

INFORMATION ON THE USE OF DATA ITEMS ON THE BUCKLING OF PLATES AND COMPRESSION PANELS MANUFACTURED FROM ISOTROPIC MATERIALS

1. INTRODUCTION

This Item gives general information on the use of the Items in the Structures Sub-series on quadrilateral plates and panels subjected to in-plane compression. It covers behaviour at initial buckling, immediately after buckling and at failure.

A plate is defined as a portion of sheet bounded by longitudinal and transverse members or a portion of sheet bounded by two or three such members and having the remaining one or two sides free. A panel is defined as a sheet bounded transversely by sturdy frames between which the sheet is stiffened by longitudinal members (stringers). For a panel the major compressive stress is taken to be acting parallel to the stringers. The stringers and frames may be integrally manufactured with the sheet or separately attached.

Sandwich panels and panels under shear loading are dealt with in separate sections of the Structures Sub-series.

Numbers appearing in this Item such as 72019 and 02.01.46 refer to other Items in the Structures Sub-series.

2. PLATES

2.1 Initial Buckling of Flat Plates

The following is a description of the buckling characteristics of thin flat plates that have no initial irregularities or eccentricities. (The effects of such imperfections are discussed in Section 2.3.)

The buckling under compression of a rectangular plate having the longer, or all, edges held in-plane is characterised by the formulation of a single buckle across the width and one or more along the plate length. Figures 4 and 5 of 72019 give the uniaxial buckling stresses for plates with several basic conditions of edge restraint. Figures 1, 2 and 3 of 72019 provide data on the effects of intermediate conditions of edge restraint. The cusps in the curves correspond to changes in the number of buckles along the plate length. It is useful to note that a long plate under uniaxial compression and having all edges simply-supported will form a series of buckles of half wavelength of about the plate width; for a plate with all edges clamped against rotation the half wavelength will be about two thirds of the plate width.

The addition of an in-plane transverse loading modifies the plate buckle form and buckling stress. If the transverse loading is tensile the buckling stress is increased and the axial wavelength is reduced; conversely, compressive transverse loading reduces the buckling stress and increases the wavelength. Figures 6 to 9 of 72019 give the combinations of loads acting along and across the plate at which the plate will buckle for basic conditions of edge restraint.

Items 02.01.46 and 47 give the buckling stresses of parallelogram plates loaded in uniaxial compression parallel to an edge. Here the wavelength is more complex but for long plates a situation similar to that in long rectangular plates is reached away from the ends. Buckling stresses for plates tapered in plan are given in 02.01.48 and for plates tapered in thickness in 02.01.49.

2.2 Post Buckling of Initially Flat Plates

When the buckling load of a plate is exceeded the effective (tangent) stiffness of the plate is reduced to a value that is dependent on the plate shape and the restraints along its edges. The longitudinal stresses near the edges of the plate then increase more rapidly with load and those over the central portion of the plate increase less rapidly. Data on this effect are limited and the Data Items cover only uniaxial compression of long plates. The case of simply-supported edges is covered in 02.01.23 and 24, and in 02.01.02 the same information is given in a different form together with one curve relating to clamped edges. Item 02.01.03 extends the information of 02.01.02, mainly on the basis of test results on one material and condition of edge restraint.

In an unbuckled plate, lateral restraint sets up lateral compression and this reduces the buckling stress (see Figures 1 and 3 of 72019, mentioned previously). As the buckle develops the lateral restraint is first relaxed and then begins to set up lateral tension that delays further development of the buckle and increases the effective stiffness of the buckled plate to further axial strain. The buckle wavelength of a laterally restrained plate will be longer than that of an unrestrained plate (see 72019). Since wavelength is the parameter that primarily affects post buckling stiffness, 02.01.24 may be used to obtain an indication of the increase in effective stiffness due to lateral restraints. Data for rotational restraint conditions other than simple support are not provided but the effect of lateral restraint is likely to be much the same whatever the degree of restraint against rotation.

2.3 Effect of Initial Irregularities

The presence of initial irregularities will cause a buckle to develop gradually below the buckling load of the corresponding perfect panel. If the displacements are comparable with the plate thickness no distinct buckling load will be discernible. With smaller irregularities the onset of buckling will be discernible both by the rapid increase in the depth of the buckles and in a rather sudden decrease in the effective stiffness of the plate to a value close to that appropriate to the perfect plate.

If the plate is initially deformed in a mode significantly different from the preferred buckling mode of the perfect plate the development under loading of this forced mode may delay, or even suppress, development of the preferred mode. However, whereas the configuration of buckles in the preferred mode is usually stable at all loadings, no forced mode can ever be completely so. Accordingly, at some stage of the loading a plate buckling in a forced mode is liable to revert to the preferred mode, accompanied by a sudden increase of strain and decrease of load in a manner typical of the buckling of curved plates (see Section 2.4 below).

2.4 Curved Plates

The buckling of laterally curved plates and their behaviour after buckling depend chiefly on the curvature and the initial imperfection from the cylindrical form. Except for nearly flat plates (in the notation of 02.01.11, b^2/Rt less than about 30) the effect of edge restraints is unimportant. Data relating to the buckling under axial compression of perfect and imperfect circular cylindrical plates with clamped edges are given in 02.01.10 and 11. As the figures indicate, buckling is usually violent and a new configuration develops immediately.

For perfect plates subjected both to axial compression and to circumferential stresses set up by normal pressure, 02.01.50 indicates the combinations of stresses at buckling. Owing to initial irregularities a reduction in the average buckling stress, similar to that shown in 02.01.11, will occur. The effect will be particularly marked in the case of plates loaded by pressure on their convex face and is less important in the more common case where the pressure is applied to the concave face.

3. COMPRESSION PANELS

Figure 1 illustrates a typical compression panel. It is convenient to describe the buckling of such panels by reference to a number of basic buckling modes each of which is associated with a particular wavelength and form of distortion. In each mode the wavelength of buckle is common to all components of the panel; consequently a mode may be illustrated by a diagram of part of the distorted cross section together with a statement of the associated wavelength. Figure 2 illustrates the more common forms of buckle for typical panels and hereafter the description of the buckled form relates to the distorted cross section.

The stiffness of the sheet to displacement in its own plane is, in practical panels, relatively so high that, at buckling, all lateral movement in this plane is virtually precluded. Accordingly, the displacement of any point in the sheet, including the feet of the stringers, may be represented as rotation about one of a set of longitudinal parallel axes in the plane of the sheet or, in the limit, as translation of the point normal to the original plane of the sheet (which may be viewed as rotation about an axis in the plane of the sheet infinitely remote from the stringers).

The buckling modes can usually be separated into two distinct classes. They are modes whose half wavelength is comparable with the stringer cross-sectional dimensions or pitch, and modes whose half wavelength is comparable with the distance between frames. The former case is termed local buckling and may include some degree of stringer torsion. In local buckling rotation occurs about the junction of the stringer webs with the sheet. The rotation is usually of opposite sense on adjacent stringers. In the case of thin-walled stringers the cross section of the stringers will also distort.

Buckling modes whose half wavelength is comparable with the frame spacing have two extreme forms. The more common of these is flexural buckling, in which the panel translates normal to the original plane of the sheet and no rotation occurs, and the other is torsional buckling, in which rotation, usually of the same sense for adjacent stringers, occurs about axes in the sheet at, or close to, the junctions of the stringer webs with the sheet. Since the wavelengths of these two forms are similar a combined mode termed flexural-torsional buckling generally occurs. In this general mode rotation takes place about a series of axes in the plane of the sheet that are away from the stringer web to sheet junctions.

Local or short wave buckling does not in itself constitute failure although its consequences may precipitate failure in another mode. Accordingly, attention is paid first to short wave or local buckling.

3.1 Local Buckling

A panel reinforced by thin-walled stringers may be regarded as being built up of a number of flat plates. If the in-plane stiffness of each plate is sufficient, the junctions between adjacent plates are restrained against significant translation. As the compressive load is increased, each component plate, if unrestrained in rotation by its neighbours, would buckle at a different stress and in a different wavelength. The connected panel buckles at a stress level and in a wavelength intermediate between the extreme values for the rotationally independent plates. Above the lowest unrestrained plate buckling stress, adjacent plates will exert a stabilising or destabilising effect on their neighbours and panel buckling occurs at the minimum stress level and at the wavelength for which these effects exactly balance.

3.1.1 Calculation of Local Buckling Stress

Item 02.01.28 sets out a method for calculating the panel local buckling stress in terms of the bending couples that are distributed sinusoidally along the edges of attached plates and that maintain continuity and equilibrium at the instant of buckling. Appropriate stiffness coefficients are given in 73007 and worked examples of this calculation are set out in 02.01.34 to 37 and 73015*. For panels reinforced by Z- and

* Data Item No. 73015 appears in the group of Items on orthotropic plates.

T-section and unflanged stringers the local buckling stresses are given in 70003 and 71014. Figure 3 illustrates the buckled form for a T-section reinforced panel.

If any of the component plates is narrow it may not suffice to maintain true nodal lines at its edges. This condition is most likely to arise in respect of free edged flanges whose total width is less than about five times the thickness of the adjacent flange, see Figure 4. An underestimate of the buckling stress may in such a case be found by disregarding the flange entirely, for instance by comparison of the data in 71014 for the Z- and T-sections with those in 70003 for the unflanged stringer. Intermediate cases where consideration must be given to the twist of the stringer section as a whole are not included in the Data Items.

3.1.2 The Behaviour after Buckling and the Effect of Initial Irregularities

After buckling, the effective (tangent) stiffness to axial loading of the buckled plates is reduced. Although precise data are lacking, upper and lower bounds may be postulated to the true condition. The upper bound is set by assuming that only the plates between the stringers are reduced in stiffness – to the value appropriate to plates with simply-supported edges; the lower bound is set by assuming that all components suffer this same reduction in stiffness. The lower bound would tend to be very conservative.

When initial irregularities are present the local buckle form develops gradually, at first slowly and then more rapidly as the buckling stress for the perfect panel is approached. In consequence the effective stiffness is appreciably reduced before the buckling stress for the perfect panel is attained and the stiffness varies less abruptly than it would otherwise. Note that this factor has a very marked influence on the optimal design of a compression panel and renders, for optimum design purposes, uncertainty regarding the precise values of the stiffness after buckling far less important than it would otherwise be.

3.2 Flexural Buckling

For stringer sections that are symmetrical about an axis perpendicular to the sheet, the pure flexural mode is strictly valid (see Figure 2) and involves neither rotation nor deformation of the stringer section. If the stringer section is asymmetrical (as in the Z-section), bending in this normal plane is in general accompanied by a tendency for the stringer to twist, and the mode of buckling is properly described as flexural-torsional (see Figure 2). However, unless the asymmetry of the stringer section is very marked the resultant reduction below the buckling stress corresponding to pure flexure is small, and usually the tendency of the stringer to twist may safely be disregarded. The effect of asymmetry is illustrated in Figure 5. Pure, or nearly pure, torsional buckling is likely to occur only with sturdy bulb angle or unflanged stringers attached to very light sheet.

3.2.1 Calculation of Flexural Buckling Stress

The flexural buckling stress may be estimated by treating the stringer-sheet combination as a strut buckling between frames. Item 01.01.01 on the strength of struts may be used for this purpose. If the stringers are sturdy, flexural buckling may be preceded by buckling of the sheet between stringers, in which case an allowance must be made for the reduced stiffness of the buckled sheet. This can be done by employing a modified sheet area and 02.01.16 provides a relationship between the ratio of stringer area to the modified sheet area and the plate stresses and 02.01.17 provides a nomogram for determination of the panel failing stress taking this into account. The average stress in the sheet at stringer failure can then be estimated from 02.01.23; however, as previously noted in Section 2.2 on post buckling of plates, data are only available for certain limiting cases of restraint.

The effects of initial irregularities of the stringer may be accounted for in the use of 01.01.01. It should be noted that prior to buckling the stress in the extreme fibres of the stringer-sheet combination will increase rapidly and that 01.01.01 makes allowance for a limiting stress to be set for those fibres.