

GUIDE TO ITEMS ON THE STRENGTH AND STABILITY OF STRUTS

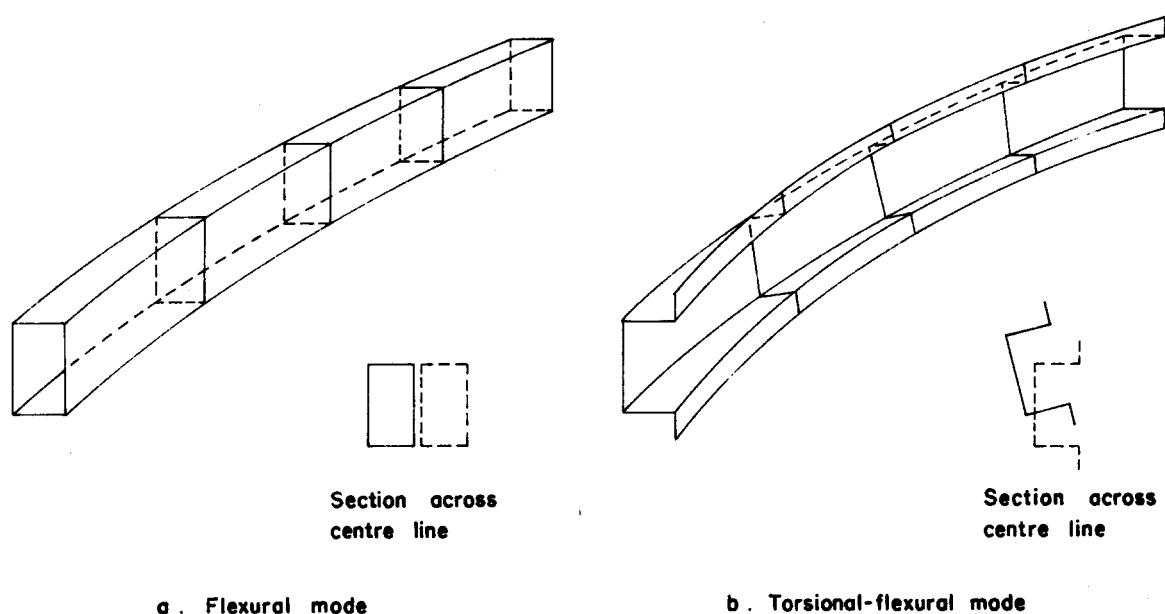
1. INTRODUCTION

This Item supplements the group of Data Items that deals with the strength and stability of struts. Data Items that relate specifically to struts are located in the Guide Card Section with that name. All other Data Items relating to struts may be located by reference to Table 10.1 or to the ESDU Index. For panel stiffeners that behave like struts see Item No. 72012.

A strut is a structural component having cross-sectional dimensions that are small in comparison with its length and that is loaded in compression parallel to that length. The cross section may be solid but, for reasons of structural efficiency, is more likely to be constructed from material that is itself thin in relation to the overall dimensions of the cross section (see Sketches 2.1 and 2.2). The cross-sectional shape is usually uniform along the length of the strut but, in order to introduce the load uniformly to the cross section, the shape may change at the ends.

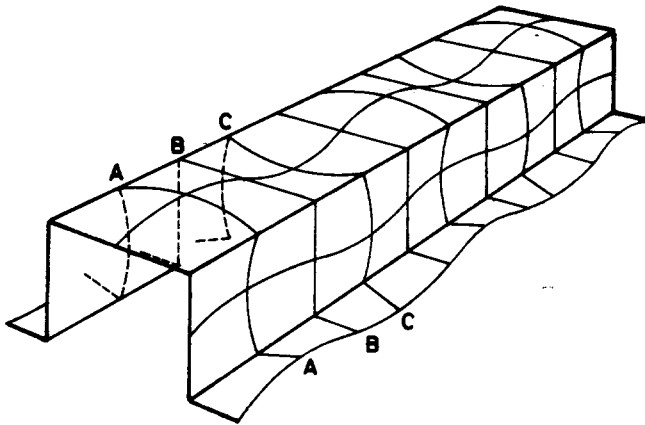
2. THE BEHAVIOUR OF STRUTS

Buckling under the action of a compressive load consists of the departure of part, or parts, of the strut from the line along which it is being compressed. Sketches 2.1 and 2.2 illustrate the buckled shape, or mode, of several common strut types. In all cases the departure of part or all of the cross section from the line of action of the compressive load varies sinusoidally along the length of the strut. Sketch 2.1 illustrates modes in which the half wavelength of the sinusoidal buckle is equal to the length of a simply-supported strut. Such modes are usually termed overall buckling modes. Sketch 2.1(a) illustrates the flexural mode (Euler), in which the cross section translates but does not rotate, Sketch 2.1(b) shows the torsional-flexural mode, in which the section both rotates and translates. There is a further mode in this group in which the section rotates without translating; this mode, termed torsional buckling, rarely occurs in practice. Sketch 2.2 illustrates modes in which the cross section distorts without translation or rotation. The half wavelength of the distortion for these modes is closely related to the principal dimensions of the strut cross section. For this reason these modes are termed local modes.

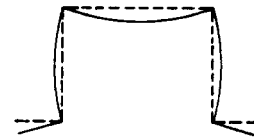


Sketch 2.1 Overall modes

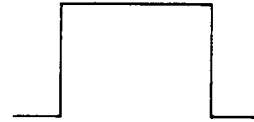
Issued October 1978
With Amendments A to C



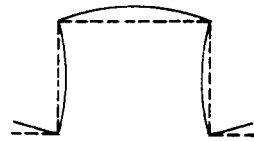
a. Local buckling of a lipped channel



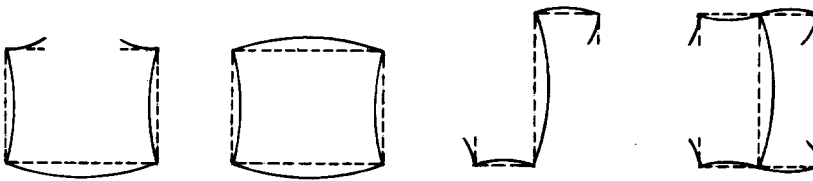
Section CC



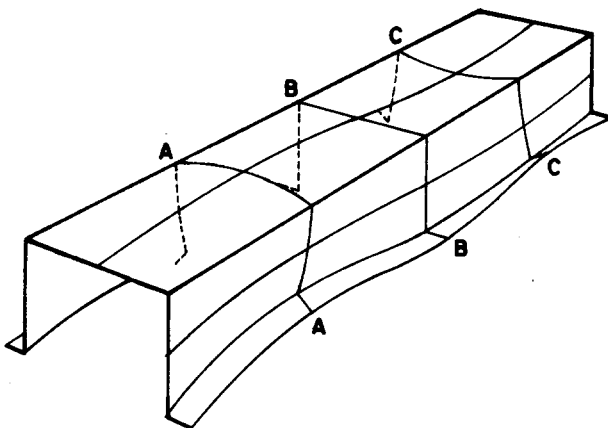
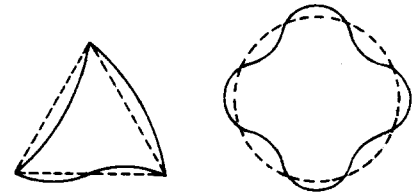
Section BB



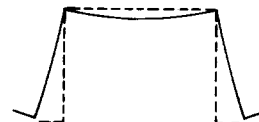
Section AA



b. Forms of local buckling of common sections



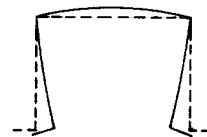
c. Flange buckling of a lipped channel



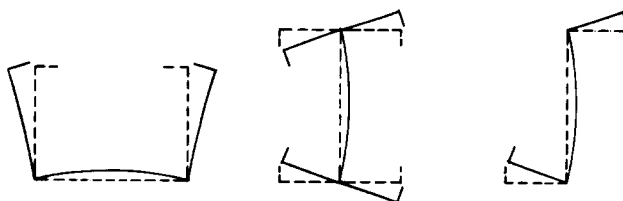
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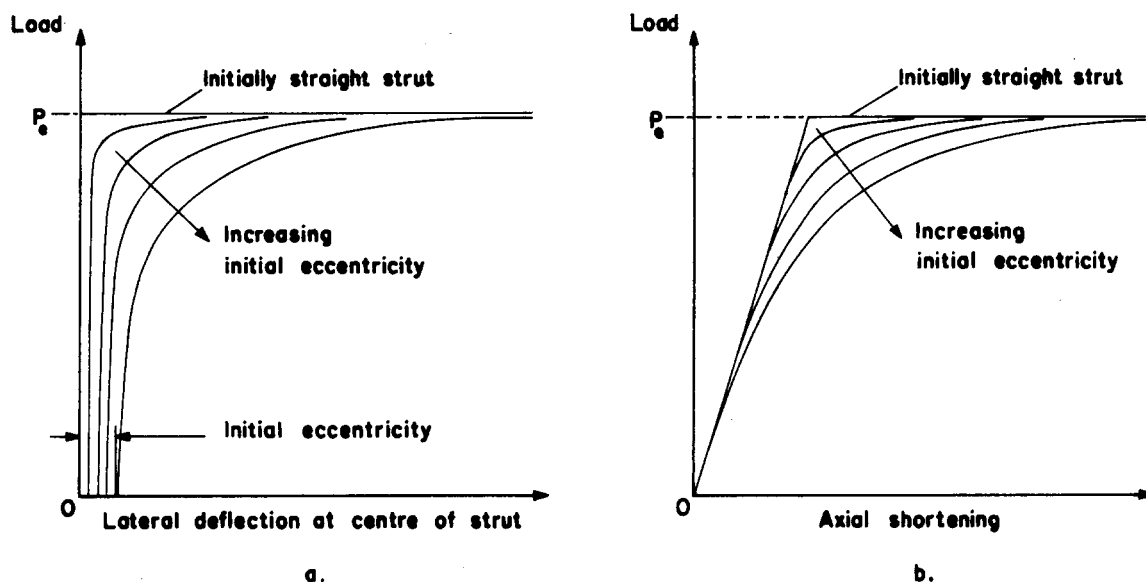
Section AA



d. Forms of flange buckling of common strut sections

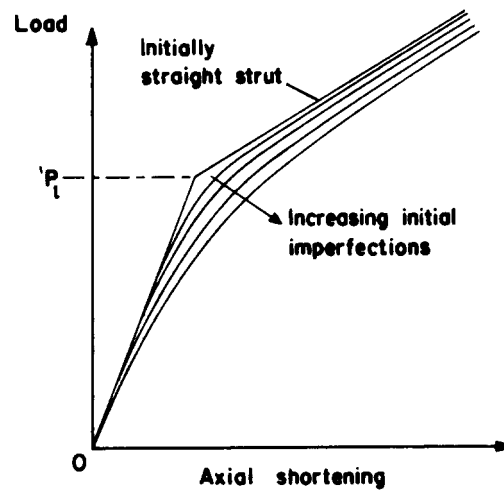
Sketch 2.2 Local modes

The behaviour of an elastic strut subject to overall buckling is illustrated by Sketch 2.3. As the load is increased the strut starts to deform, the central portion being deflected and/or twisted out of the line of action of the compressive load. By this means the axial displacement or shortening, that is the reduction in distance between the ends of the strut, is increased over that resulting solely from the direct compressive strain. The deflected strut is therefore reacting the applied compressive load by a direct compressive stress and the offset bending moment by bending stresses. Sketch 2.3(a) shows that the lateral deflections, and therefore the associated bending stresses, increase steadily for struts with significant initial deviation from straightness. For almost straight struts, the lateral deflection increases slowly at first then very rapidly. Similarly for struts with significant initial deviation from straightness Sketch 2.3(b) shows that the stiffness against axial compression (load divided by axial displacement or shortening) decays steadily with increasing load but that for almost straight struts there is only a slight reduction in stiffness at first followed by a sudden drop to a very low value. As a result of this behaviour an elastic strut may reach the limit of its usefulness as a structural member on one of two counts. Either, as is usually the case, the extreme fibre compressive stress reaches a maximum allowable stress criterion, or the reduced compressive stiffness becomes unacceptably low.



Sketch 2.3 Overall elastic buckling of nominally identical struts

The behaviour of a thin-walled strut composed of flat plate elements subject to local buckling is illustrated in Sketch 2.4. Local buckling modes are such that all or most of the junctions between the plate elements remain nominally straight whilst the centres or free edges of the plates bow out of the line of action of the applied load. Thus the load/axial displacement curve shown in Sketch 2.4 differs from that in Sketch 2.3 in that the stiffness against axial compression is always positive. Because of this behaviour the limit of usefulness of the strut can be reached in one of two ways. Firstly the stresses at the junctions, which grow more rapidly than the average stress, can become sufficiently high to cause local collapse. This mode of failure is termed crippling and is usually associated with exceeding the limit of proportionality of the material. Secondly the reduced stiffness can lead to a reduction in the resistance of the strut section to buckling in one of the overall modes so that its limiting load is reached in one of the ways described above for overall buckling. In certain circumstances this latter case can occur below the load marked P_l on Sketch 2.4.



Sketch 2.4 Local elastic buckling of nominally identical struts

As local buckles develop the stiffness of a strut depends upon the number of plate junctions that remain straight. Therefore in lipped sections flange buckling causes a greater reduction in stiffness than does local buckling.

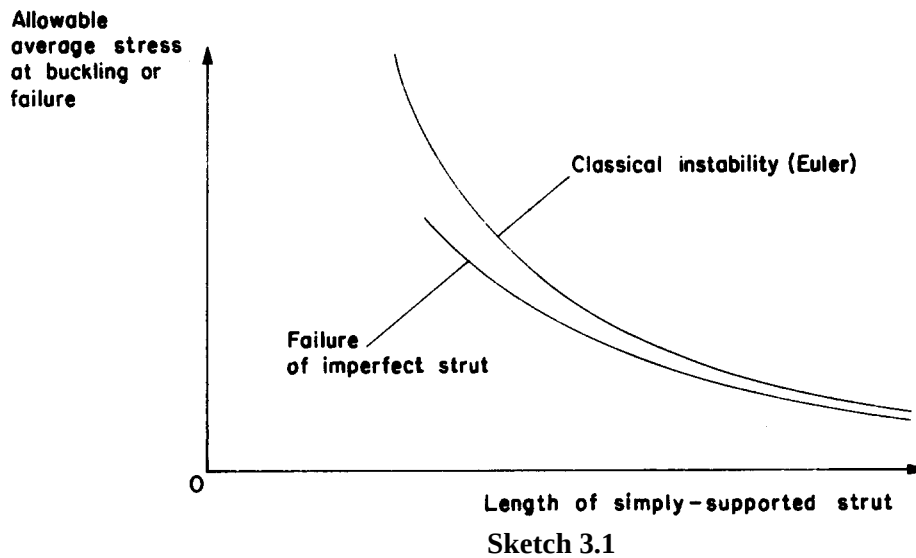
The local buckling of circular tubular struts is a special case that is highly dependent upon initial imperfection of form, so much so that buckling usually occurs suddenly at a load well below the theoretical buckling load of the perfect strut. Normally local buckling of such sections represents the limit of their structural usefulness.

As overall buckling is approached the offset bending moments produce a non-uniform stress distribution across the section that will reduce the average stress at which local buckling occurs.

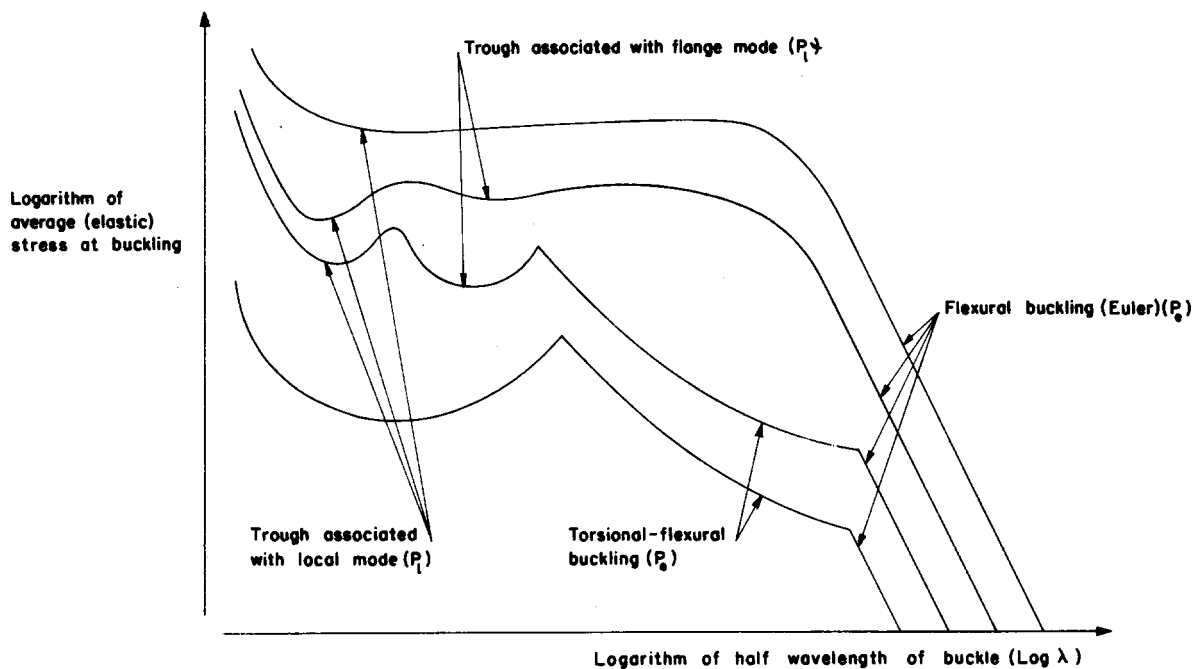
3. CALCULATIONS RELATING TO BUCKLING

Most calculations relating to buckling deal with theoretically perfect geometry and precise axial alignment of the load. The most elementary of these is the classical Euler calculation for flexural buckling. Similar analyses can be performed for torsional-flexural and torsional buckling. Such calculations provide the load labelled P_e in Sketches 2.3(a) and 2.3(b). For struts subject to flexural buckling the effect of the initial deviation from straightness can be included in calculating the average stress in the strut at which the extreme fibre stress reaches its allowable value or in determining the compressive stiffness of the strut. Although such calculations are dependent on the form of the initial deviation from straightness it is usual to assume a sinusoidal form. The resulting stresses may conveniently be plotted against the length of the simply-supported strut to give the familiar strut curves shown in Sketch 3.1. The abscissa of Sketch 3.1 could equally be the buckle half-wavelength since the overall mode of buckling always occurs at the highest wavelength possible.

Calculation of the local buckling load of sections composed of flat plate elements normally uses plate theory modified to take account of the connections between the elements. The plates are usually assumed not to translate in their own planes and this implies that the plate junctions remain straight along the length of the strut. Such an analysis provides the load labelled P_l in Sketch 2.4. To account for flange buckling it is necessary to remove the restraint on translation. Removing this restraint for all elements means that the calculation then yields the theoretical buckling loads for all modes, including the overall ones. From these more general calculations it is found that, for a given buckle wavelength, there is a mode of deformation that occurs at a lower load than any other. It is then useful to plot the associated minimum elastic buckling



stress against the wavelength and four example curves of this type are illustrated in Sketch 3.2. For a simply-supported strut the half wavelength of buckle must be the strut length or a sub-multiple of it. Thus, as Sketch 3.2 shows, if the length is sufficiently great the flexural or torsional-flexural mode of buckling will occur. However, for shorter struts the lowest stress at which buckling will occur will be near to one of the troughs towards the left of Sketch 3.2. In practice it is wise and conservative to assume that for short wavelength modes the buckle wavelength adjusts itself to the value corresponding to the trough whether or not this is an exact sub-multiple of the strut length.



Sketch 3.2