Section 11

Pressure Vessels

11.1 Vessel codes and standards

Pressure vessels can be divided broadly into 'simple' vessels and those which have more complex features. The general arrangement of a simple vessel is as shown – note it has no complicated supports or sections and that the ends are dished, not flat.

The main code for simple pressure vessels is:

BS EN 286-1: 1991: Simple unfired pressure vessels *designed to contain air or nitrogen.*

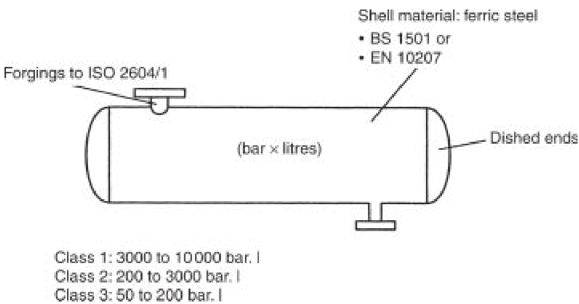

Figure 11.1

All aspects of designing and manufacturing the vessel are included under the following sections:

Section 4:	Classification and certification procedures
Section 5:	Materials
Section 6:	Design
Section 7:	Fabrication
Section 8–9:	Welding
Section 10:	Testing

Engineers' Data Book, Fourth Edition. Clifford Matthews.

Section 11: Documentation
Section 12: Marking

There are three vessel categories, based on capacity in bar × litres. More complex pressure vessels follow accepted codes such as:

BS PD 5500: 2010: Specification for unfired fusion welded pressure vessels.
ASME VIII: 2010: Pressure Vessel Code.

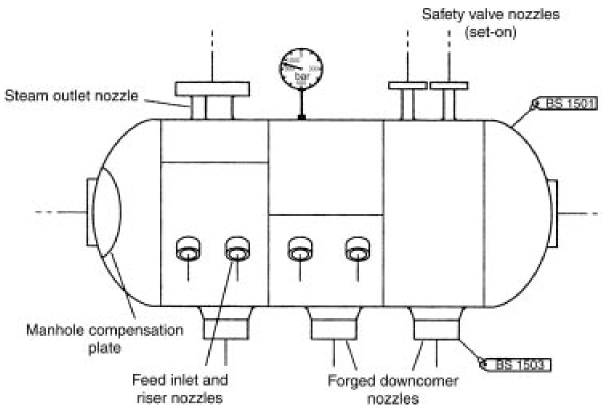

Figure 11.2

These also divide vessels into different categories depending on their application and manufacture.

The codes provide comprehensive information about the design and manufacture of the vessels. BS PD 5500 sections are:

BS PD 5500 Section 1: General
BS PD 5500 Section 2: Materials
BS PD 5500 Section 3: Design
BS PD 5500 Section 4: Manufacture and workmanship
BS PD 5500 Section 5: Inspection and testing

There are also several other BSI documents that give BS PD 5500-related background information.

BS 7910: 2006

The full title of this standard is BS 7910: 2006: *Guide for assessing the acceptability of flaw in metallic structures*. It evolved from the British Standard published document PD 6493 first published in 1980 and was issued as a more comprehensive version of BS PD 6493, covering both high and low-temperature failure modes resulting from flaws in welds and some types of corrosion.

EN 13445:2002 Unfired Pressure Vessels

This is the European harmonized standard for unfired pressure vessels. Vessels manufactured to this standard receive an automatic 'presumption of conformity' with the PED. It consists of several parts:

- Part 1: General
- Part 2: Materials
- Part 3: Design
- Part 4: Fabrication
- Part 5: Inspection and testing
- Part 6: Requirements for the design and fabrication of pressure vessels and pressure parts constructed from spheroidal graphite cast iron

This standard is one of a developing set of similar standards that address piping, boilers, and other items of pressure equipment.

ASME VIII

The ASME Boiler and Pressure Vessel Code, Section VIII is an accepted code used in the USA and many other parts of the world. It provides a thorough and basic reference for the design of pressure vessels and heat exchangers covering: design, material selection, fabrication, inspection, and testing.

Being a comprehensive code, ASME VIII is complicated and can be difficult to follow, until you become familiar with its structure and principles. ASME VIII is divided into two divisions.

- *Division 1* (VIII-1) covers normal vessels.
- *Division 2* (VIII-2) covers alternative rules for pressure vessels and is used for various types of special applications,

including nuclear. VIII-2 was recently formally withdrawn, but is still used by many manufacturers.

Both divisions are structured into a large number of paragraphs designated by reference letters, e.g. UG-22.

ASME VIII is written against a well-defined theoretical background that is similar, but not identical, to that used for other pressure vessel codes. This theoretical background is reflected in the design rules that apply to all the components of pressure vessels and the way in which size, shape, and material choices are made.

11.2 Pressure vessel design features

Although straightforward in concept, pressure vessels can exhibit a variety of design features. Different methods of design and assessment are used – all of which are covered in detail in the design codes. Common weld, nozzle, and flange types are as shown.

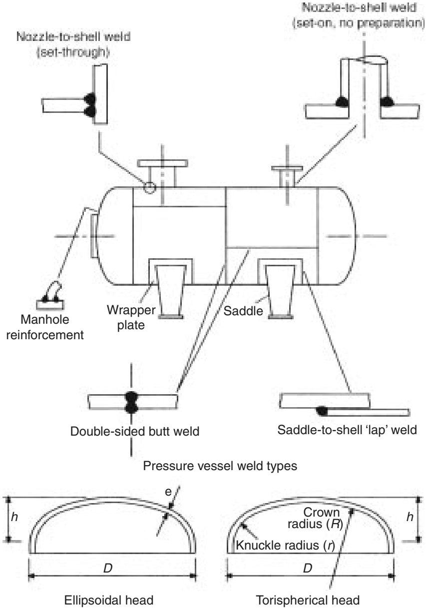

Figure 11.3

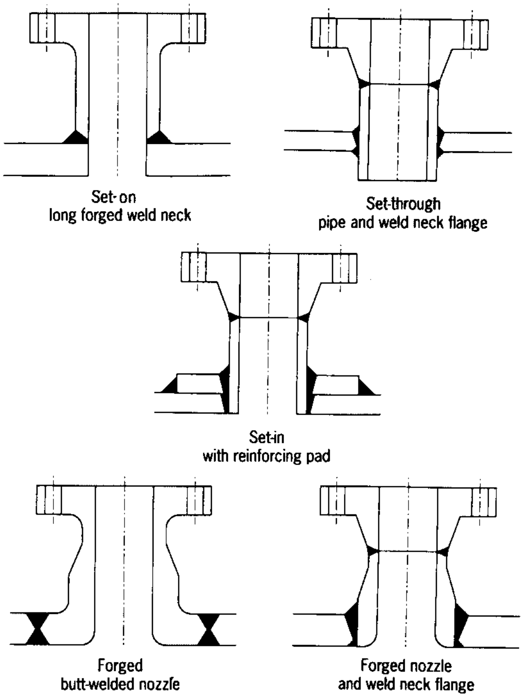

Figure 11.3 (Cont.)

11.3 Cylindrical pressure vessel design stresses

Design stress formulae in cylindrical pressure vessels are well defined in codes and standards. ASME VIII-1 gives rules for the design of cylindrical shells of uniform thickness subject to internal pressure, external pressure, and axial loads. The governing equations for longitudinal and circumferential stresses are broadly as shown below.

Cylindrical Shells: Basic Equations ASME VIII-1
Thin cylindrical shells under internal pressure:
For circumferential stress:

$$t = PR/(SE - 0.6P)$$

when $t < 0.5R$ or $P < 0.385\,SE$

For longitudinal stress

$$t = PR/(2SE + 0.4P)$$

when $t < 0.5R$ or $P < 1.25\,SE$

where

P = internal pressure
R = internal radius
S = allowable stress in the material
E = joint efficiency factor
t = thickness of shell material

Note how these equations are expressed in terms of the *inside* radius of the cylinder shell.

Thick cylindrical shells under internal pressure
For circumferential stress

$$t = R(z^{1/2} - 1)$$

where $Z = (SE + P)/(SE - P)$
For longitudinal stress

$$t = R(Y^{1/2} - 1) \text{ for } t > 0.5R \text{ or } P > 1.25\,SE$$

where $Y = (P/SE) + 1$

For vessels in ASME VIII Div 2, different equations have to be used.

11.4 Stress categories

The three stress categories recognized by ASME VIII-2 are listed below.

Primary stress

The best examples are longitudinal and circumferential stresses in a cylindrical vessel under internal pressure. Primary stress does not cause load redistribution and can itself be subdivided into:

- bending stress;
- general membrane stress (e.g. from internal pressure);
- local membrane stress (such as caused by local nozzle loads, etc.).

Secondary stress

This is essentially caused by some component of a pressure vessel being *restrained*, either by other components, or by being fixed to something external to the vessel. In contrast to primary stresses, which can cause failure if they rise too high, secondary stresses are self-limiting, i.e. they can be redistributed by local yielding, without the vessel having 'failed'. Thermal stresses are classed as having secondary stress characteristics.

Peak stress

This is highly localized stress that, although does not necessarily cause detectable yielding, may result in fatigue. Typical examples are notches and crack-like features.

11.5 Analysis of stress combinations

ASME VIII-2 covers various simplified methodologies for calculating acceptable stresses when a component is subjected to a *combination* of stresses. The basic idea is outlined below.

- Three normal stresses σ_r, σ_l, σ_h are calculated
- Three tangential stresses τ_rl, τ_rh, τ_lh are calculated.
- The three principal stresses σ_1, σ_2, σ_3 are calculated using

$$\sigma_{\substack{max \\ min}} = \frac{(\sigma_{1i} + \sigma_j)}{2} \pm \left[\frac{(\sigma_{1i} + \sigma_j)^2}{2} + \tau_{ij}{}^2 \right]^{\frac{1}{2}}$$

- The maximum stress intensity (S) as defined in VIII-2 is then assumed to be the largest value obtained from

$$S_{12} = \sigma_1 - \sigma_2$$
$$S_{13} = \sigma_1 - \sigma_3$$
$$S_{23} = \sigma_1 - \sigma_3$$

11.6 Vessel certification

Pressure vessels contain large amounts of stored energy and hence are considered as potentially dangerous pieces of equipment. Prior to the inception of the Pressure Equipment Directive, most vessels were subject to independent 'certification' involving design review, witnessing of testing etc by an independent 'third-party' authority.

11.7 Flanges

Vessel flanges are classified by type and *rating*. The main British and US standards differ slightly in their classification but the essential principles are the same.

11.7.1 Flange types

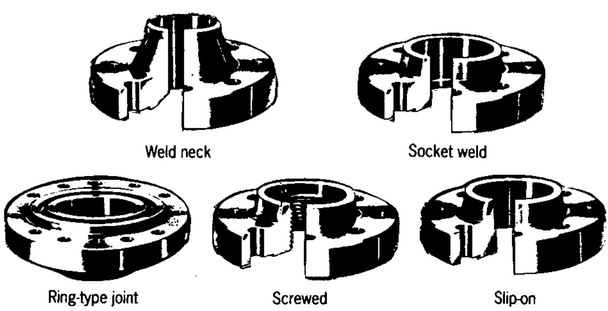

Figure 11.4

11.7.2 Flange ratings

Flanges are rated by pressure (in psi) and temperature e.g. ASME B16.5 classes:

150	psi	
300	psi	Detailed size and design information is given in the ASME B16.5 standard
600	psi	
900	psi	
1500	psi	
2500	psi	

11.7.3 Flange facings

The type of facing is important when designing a flange. Pressure vessel and piping standards place constraints on the designs that are considered acceptable for various applications.

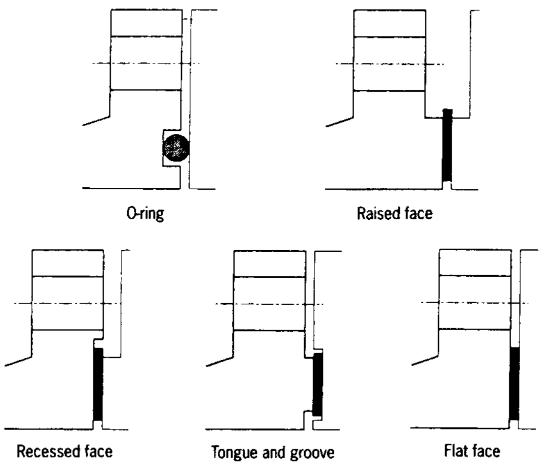

Figure 11.5