
Explanatory supplement to BS 5500 : 1988 'Specification for unfired fusion welded pressure vessels', section three 'Design'

Part 3. Vessels under external pressure

**Supplément explicatif à la norme 5500 — Récipients sous pression non soumis à la flamme soudé
par fusion : Section 3 : Conception
Partie 3. Récipients sous pression externe**

**Erläuterungen zu BS 5500 : Schmelzgeschweißte Druckbehälter
Abschnitt 3 : Auslegung
Teil 3. Behälter unter äußerem Druck**

Foreword

This Part of PD 6550 has been prepared under the direction of the Pressure Vessel Standards Policy Committee.

This explanatory supplement to section three 'Design' of BS 5500 'Specification for unfired fusion welded pressure vessels', has been written to assist both the newcomer to pressure vessel design and the experienced vessel designer. It describes the background to BS 5500 and its theoretical basis in design. Answers are given to many of the questions that are asked about the detailed and complex rules and requirements concerning the design of pressure vessels to BS 5500.

PD 6550 is published in separate Parts.

Each Part of the supplement is current with the 1988 edition of BS 5500, the nomenclature of which has been followed throughout. It is assumed that the reader is reasonably familiar with the terms used in BS 5500.

The committee wishes to acknowledge the fundamental contribution of Mr R A McFarlane of British Petroleum International Limited, as the primary author of the text of this Part of the supplement.

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1 Introduction

This Part of PD 6550 describes the design of vessels for external pressure. It describes the collapse modes which apply and shows how each is taken into account in 3.6 of BS 5500.

To design a vessel for external pressure, each shell component must be checked against its likely mode of collapse. Predicting the collapse pressure of a cylinder or a sphere under external pressure presents a number of problems. There are many collapse modes and the analysis of them is complex. The critical mode for the component must be identified and the collapse pressure calculated for that mode. An allowance must be made for geometric imperfections.

There must also be a margin between the predicted collapse pressure and the pressure which is permitted by the code. In BS 5500, providing the vessel is circular to within 0.5 % on radius measured from true centre, there is a margin of at least 50 % between the estimated collapse pressure and the code allowable pressure.

There is a large theoretical content in the BS 5500 method but it also makes considerable use of results from collapse tests. Both elements, the theoretical and the experimental, contribute greatly to the success and integrity of the method.

NOTE. The titles of the BSI publications referred to in this Part of PD 6550 are listed on the inside back cover.

References to publications (other than BSI publications) are identified in the text by numbers in square brackets and are listed in clause 8.

2 Collapse types

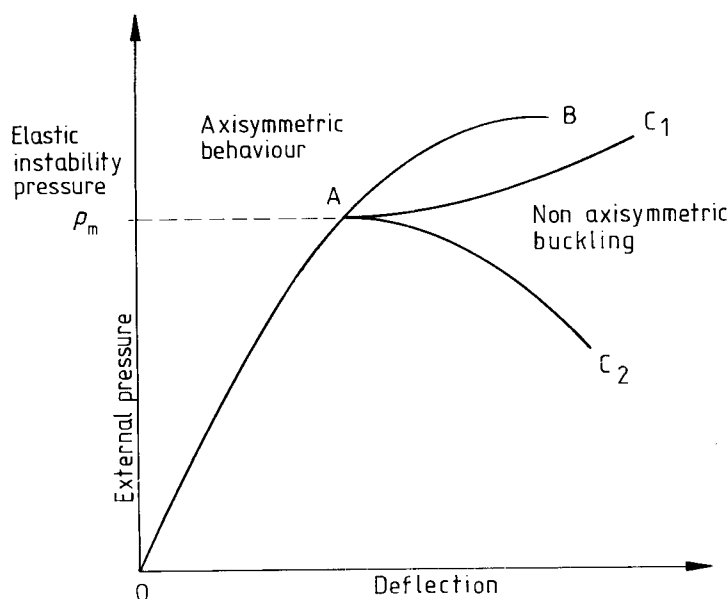
2.1 What is the designer trying to prevent?

For linear elastic shells of perfect shape, a general graph of external pressure against deflection, given by Kendrick [1] is shown in figure 1.

On the portion of the graph marked OA, there is a uniform response from different types of shell. At any pressure, there is a single value of deflection. The shell is stable and a small pressure disturbance would merely produce oscillation about the equilibrium position. There is non-linearity along OA but in practical cases at pressure p_m , which is known as the elastic instability pressure, the non-linearity is only a few per cent.

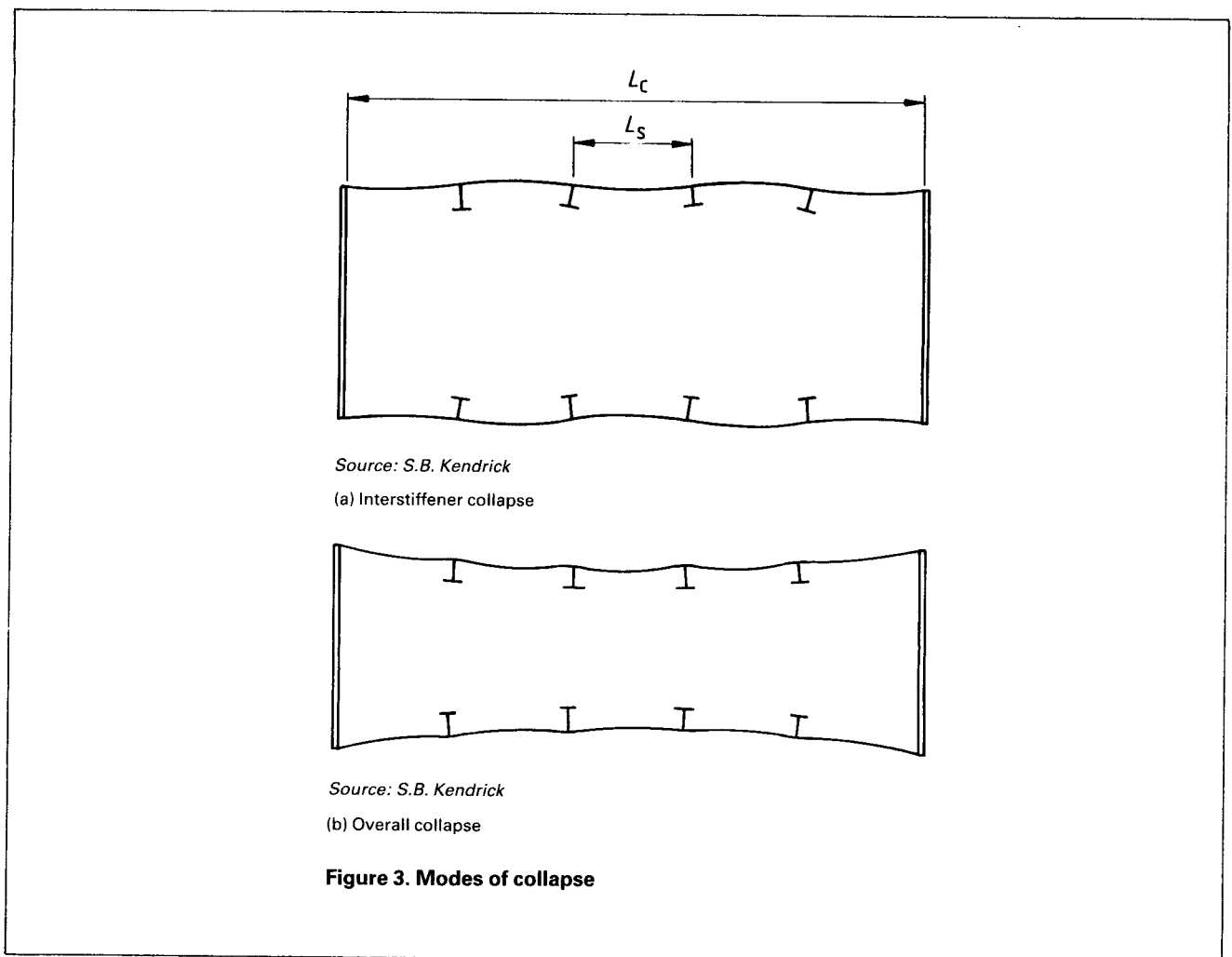
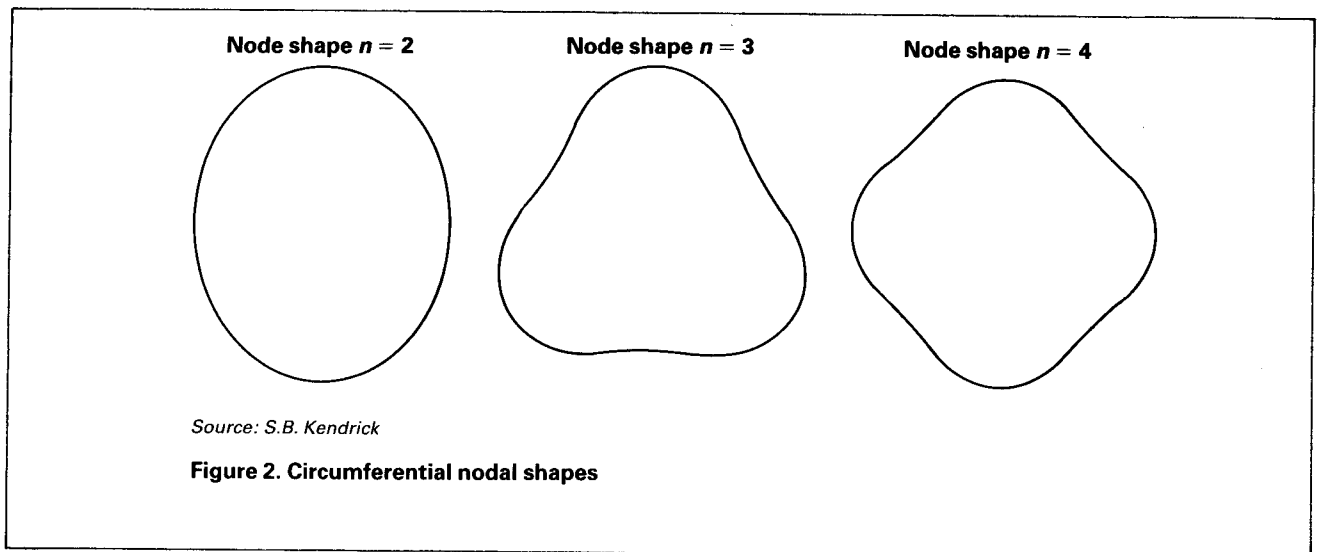
Beyond p_m , shells become unstable. In theory, they could continue to follow curve AB and buckle axisymmetrically at high pressure but real structures more usually follow the two quite different curves AC₁ and AC₂.

Cylinders under external pressure usually follow curve AC₁ in figure 1 (although the full AC₁ pressures are not normally achieved due to the onset of yielding). A small disturbance causes a sudden dynamic motion and the shell develops departures from the circular which are in the form of sine waves in the circumferential direction. The lower order sine waves are shown in figure 2. At the same time as waves form in the circumferential direction, they also develop longitudinally. The latter are shown in figures 3(a) and (b). They may be either symmetrical or asymmetrical about the light stiffeners along the cylinder.



Source: S.B. Kendrick [1]

Figure 1. Buckling behaviour of ideal shells



When the longitudinal waves are asymmetrical about each light stiffener, as shown in figure 3(a), the buckling occurs in the shell plate between the stiffeners. This is called **interstiffener** collapse and is also known as von Mises buckling. In two dimensions, it is the familiar Euler buckling of a strut. An example from experimental work is shown in figure 4.

When the longitudinal waves are symmetrical (or nearly so) about the light stiffeners, as shown in figure 3(b), the buckling is of the combined stiffener and its adjacent length of shell. This is **overall** buckling. An example from experimental work is shown in figure 5.

Spheres under external pressure follow the curve AC₂ in figure 1. They are unable statically to withstand pressures above the elastic instability pressure. Once the pressure rises above the elastic instability pressure, a gross change in geometry occurs. This is **snap-through** buckling. It also occurs in cylinders under axial load.

Examples of snap-through buckling may be seen in figures 6(a) and 6(b). The head in figure 6(a) is the thicker of the two and the buckling has occurred on the crown but extends towards the knuckle. The thinner head in figure 6(b) has buckled in the centre of the crown.

Snap-through buckling is more sensitive to shape imperfections than interstiffener collapse and this is shown in figure 7 where a comparison is made of the sensitivity to imperfections in each case. The critical stresses (σ_{cr}) in figure 7 have been calculated by Galletly [2] assuming an initial sinusoidal imperfection of amplitude δ_0 . Curve 1 for snap-through buckling is markedly lower than curves 2 and 3 for interstiffener collapse showing the greater sensitivity which applies to snap-through buckling.

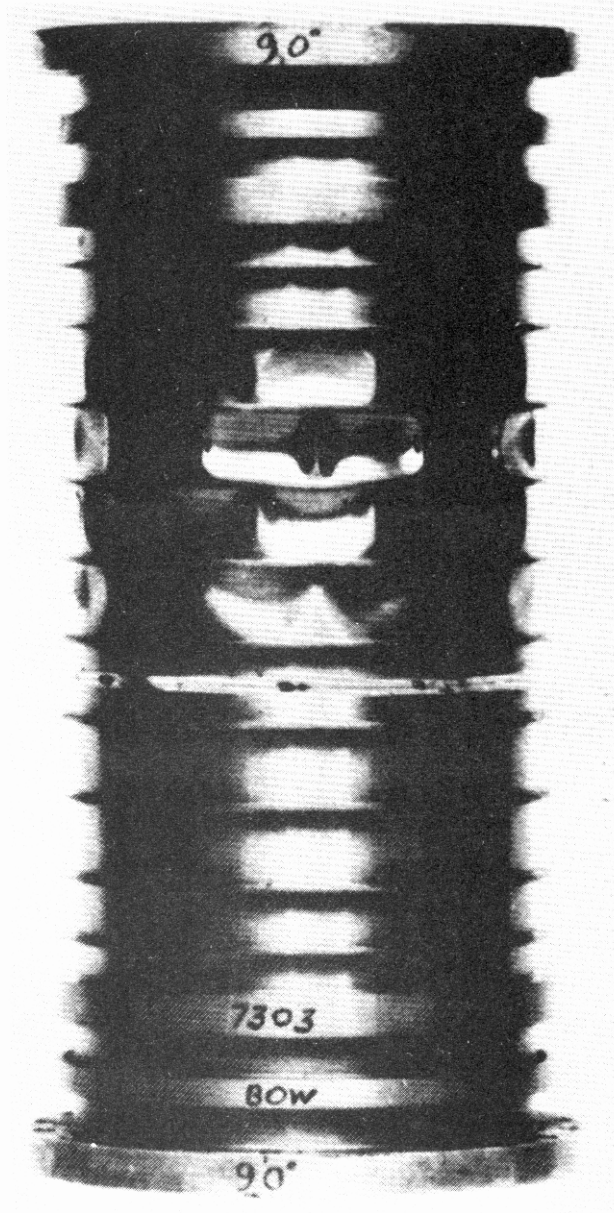
Although not a general type of shell buckling, there is one further type of collapse for which rules are given in BS 5500. This is **sideways tripping** of stiffeners. It is discussed in clause 5 of this published document.

2.2 The method in BS 5500 : a summary table

The main features of the BS 5500 method for the three types of collapse are summarized in table 1.

The table states the design criterion used and whether it is one based on experimental results or a limit on stress. Two pressures have to be calculated for each collapse type. The table lists the elastic instability pressures and indicates the source of the expressions for each. It also lists the yield pressures and states the location where yield stress is reached in the vessel at each yield pressure.

Table 1. Main features of the BS 5500 method			
Type of collapse	Interstiffener collapse	Overall collapse	Snap-through buckling
Relevant BS 5500 clauses	3.6.2.1 Unsupported cylinders 3.6.3.1 Cones: unsupported lengths	3.6.2.2 Stiffening rings for cylinders 3.6.3.2 Stiffened conical shells	3.6.4 Spheres A.3.5 Longitudinal compressive stress
Design criterion	Based on experimental results contained in a graph: curve (a) of figure 3.6(3)	Limit on total stress in ring/shell section. Calculated at design pressure enhanced by a margin	Based on experimental results contained in a graph: curve (b) of figure 3.6(3)
Safety factor	1.5 (min.)	1.5 (min.)	1.5 (min.)
Elastic instability pressure and its source	p_m : von Mises (modified) p_{mc} : Niordson (modified)	p_n : Bryant (modified)	p_e : van der Neut
Yield pressure and the location of the yield stress	p_y and p_{yc} — mean circumferential stress midway between stiffeners	p_{ys} — maximum circumferential stress in stiffener	p_{yss} — membrane stress in sphere



Source: G.D. Galletly [2]

Figure 4. Interstiffener collapse of a ring-stiffened cylinder under external pressure

