

BUCKLING OF FLAT RECTANGULAR PLATES

(Isotropic, orthotropic and laminated composite plates and sandwich panels.)

1. INTRODUCTION, THEORY AND APPLICATION

1.1 Introduction

This Item, together with the accompanying ESDUpac A8147V40, provides a computer program for calculating the elastic buckling loads of flat rectangular specially orthotropic plates under combinations of uniform in-plane biaxial and shear loads. A particular feature of the solution employed is that it includes the effect of the through-the-thickness shear stiffness which can significantly influence the buckling load of laminated composites and sandwich panels. The program deals with symmetrical combinations of clamped and simply-supported edge conditions and takes account of out-of-plane shear deformations. The program may be used to calculate the buckling load of

- (a) isotropic (metallic) plates,
- (b) orthotropic plates,
- (c) laminated composite plates or
- (d) sandwich panels.

The program allows for input of the appropriate type of plate and its properties. For cases (c) and (d) above the program can calculate the properties of the equivalent orthotropic plate for use in the computation of the buckling load(s).

Of the two in-plane direct loads and the shear load that the program deals with, two values may be fixed and the remaining load at buckling calculated. Alternatively, the ratios between any two or all three applied loads may be provided and the program will calculate the loads in the required ratio(s) at buckling.

The Data Item is provided in two parts. Section 1 describes the theoretical solution to the buckling of orthotropic plates used by the program and its application to practical plates. Section 2 describes the use of the Fortran program, its input, output and all messages, and gives example calculations. The program is available in two formats: (a) a Fortran source code with example input and output files, and (b) an executable program for PC's. Both versions can be found on the Compact Disc and on disk in the Sub-series Software Volume.

1.2 Notation

Both SI and British units are quoted but any coherent system of units may be used.

A	in-plane stiffness sub-matrix for plate (see Section 1.3.1)	N/m	lbf/in
A_{ij}	element of A in row <i>i</i> and column <i>j</i>	N/m	lbf/in
<i>a, b</i>	plate length in x- and y-directions, respectively	m	in
B	coupled in-plane and flexural stiffness sub-matrix for plate (see Section 1.3.1)	N	lbf

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B_{ij}	element of B in row i and column j	N	lbf
C	layer type identification number		
D	flexural stiffness sub-matrix for plate (see Section 1.3.1)	N m	lbf in
D_{ij}	element of D in row i and column j	N m	lbf in
$\bar{D}$	$D_{11}D_{22} - D_{12}^2$	$N^2 m^2$	$lbf^2 in^2$
E	modulus of elasticity (for isotropic plates)	N/m^2	lbf/in^2
$E_{\alpha k}, E_{\beta k}$	moduli of elasticity of k th layer in α - and β -directions, respectively	N/m^2	lbf/in^2
$G_{\alpha\beta k}$	shear stiffness of k th layer in (α, β) directions	N/m^2	lbf/in^2
H	transverse (through-the-thickness) shear stiffness matrix (see Equation (1.3))	N/m	lbf/in
H_{11}, H_{22}	transverse (through-the-thickness) shear stiffness with respect to xz - and yz -planes, respectively (elements of H)	N/m	lbf/in
H_{12}, H_{21}	coupling transverse (through-the-thickness) shear stiffnesses with respect to xz - and yz -planes (elements of H)	N/m	lbf/in
K	$\begin{bmatrix} -\partial^2 w / \partial x^2 \\ -\partial^2 w / \partial y^2 \\ -2\partial^2 w / \partial x \partial y \end{bmatrix}$ column sub-matrix of curvatures of plate (see Section 1.3.1)	m^{-1}	in^{-1}
k	layer reference number (also used as a suffix)		
l_{ij}	amplitude of wave component in buckled plate (see Table 1.1)	m	in
M	$\begin{bmatrix} M_x \\ M_y \\ M_{xy} \end{bmatrix}$ column sub-matrix of bending moment intensities acting in xz - and yz -planes and twisting moment intensities acting about x - and y -axes, respectively (see Section 1.3.1)	N m/m	lbf in/in
m, n	number of half waves in x - and y -directions, respectively, into which plate buckles		

N	$\begin{bmatrix} N_x \\ N_y \\ N_{xy} \end{bmatrix}$	column sub-matrix of direct load intensities and shear load intensity acting in neutral plane of plate, referred to (x, y) coordinates (see Section 1.3.1)	N/m	lbf/in
(an additional suffix <i>b</i> indicates load at buckling)				
Q	$\begin{bmatrix} Q_x \\ Q_y \end{bmatrix}$	column matrix of through-the-thickness shear forces	N/m	lbf/in
Q_x, Q_y		transverse (through-the-thickness) shear forces per unit length acting on yz- and xz-planes respectively	N/m	lbf/in
t		plate thickness (isotropic plates)	m	in
t_k		thickness of <i>k</i> th layer	m	in
w		normal deflection of plate, positive in z-direction	m	in
x, y, z		plate coordinate system (see Sketch 1.1) (plane <i>xy</i> is neutral plane of plate)		
α, β		layer coordinates aligned with principal axes of orthotropy of layer (see Sketch 1.1)		
ϵ	$\begin{bmatrix} \epsilon_x \\ \epsilon_y \\ \epsilon_{xy} \end{bmatrix}$	column sub-matrix of direct strains and shear strain acting in neutral plane of plate referred to (x, y) coordinates (see Section 1.3.1)		
γ	$\begin{bmatrix} \gamma_{xz} \\ \gamma_{yz} \end{bmatrix}$	column matrix of through-the-thickness shear strains (see Equation (1.3))		
γ_{xz}, γ_{yz}		transverse through-the-thickness shear strains in xz- and yz-planes, respectively		
ψ_k		angle of principal axis of orthotropy, α , of <i>k</i> th layer measured from plate reference axis <i>x</i> (see Sketch 1.1)	deg	deg
ν		Poisson's ratio (for isotropic materials)		
$\nu_{\alpha\beta k}$		Poisson's ratio for <i>k</i> th layer referred to layer (α, β) coordinates		

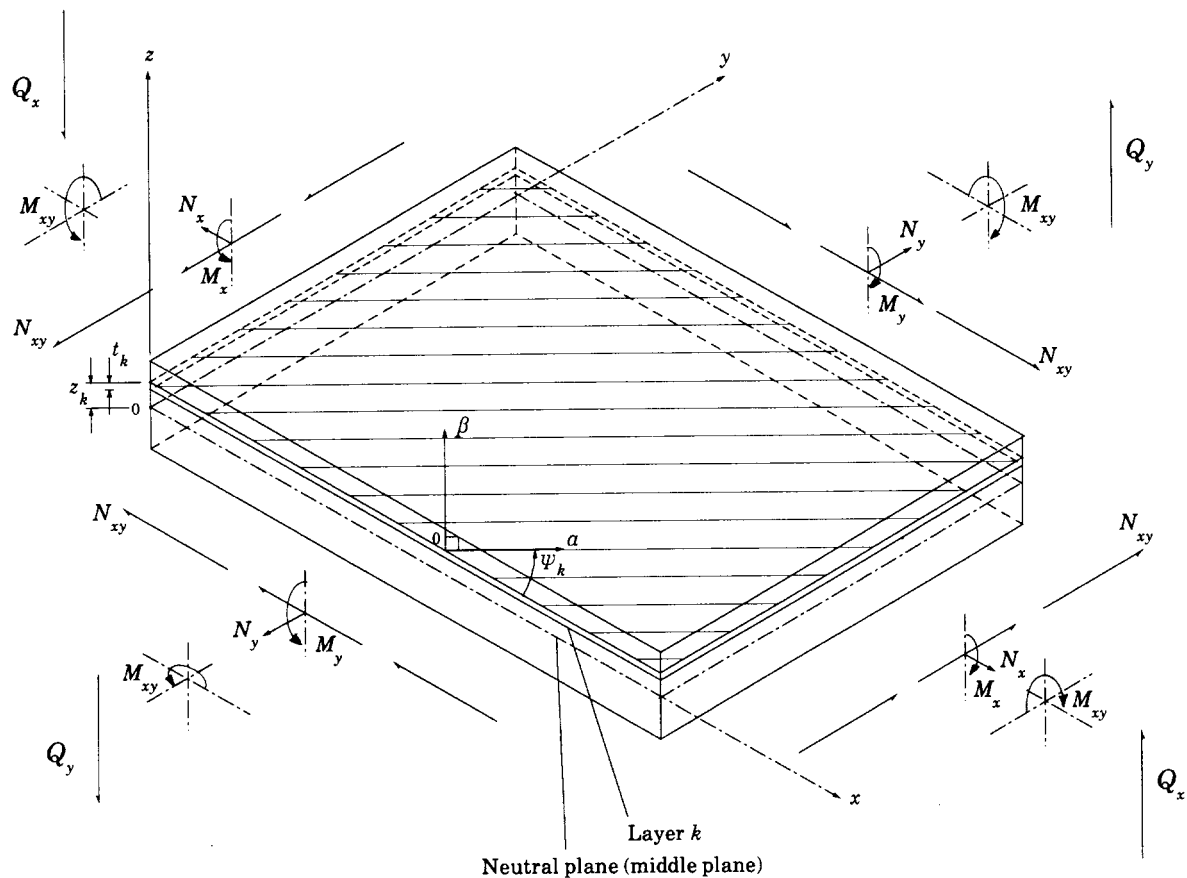
1.2.1 Suffixes

b added to N_x , N_y or N_{xy} to indicate value at buckling

1.2.2 Sign Convention

Tensile loads are positive, compressive loads are negative.

Shear loads may be positive or negative (see Sections 1.3 and 2.3).



Sketch 1.1 Sign convention for forces and moments

1.3 Theoretical Basis of the Program of ESDUpac A8147

The solution used is that of Derivation 1. This is based upon elastic small deflection theory in which the plate is assumed to be made of a homogeneous orthotropic material whose principal axes of orthotropy are aligned with the edges of the plate (axes x, y). The theory summarised below takes account of the flexural and twisting deformations, as governed by the **D** sub-matrix, and also takes account of the through-the-thickness shear deformations as governed by the **H** matrix.

1.3.1 Plate stiffness relationships

For a homogeneous orthotropic plate the following in-plane and flexural stiffness matrix applies.

$$\begin{bmatrix} \mathbf{N} \\ \mathbf{M} \end{bmatrix} = \begin{bmatrix} \mathbf{A} & \mathbf{B} \\ \mathbf{B} & \mathbf{D} \end{bmatrix} \begin{bmatrix} \boldsymbol{\varepsilon} \\ \mathbf{K} \end{bmatrix}. \quad (1.1)$$

For the case of special orthotropy where the principal axes of orthotropy are aligned with the plate edges Equation (1.1) takes the following form.

$$\begin{bmatrix} N_x \\ N_y \\ N_{xy} \\ M_x \\ M_y \\ M_{xy} \end{bmatrix} = \begin{bmatrix} A_{11} & A_{12} & 0 & 0 & 0 & 0 \\ & A_{22} & 0 & 0 & 0 & 0 \\ & & A_{33} & 0 & 0 & 0 \\ - & - & - & D_{11} & D_{12} & 0 \\ & & & & D_{22} & 0 \\ & & \text{Symmetric} & & & D_{33} \end{bmatrix} \begin{bmatrix} \varepsilon_x \\ \varepsilon_y \\ \varepsilon_{xy} \\ -\partial^2 w / \partial x^2 \\ -\partial^2 w / \partial y^2 \\ -2\partial^2 w / \partial x \partial y \end{bmatrix}. \quad (1.2)$$

Thus, specially orthotropic plates satisfy the following three conditions.

- (i) The in-plane stiffness sub-matrix **A** is orthotropic with direct and shear stiffnesses uncoupled so that A_{13} and A_{23} are zero.
- (ii) The flexural stiffness sub-matrix **D** is orthotropic with the bending and twisting terms uncoupled so that D_{13} and D_{23} are zero.
- (iii) The in-plane and flexural stiffness sub-matrices are uncoupled, that is **B** = 0.

In addition to the conditions of special orthotropy the following through-the-thickness shear stiffness matrix is taken to apply.

$$\mathbf{Q} = \mathbf{H}\boldsymbol{\gamma} \quad (1.3)$$

$$\begin{bmatrix} Q_x \\ Q_y \end{bmatrix} = \begin{bmatrix} H_{11} & 0 \\ 0 & H_{22} \end{bmatrix} \begin{bmatrix} \gamma_{xz} \\ \gamma_{yz} \end{bmatrix}. \quad (1.4)$$

Thus, the shear stiffnesses in the xz - and yz -planes are assumed to be uncoupled, that is, $H_{12} = H_{21} = 0$.

1.3.2 Equations governing buckling

The analysis of the plate assumes that all loads are applied to the neutral plane of the plate. Because of this, and because of the lack of coupling in specially orthotropic plates and the form assumed for the through-the-thickness shear stiffnesses, bifurcational buckling occurs. Thus, the sign (direction) given to applied in-plane shear loading is unimportant.

For plates defined by Equations (1.2) and (1.4) the curvatures and twists may be expressed as follows. (Note that here w relates to the total deflection, including shear, whereas in Equation (1.2) w relates to bending only.)

$$\frac{\partial^2 w}{\partial x^2} = -\frac{D_{22}M_x}{\bar{D}} + \frac{D_{12}M_y}{\bar{D}} + \frac{1}{H_{11}} \frac{\partial Q_x}{\partial x}, \quad (1.5)$$

$$\frac{\partial^2 w}{\partial y^2} = \frac{D_{12}M_x}{\bar{D}} - \frac{D_{11}M_y}{\bar{D}} + \frac{1}{H_{22}} \frac{\partial Q_y}{\partial y} \quad (1.6)$$

$$\text{and} \quad \frac{\partial^2 w}{\partial x \partial y} = \frac{M_{xy}}{2D_{33}} + \frac{1}{2H_{11}} \frac{\partial Q_x}{\partial y} + \frac{1}{2H_{22}} \frac{\partial Q_y}{\partial x}. \quad (1.7)$$

From the equilibrium of normal forces

$$\frac{\partial^2 M_x}{\partial x^2} - \frac{2\partial^2 M_{xy}}{\partial x \partial y} + \frac{\partial^2 M_y}{\partial y^2} = -\left(N_x \frac{\partial^2 w}{\partial x^2} + N_y \frac{\partial^2 w}{\partial y^2} + 2N_{xy} \frac{\partial^2 w}{\partial x \partial y}\right) \quad (1.8)$$

and from the equilibrium of moments about the y - and x -axes,

$$Q_x = -\frac{\partial M_{xy}}{\partial y} + \frac{\partial M_x}{\partial x} \quad (1.9)$$

$$\text{and} \quad Q_y = -\frac{\partial M_{xy}}{\partial x} + \frac{\partial M_y}{\partial y}. \quad (1.10)$$

Equations (1.5) to (1.10) can be reduced to the following three equations by eliminating the bending and twisting moments.

$$\left. \begin{aligned} (2D_{33} + D_{12})\partial^3 w / \partial x \partial y^2 + D_{11}\partial^3 w / \partial x^3 + Q_x \\ = (D_{11}/H_{11})\partial^2 Q_x / \partial x^2 + (1/H_{22})(D_{33} + D_{12})\partial^2 Q_y / \partial x \partial y + (D_{33}/H_{11})\partial^2 Q_x / \partial y^2, \\ (2D_{33} + D_{12})\partial^3 w / \partial x^2 \partial y + D_{22}\partial^3 w / \partial y^3 + Q_y \\ = (D_{22}/H_{22})\partial^2 Q_y / \partial y^2 + (1/H_{11})(D_{33} + D_{12})\partial^2 Q_x / \partial x \partial y + (D_{33}H_{22})\partial^2 Q_y / \partial x^2 \\ \text{and} \quad \partial Q_x / \partial x + \partial Q_y / \partial y = -(N_x \partial^2 w / \partial x^2 + N_y \partial^2 w / \partial y^2 + 2N_{xy} \partial^2 w / \partial x \partial y). \end{aligned} \right\} \quad (1.11)$$

The boundary conditions are as follows.

(a) No deflection of any edge normal to the plate in the z -direction, that is, $w = 0$,

and

(b) either the shear strain along the line of support is zero, that is $Q_y/H_{22} = 0$ for edges at $x = 0$ and $x = a$ that are parallel to the y -direction and $Q_x/H_{11} = 0$ for edges parallel to the x -direction at $y = 0$ and $y = b$,

or the support is applied only to the middle surface and $M_{xy} = 0$

and

(c) for simple-support conditions

no bending moment acting about the line of support

$$M_x = 0 \text{ at } x = 0 \text{ and } x = a$$

$$\text{and } M_y = 0 \text{ at } y = 0 \text{ and } y = b,$$

or, for clamped conditions,

no rotation of the normals to the plate at the boundaries so that

$$\frac{\partial w}{\partial x} = \frac{Q_x}{H_{11}} \text{ at } x = 0 \text{ and } x = a$$

$$\text{and } \frac{\partial w}{\partial y} = \frac{Q_y}{H_{22}} \text{ at } y = 0 \text{ and } y = b$$

TABLE 1.1 Buckled waveforms

Buckled waveform	<i>m and n</i>	
	<i>6 × 6 series</i>	<i>5 × 5 series</i>
All edges simply-supported $\sum_{i=1}^m \sum_{j=1}^n l_{ij} \sin \frac{i\pi x}{a} \sin \frac{j\pi y}{b}$ <i>i = 1 j = 1</i>	<i>m = 6 n = 6</i>	<i>m = 5 n = 5</i>
Edges parallel to x -axis clamped, edges parallel to y -axis simply-supported $\sum_{i=1}^m \sum_{j=2}^n l_{ij} \sin \frac{i\pi x}{a} \left[\cos \frac{(j-2)\pi y}{b} - \cos \frac{j\pi y}{b} \right]$ <i>i = 1 j = 2</i>	<i>m = 6 n = 7</i>	<i>m = 5 n = 6</i>
Edges parallel to x -axis simply-supported, edges parallel to y -axis clamped $\sum_{i=2}^m \sum_{j=1}^n l_{ij} \left[\cos \frac{(i-2)\pi x}{a} - \cos \frac{i\pi x}{a} \right] \sin \frac{j\pi y}{b}$ <i>i = 2 j = 1</i>	<i>m = 7 n = 6</i>	<i>m = 6 n = 5</i>
All edges clamped $\sum_{i=2}^m \sum_{j=2}^n l_{ij} \left[\cos \frac{(i-2)\pi x}{a} - \cos \frac{i\pi x}{a} \right] \left[\cos \frac{(j-2)\pi y}{b} - \cos \frac{j\pi y}{b} \right]$ <i>i = 2 j = 2</i>	<i>m = 7 n = 7</i>	<i>m = 6 n = 6</i>

The panel buckling load is found by obtaining an approximate solution for Equations (1.11) by using the expressions for the deflected shapes of the plate set out in Table 1.1. In order to show whether or not a sufficient number of terms exists in the 6×6 term series of Table 1.1 to give the required buckling load, the calculation is repeated and the result is output for the same series curtailed at m and n reduced by one, that is, using the 5×5 series as shown in Table 1.1. If the differences between these two sets of buckling loads are small then the value of m or n for the given buckling load is within the range examined and the solution is valid.

1.4 Application of the Program of ESDUpac A8147

1.4.1 Application to isotropic plates

The program relates strictly to specially orthotropic plates of which isotropic plates are a sub-set. The program may therefore be applied directly to isotropic plates and a facility for this is included in the input. The program takes account of the plate through-the-thickness shear stiffness and this is calculated by the program from the given values of E , ν and t using the relationship

$$H_{11} = H_{22} = Et/\{2(1 + \nu)\}. \quad (1.12)$$

The influence of the through-the-thickness shear stiffness on the buckling of practical metallic plates is usually small. Thus, for normal metallic plates the program provides solutions that agree with those in Data Items Nos 72019*, Struct 02.04.01† and 71005‡ on the buckling of flat metallic plates. Note that Data Item Nos 72019 and 71005 include methods of correcting elastic buckling loads for material plasticity and that these corrections may be applied to buckling loads obtained from the program.

1.4.2 Application to homogeneous orthotropic plates

The program is applicable to homogeneous orthotropic plates provided that the principal axes of orthotropy are parallel to the plate axes. For these plates the value of the through-the-thickness shear stiffnesses H_{11} and H_{22} are likely to differ. The program takes account of these stiffnesses and the values of H_{11} and H_{22} are required in the input. They are a function of the plate material and thickness and may be estimated from the usually known material properties or obtained by experiment.

As illustrated in Sketch 1.2, by independently increasing the through-the-thickness shear stiffnesses eventually values are reached beyond which the buckling load remains unaltered. At these high shear stiffness values buckling is governed by the flexural stiffnesses alone. If such large values of H_{11} and H_{22} are introduced the program will provide solutions that agree with those in Data Item No. 80023** on the buckling of orthotropic plates in which shear stiffnesses are taken to be infinite.

1.4.3 Application to laminated (fibre reinforced) composite plates

The program provides for the input of the orthotropic in-plane properties of layered plates of up to 500 layers. The principal axes of orthotropy of the layers may be at any angle to the plate axes. The program calculates the **A**, **B** and **D** stiffness matrices for the plate (in the plate axes) using the middle plane of the plate and the equations set out in Data Item No. 94003††. If the arrangement of the layers is such as to produce a specially orthotropic plate then the program is applicable. A statement that special orthotropy applies is output and the computation is carried out.

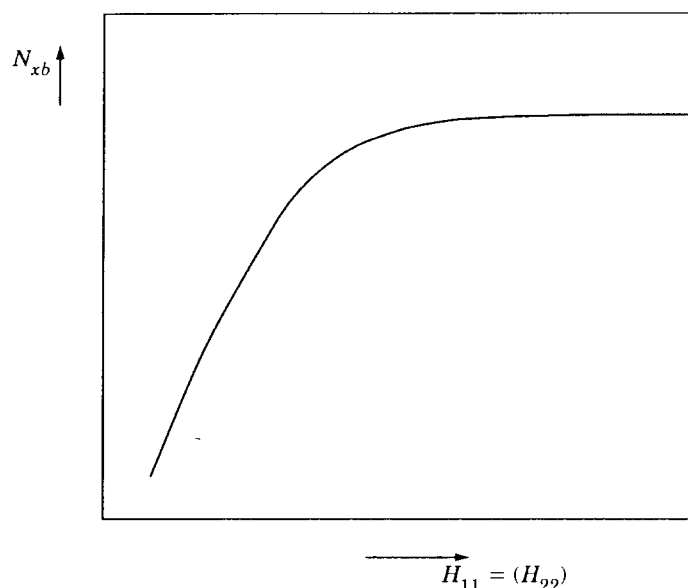
* Data Item No. 72019 "Buckling of flat isotropic plates under uniaxial and biaxial loading".

† Data Item No. Struct., 02.04.01 "Buckling stress ratios for plates under uniform compression and shear".

‡ Data Item No. 71005 "Buckling of flat plates in shear".

** Data Item No. 80023 "Buckling of rectangular specially orthotropic plates".

†† Data Item No. 94003 "Stiffnesses of laminated flat plates".



Sketch 1.2 Effect of through-the-thickness shear stiffness on buckling load

The through-the-thickness shear stiffnesses H_{11} and H_{22} may be calculated using ESDUpac A8913 which accompanies Data Item No. 89013^{*}. (The program of ESDUpac A8913 can be found on the Compact Disc and on disk in the Software Volume.)

If the **A**, **B** and **D** stiffness matrices show that the plate is not specially orthotropic then the program prints out a statement to this effect immediately following the stiffness matrices. The buckling loads are calculated and each buckling load is accompanied by a warning, see Section 2.4.2.

Note that Data Item No. 94006[†] deals with a particular class of unbalanced orthotropic plates and Section 1.4.1 of that Item gives a general description of the behaviour of unbalanced plates. Data Item No. 94006 should therefore be consulted if the plate is not specially orthotropic.

1.4.4 Application to sandwich panels

The program is applicable to sandwich panels having isotropic or orthotropic face plates and cores. Orthotropic face plates may be composed of laminated fibre reinforced composite. The program treats the sandwich as a laminated plate and the notes of Section 1.4.3 apply. Note that the program accompanying Data Item No. 94005[‡] is also applicable to sandwich panels and uses the notation of the Data Items on sandwich panels and may therefore be more convenient to use where that notation is preferred.

The through-the-thickness shear stiffnesses H_{11} and H_{22} are usually governed by the core. Data Item Nos. Struct 07.03.01^{**} and 67022^{††} give methods of calculating these stiffnesses for corrugated cores and hexagonal cell (honeycomb) cores respectively. Data Item No. 66025^{‡‡} indicates an experimental method for determining these stiffnesses for a sandwich complete with face plates. (Note that these Data Items use

^{*} Data Item No. 89013 "Transverse (through-the-thickness) shear stiffnesses of fibre reinforced composite laminated plates".

[†] Data Item No. 94006 "Elastic buckling of unbalanced laminated fibre reinforced composite plates. (Rectangular plates of AsBtDs type, all edges simply-supported under biaxial loading.)"

[‡] Data Item No. 94005 "Buckling of flat rectangular orthotropic plates."

^{**} Data Item No. Struct 07.03.01 "Sandwich panels with corrugated core and equal face plates. Transverse shear stiffness."

^{††} Data Item No. 67022 "Modulus of rigidity of sandwich panels with hexagonal cell cores".

^{‡‡} Data Item No. 66025 "Experimental determination of the shear and flexural stiffnesses of a sandwich panel".

the symbols D_{qx} and D_{qy} to represent the shear stiffnesses and that $D_{qx} = H_{11}$ and $D_{qy} = H_{22}$.)

When the sandwich stiffnesses calculated about the middle plane of the plate are not specially orthotropic, a note to this effect is output. The buckling loads are computed and are accompanied by a warning (see Section 2.4.2). In certain sandwich constructions there is a neutral plane, which is not the middle plane, about which the plate is specially orthotropic. Sandwiches with unequal thickness isotropic face plates and cores of negligible flexural stiffness are an example. Their neutral plane may be found by application of Equation (6.3) of Data Item No. 94003 using the computed B_{ij} and A_{ij} to calculate its distance from the middle plane. The elements of **D** are then calculated using Equation (6.2) of Data Item No. 94003 and can be input directly into the program as orthotropic plate properties (see Section 1.4.2) and the buckling loads computed.

Note that sandwich panels are subject to wrinkling or to various forms of local buckling that are not covered by this Data Item. Data Items dealing with other modes of buckling are available and may be located by means of the ESDU Index.

1.4.5 Accuracy of buckling loads calculated by the program

This Data Item provides a program based upon a mathematical model that can be used to describe the behaviour in respect of buckling of an orthotropic plate. The solutions provided for orthotropic and isotropic plates agree with other available analyses. The results for isotropic plates have been shown to give satisfactory agreement with experiment and, where the assumptions of the theory are valid, errors are typically within about ± 5 per cent.

For orthotropic plates, and more particularly for laminated plates and sandwich panels, calculated buckling loads depend on a large number of independent variables. Test data that can be used to verify the accuracy of the model are only available for a few particular cases. Sufficient data with which to verify the model over its complete range are highly unlikely to become available in the foreseeable future. The model is based upon well known principles of elastic behaviour that have been employed successfully in many models of structural elements and components. This is illustrated by the agreement, noted above, for isotropic plates and which may be assumed to give an indication of the accuracy when applying the model to properly designed, structural, laminated composites or sandwich panels employing current materials. However, because of the lack of comprehensive test data, consideration should be given to testing the structure.

1.5 Derivation

This section lists selected sources that have assisted in the preparation of this Item.

1. BRUCE, J. The buckling and bending of orthotropic sandwich panels in compression and shear. Unpublished work at Handley Page Ltd, 1956.
2. BOWDLER, H.J. Solution of real and complex systems of linear equations. *Numerische Mathematik* 8, pp 217-234, 1966.

2. ESDUpac A8147

2.1 Introduction

ESDUpac A8147 contains a Fortran computer program that accepts the properties of an isotropic or orthotropic plate or the layer properties of a laminate or sandwich panel, the plate edge conditions and geometry, and the applied loading and calculates the loading at buckling. Section 2.2 gives the scope and limitations of the program, Section 2.3 details the input requirements and Section 2.4 gives an explanation of the output, including all messages. Section 2.5 provides a selection of examples that illustrate the use of the program.

This Data Item relates to Version 4.0 of ESDUpac A8147V40 and FORTRAN program A8147V40.FOR. Both the ESDUpac number and the program number contain the version number, encoded in the three characters V40. Throughout this Data Item the ESDUpac and its program are referred to by the number A8147 and the current version number is taken to apply. Note that the Contents to the Sub-series Software Volume states the current version number.

The program is available in two formats: (a) a Fortran source code with example input and output files, and (b) an executable program for PC's. Both versions can be found on the Compact Disc and on disk in the Software Volume. Information on how to install and run the Fortran program is contained in "Introduction to ESDUpacs" in the Sub-series Software Volume.

The basis of the Fortran computer program of ESDUpac A8147V10 is described in Section 1 of this Data Item. Every reasonable effort has been made to ensure that the program performs the intended calculation satisfactorily. No representation as to the suitability or fitness of the program for any particular purpose is made and no liability for any loss occasioned by any persons as a direct or indirect result of use of the program whether arising from negligence or otherwise can be accepted. In no event shall ESDU or any individuals associated with the development of the program be liable for any damages, including loss of profit or consequential loss, arising out of or in connection with the program.

2.2 Program Scope and Limitations

The program can deal with any combination of the following.

- (i) Specially orthotropic plates in which the principal axes of orthotropy are parallel to sides of the plate. See Section 1.4 for application to various types of plate construction.
- (ii) Buckling under the following in-plane loading combinations.
 - (a) Uniaxial direct loading.
 - (b) Shear loading.
 - (c) Biaxial direct loading with one loading fixed.
 - (d) Uniaxial direct and shear loading with one of these loadings fixed.
 - (e) Biaxial direct and shear loading with two of these loadings fixed.
 - (f) Biaxial direct loading with loadings in a specified ratio.
 - (g) Uniaxial direct and shear loading with loadings in a specified ratio.
 - (h) Biaxial direct and shear loading with loadings in a specified ratio.

Applied direct loading may be tensile (positive) or compressive (negative). Shear loading may be positive or negative. In Cases (c), (d), or (e) if the loadings supplied would cause the plate to buckle prior to the application of another load the program will indicate this. Loadings that are required to stabilise a buckled plate are not calculated.