 1-1 if we chose to.

Also, there is the situation where you are given only the Outside Dimension (O.D.) and asked to solve for the thickness required or maximum allowable working pressure.

Example 4: External Formula for Thickness

A vessel shell has an outside radius of 24.0 " its working pressure is 500 psi and its stress allowed is 15,000 psi. The joint efficiency, E = 1.0. The shell has corroded internally to a thickness of 0.343". What is its present Maximum Allowable Working Pressure?

Here you must use the O.D. Formula since you cannot determine the present internal corroded radius, not having the original thickness you cannot determine the original I.D.!

Here is an example of working a problem using both Inside and outside dimensions having all the information needed.

A cylindrical shell has been found to hate a minimum thickness of .353'. its original thickness was .375' with an original inside radius of 12.0'. What is its present MAWP?

Puffing the information from the stated problem. we have:

P= 300 psi

t = 353'

S = 13.800 psi

E =.85

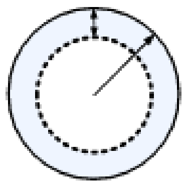
R = 12.0” + (0.375 - 353) = 12.022 *corroded Inside radius*

Ro= 12.0' +0.375 (orig. t) =12.375 original *outside radius*

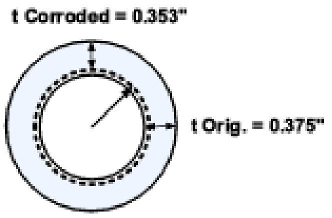
Hove is a graphical representation of the problem:

Which formula?

R inside corroded = 12 + (0.375 – 0.353) = 12.022”



R outside = 12.0" + 0.375 (orig. t) = 12.375"



You Choose!

Radius Inside for MAWP using UG-27(c)(1).

$$\text{UG-27(c)(1)} \quad P = \frac{SEt}{R+0.6t} = \frac{13{,}800 \times .85 \times .353}{12.022 + (0.6 \times .353)} = \frac{4140.69}{12.2338} = 338.46\ psi$$

Radius **Outside** for MAWP using App: 1 (1-1).

$$\text{App 1 (1-1)} \quad P = \frac{SEt}{R_o - 0.4t} = \frac{13{,}800 \times .85 \times .353}{12.375 - (0.4 \times .353)} = \frac{4140.69}{12.2338} = 338.46\ psi$$

Let's do a simple internal shell calculation now. We will use a shell which is seamless. You may find the following approach helpful in keeping track of the data.

As the problems become more difficult, it becomes harder to track the variables if you are not organized.

Make a simple sketch of the shell and label its dimensions.

List what is required to know. We will call these givens.

State the code paragraph that applies, i.e., UG-27, etc.

Use this approach for all calculations.

Givens:

t =

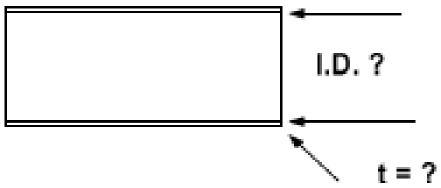
P =

R =

S =

E =

Sketch



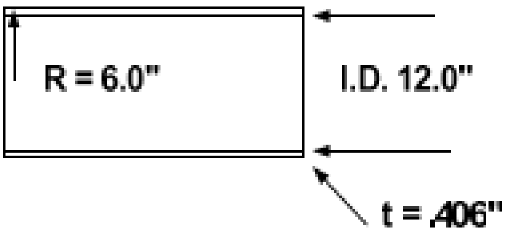
Code Paragraph UG-27 (c) (1)

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

Problem # 1

Find the Maximum Allowable Working Pressure (MAWP) of a 12 inch inside diameter shell. This shell is seamless and is stamped RT 2. It has an allowable stress value of 16,600 psi and the wall thickness is .406". No corrosion is expected.

SKETCH



Givens: Plug in from the values given in the question!

P =?

t= .406

R = D/2 = 12/2 = 6.0" this formula uses the Radius.

S= 16,600 psi

E= 1.0 per UW-12(d) Seamless shells and heads

From UG-27 (c) (1) Circumferential Stress

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

$$P = \frac{16{,}600 \times 1.0 \times .406}{(6.0) + (0.6 \times .406)} = \frac{6739.6}{6.2436} = 1079.44 \text{ psi}$$

As can be seen the calculations are simple, it is more a matter of deciding on the correct formula to use, inside or outside, and transferring the givens accurately to the formula. Once again use the approach;

Givens: SKETCH

P=

t=

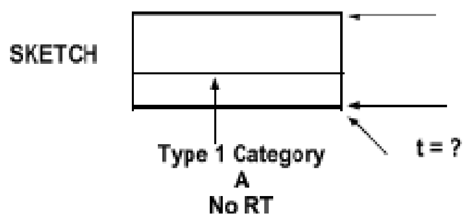
etc.

About rounding answers. In the ASME Code and for the exam you must round DOWN for pressure allowed so in our solution below we would round down to 1079 psi. Even if our solution had been 1079.999 we cannot round to 1080, we still round down to 1079 psi.

This is the conservative approach taken by the Codes in general and of course is different for the normal rules of rounding.

Problem # 2

Find the minimum required thickness of a cylindrical shell designed for a working pressure of 100 psi. The shell's inside radius is 2'431'. The longitudinal joint is type 1 (table UW-12) and no radiography was performed. The shell is made of carbon steel rolled plate with an allowable stress of 15,000 psi.



Givens:

t = ?

P = 100 psi

R = 24"

S = 15000

E = .70 (From Table UW-12 column C)

From UG-27 (c) (1) Circumferential Stress

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

$$t = \frac{100 \times 24}{(15{,}000 \times .70) - (0.6 \times 100)} = \frac{2400}{10440} = .2298''$$

When rounding thickness required, we must round up. The most conservative thing to do. So, our example below would round to .230". Even it had been .2291 we would still round up to .230".

$$t = \frac{100 \times 24}{(15{,}000 \times .70) - (0.6 \times 100)} = \frac{2400}{10440} = .2298''$$

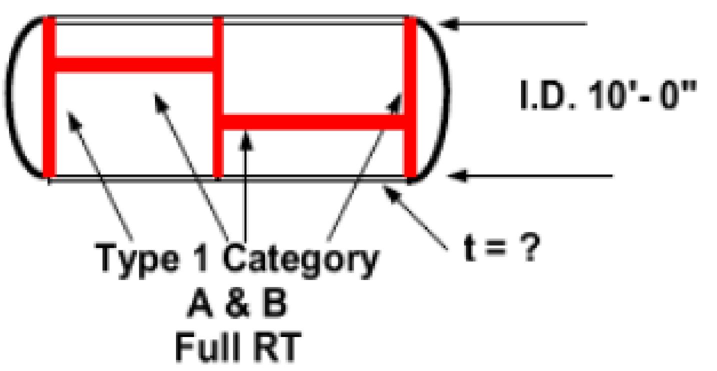
We have now calculated the pressure allowed on a seamless shell in Problem #1 and have calculated the thickness required of a seamed shell in Problem #2.

Now for one more example.
Problem # 3

Determine the minimum required thickness of a cylindrical shell designed for an internal pressure of 50 psi, no corrosion is expected.

The shell's Category A and B, Type 1 welds have been fully radiographed. The material's stress allowable is 17,500 psi. The vessel will be stamped RT 1.

Long Joint (Circumferential Stress)
SKETCH:



Givens:

t = ?

P = 50

R= 10' x 1T = 12072 = 60"

S = 17500

E= 1.0 (RT 1)

From UG-27 (c) (1)

$$t = \frac{50 \times 60}{(17{,}500 \times 1.0) - (0.6 \times 50)} = \frac{3000}{17470} = .1717\text{" rounds to .172"}$$

You are now familiar with the basic cylindrical shell formula from UG-27. However, that formula in its published form is only useful for the calculation of vessel shells that are designed without a corrosion allowance. Usually during design a corrosion allowance will be given to vessel part.

Example:

A vessel is being designed for a specific volume of water. The designer determines the optimum inside diameter and length of the vessel to obtain that volume.

The engineer set the inside diameter at 48" so it must be constructed with that inside diameter, resulting in an inside radius of 24" to be used in the calculation.

In the design calculation the engineer adds the corrosion allowance to the radius. The basic formula of UG-27 would be modified to be;

$$t = \frac{P\,(R + c.a.)}{SE - 0.6\,P} \qquad \text{or} \qquad P = \frac{SEt}{(R + c.a) + 0.6\,t}$$

Inside diameter = 48.0"

Inside radius = 24.0"

c.a. = 1/8" = 0.125"

Inside radius used in calculations = 24.0 + 0.125 = 24.125" resulting in the following;

$$P = \frac{SEt}{(24 + 0.125) + 0.6t}$$

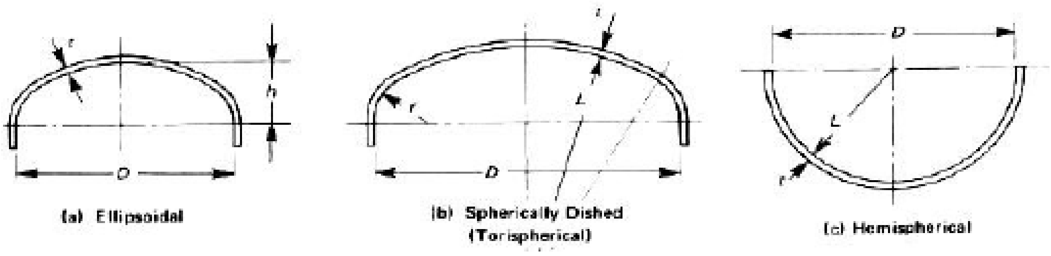
The vessel shell would be constructed of the required calculated thickness and then rolled to an inside radius of 24", it retirement radius would be 24.125"

This is no different from what occurs during the evacuation of an in-service vessel that has corroded. However here we use actual measurements. Suppose the vessel shell above was built with a thickness of 0.500" and rolled to the 24.0" inside radius. Corrosion has occurred and the new minimum wall thickness is 0.450". To calculate we would use a radius of 24.0 + (0.500 — 0.450) or 24.050". This would leave a remaining corrosion allowance of 0.125 - 0.050 = 0.075"

UG-32

Internal Pressure on Formed Heads

There are three types of calculations for formed heads listed in the Body of Knowledge: Ellipsoidal, Torispherical and Hemispherical. A sketch and the formulae for thickness of each kind are below.



$$t = \frac{PD}{2SE - 0.2\,P} \qquad t = \frac{0.885PL}{SE - 0.1P} \qquad t = \frac{PL}{2SE - 0.2P}$$

The required thickness at the thinnest point after forming of ellipsoidal, torispherical, hemispherical, conical, and toriconical (not on exam) heads under pressure on the concave side (plus heads) shall be computed

The thickness of an unstayed ellipsoidal or torispherical head shall in rid case be less than this is a test to see if you should use this formula or the ones given in Appendix 1. Not on Exam!

The symbols defined below are used in the formulas of this paragraph:

t = minimum required thickness of head after forming, in. (mm)

P = internal design pressure (see UG-21), psi (kPa)

D = inside diameter of the head skirt; or inside length of the major axis of an ellipsoidal head; in. (mm)

S = maximum allowable stress value in tension.

E = lowest efficiency of any joint in the head; for hemispherical heads this Includes head-to-shell joint for welded vessels, use the efficiency specified in UW-12

L = inside spherical or crown radius, in. (mm)

There are 5 formed heads listed in UG-32. You will be responsible for the calculations of these 3 only;

Hemispherical, Ellipsoidal and, *Torispherical* Heads

The next series of slides are example calculations of al three types for thickness required. These calculations wil use the exact same conditions for service, stress allowed, Joint E, dimensions, and pressure.

With all things being equal which do you suspect will be the thinnest allowed?

Which do you think will be the thickest required?

Which is in the middle?
Examples:

Givens: The same pressure, stress and, dimension values will be used for all heads. Let's determine which type of head will be the thickest required and which will be the thinnest allowed.

Given:

P = 100 psi

S = 17500 PSI

E = .85 for spot RT of Hemi-head joint to shell

E = 1.0 for seamless heads (Ellipsoidal and Torispherical)

L = 48" for the inside spherical radius for the hemi-head

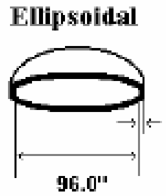
L = 96" for the inside crown radius of the torispherica head

D = 96" inside diameter of the ellipsoidal

t = ? Required wall thickness, inches

Problem # 1

Given the above data find the required thickness of a seamless ellipsoidal head.



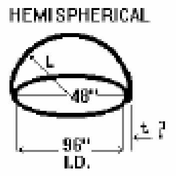
From UG-32 (d)

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

$$t = \frac{100 \times 96}{(2 \times 17{,}500 \times 1.0) - (0.2 \times 100)} \frac{9600}{34980} = .2744\text{ "}$$

Problem # 2

Using the same data, calculate the required thickness of a hemispherical head.



From UG-32 (f)

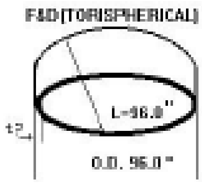
$$t = \frac{PL}{2SE - 0.2P}$$

$$t = \frac{100 \, x \, 48}{(2 \, x \, 17{,}500 \, x \, 0.85) - (0.2 \, x \, 100)} = \frac{4800}{29730} = 0.1614''$$

Problem # 3

Determine the required “t” this torisphedcal head. (These are also called ASME flanged and dished

heads, by the way).



From UG-32(e)

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

$$t = \frac{0.885 \, x \, 100 \, x \, 96}{(17{,}500 \, x \, 1.0) - (0.1 \, x \, 100)} = \frac{8496}{17490} = .4857''$$

So, we have from thickest to thinnest all things equal:

Torispherical = 0.485r (Rounds to 0.486")
Ellipsoidal = 2744 (Rounds up to 275")
Hemispherical = 0.1614 (Rounds to 0.162")

There have been several exams where the question was asked, "Which is required to be thickest or 'Which can be the thinnest" Remember this.

One last Important comment

Hemispherical heads while they can be formed seamless are not considered seamless heads by Section V111. As mentioned previously they essentially form a Category A seam between the head and the other part. The spot RT of UW-12(d) does not apply to the Joint E used to calculate a Hemispherical head. They are never seamless; their Joint E comes from Table UW-12 based on the Type of weld and the extent of Radiography applied.