

Local buckling and crippling of rectangular tube section struts

Associated software: ESDUpac S1119

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Mr P. Stocking	— Cranfield Aerospace Ltd
Mr J.H. van der Sloot	— Independent
Mr K. van Katwijk*	— European Space Agency, Noordwijk, The Netherlands.
* Corresponding Member	

The construction and subsequent development of the Data Item was undertaken, under contract to ESDU, by

Mr J.H. van der Sloot.

The person with overall responsibility for the work in this subject area is Mr A.C. Quilter, Head of Strength Analysis Group.

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INTRODUCTION

This Data Item provides means of estimating the elasto-plastic local buckling stress and crippling stress for rectangular tubes.

The Data Item is provided in three main sections.

Section 1 effectively constitutes the previous version, that is Issue 1, Amendment A, of the Data Item, which has been retained for convenience and the usefulness of Figure 1 in providing information on the sensitivity of the buckling coefficient to changes in geometric parameters.

Section 2 describes the theory on which the program accompanying the Item is based and its application. The program is provided as a means for computing the local buckling stresses of rectangular tubes with a wide variety of geometries and material properties, without having to consult other Data Items or figures. The program allows for plasticity in a more sophisticated manner than the method of Section 1 and also uses alternative expressions, Equations (2.1a) and (2.1b), to estimate the crippling stress.

Section 3 describes the use of the program, its input, output and messages. An example of the use of the program is also included.

It is emphasized here that the main difference between the method presented in Section 1 to estimate buckling and crippling stresses and that presented in Section 2 (and used by the program) is in the treatment of plasticity as it develops in the cross-section of the tube; for a value of Poisson's ratio of 0.3 and for the range of geometries represented in Figure 1, *elastic* buckling stresses obtained via Figure 1, which tends to give slightly conservative values, are within 5 per cent of those given by the program, see Derivation 7.

1. GRAPHICAL METHOD

1.1 Notation

Both SI and British units are quoted but any coherent system of units may be used. Additional notation used in Sections 2 and 3 of the Item is defined in Section 2.2.

d	width of short side of tube cross-section (see sketch on Figure 1)	m	in
E	Young's modulus of strut material	N/m ²	lbf/in ²
E_t	tangent modulus	N/m ²	lbf/in ²
f_b	'modified' stress at onset of local buckling, defined by $f_b = KE_t \left(\frac{t_h}{h} \right)^2$	N/m ²	lbf/in ²
f_c	crippling stress, according to Equation (1.1)	N/m ²	lbf/in ²

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f_p	0.2 per cent compressive proof stress of strut material	N/m ²	lbf/in ²
h	width of long side of tube cross-section (see sketch on Figure 1)	m	in
K	buckling stress coefficient as in $f_b = KE \left(\frac{t_h}{h} \right)^2$		
t_d	thickness of short side of tube cross-section (see sketch on Figure 1)	m	in
t_h	thickness of long side of tube cross-section (see sketch on Figure 1)	m	in

Sign Convention: compressive stresses are positive; tensile stresses are negative.

1.2 Notes and Theory

In Figure 1, the coefficient K is plotted against the ratio d/h for various values of t_d/t_h .

The figure is divided into two regions by a dotted line. For points above the dotted line, the long side is primarily responsible for the instability and requires some restraint from the short side in order to delay buckling until that load is reached for which the cross-section as a whole becomes unstable; the half-wavelength of the buckle will be comparable with h . For points below the dotted line the short side is primarily responsible for the instability; in this case the half-wavelength will be comparable with d .

The onset of local buckling results in a reduction of stiffness which is usually of the order of 50 per cent for this type of section. If the crippling stress is appreciably greater than the buckling stress, then the reduction of stiffness may be greater and should be taken into consideration for overall flexural failure.

After local buckling the section may continue to carry more load before crippling finally occurs. The crippling stress is given by the expression

$$f_c = (f_p f_b)^{1/2} \quad (1.1)$$

Equation (1.1) is a form of the well-known crippling stress formula proposed by von Kármán *et al.*, see Derivation 3 of Section 2.5.

It should be noted that in all instances the liability of the strut to flexural instability must be examined separately.

An example of the use of Figure 1 and Equation (1.1) is given in Section 1.4 where a correction to the buckling stress to allow for plasticity is made using the factor E/E_0 .

1.3 Derivation

This section lists selected sources that have assisted in the preparation of Section 1 of the Data Item. Sources that have assisted in the preparation of Section 2 of the Data Item are listed there.

1. SECHLER, E.E. The ultimate strength of thin flat sheets in compression. California Institute of Technology, Publication No. 27, 1933.
2. KROLL, W.D.
FISHER, G.P.
HEIMERL, G.J. Charts for calculation of the critical stress for local instability of columns with I, Z, channel and rectangular-tube section. NACA ARR 3K04, 1943.

1.4 Example 1

This section gives an example of the use of Figure 1 and Equation (1.1) to investigate the local buckling and crippling of a rectangular tube section strut. An example of using ESDUpac S1119 for the same problem is given in Section 3.5, where the crippling stresses from both Equations (1.1) and (2.1a) and (2.1b) are given in the output file.

The strut has the following dimensions:

$$t_d = t_h = 0.036 \text{ in, } d = 0.8 \text{ in, } h = 1.0 \text{ in;}$$

and the strut material has the following properties:

$$\begin{aligned} \text{Young's modulus, } E &= 10.7 \times 10^6 \text{ lbf/in}^2, \\ \text{the 0.5 per cent proof stress} &= 48\,700 \text{ lbf/in}^2, \text{ and} \\ \text{the 0.2 per cent proof stress} &= 45\,000 \text{ lbf/in}^2. \end{aligned}$$

It follows that $d/h = 0.8$, $t_d/t_h = 1.0$ and, from Figure 1, $K = 4.18$.

$$\text{Therefore } \frac{f_b}{E_t} = 4.18 \times \left(\frac{0.036}{1.0} \right)^2 = 0.005\,42.$$

Now, using Data Item No. 76016* (and the notation of that Item),

$$\begin{aligned} \epsilon_R &= 0.005, & f_R &= 48\,700 \text{ lbf/in}^2, \\ \epsilon_R' &= 0.002, & f_R' &= 45\,000 \text{ lbf/in}^2, \\ \epsilon_R/\epsilon_R' &= 2.5 & \text{and } f_R/f_R' &= 1.082, \end{aligned}$$

and thus, from Figure 5 of Item No. 76016, $m = 11.5$ so that

$$\frac{m \epsilon_R E}{f_R} = 12.6.$$

* Data Item No. 76016 "Generalisation of smooth continuous stress-strain curves for metallic materials".

Hence, from Figure 6 of Item No. 76016,

$$f_n/f_R = 0.786$$

and $f_n = 38\,300 \text{ lbf/in}^2$

giving $\frac{f_b E}{E_t f_n} = 1.515.$

So that, from Item No. 76016,

$$f_b/f_n = 0.95,$$

$$f_b = 0.95 \times 38\,300 = 36\,400 \text{ lbf/in}^2$$

and $f_c = (45\,000 \times 36\,400)^{1/2} = 40\,500 \text{ lbf/in}^2.$

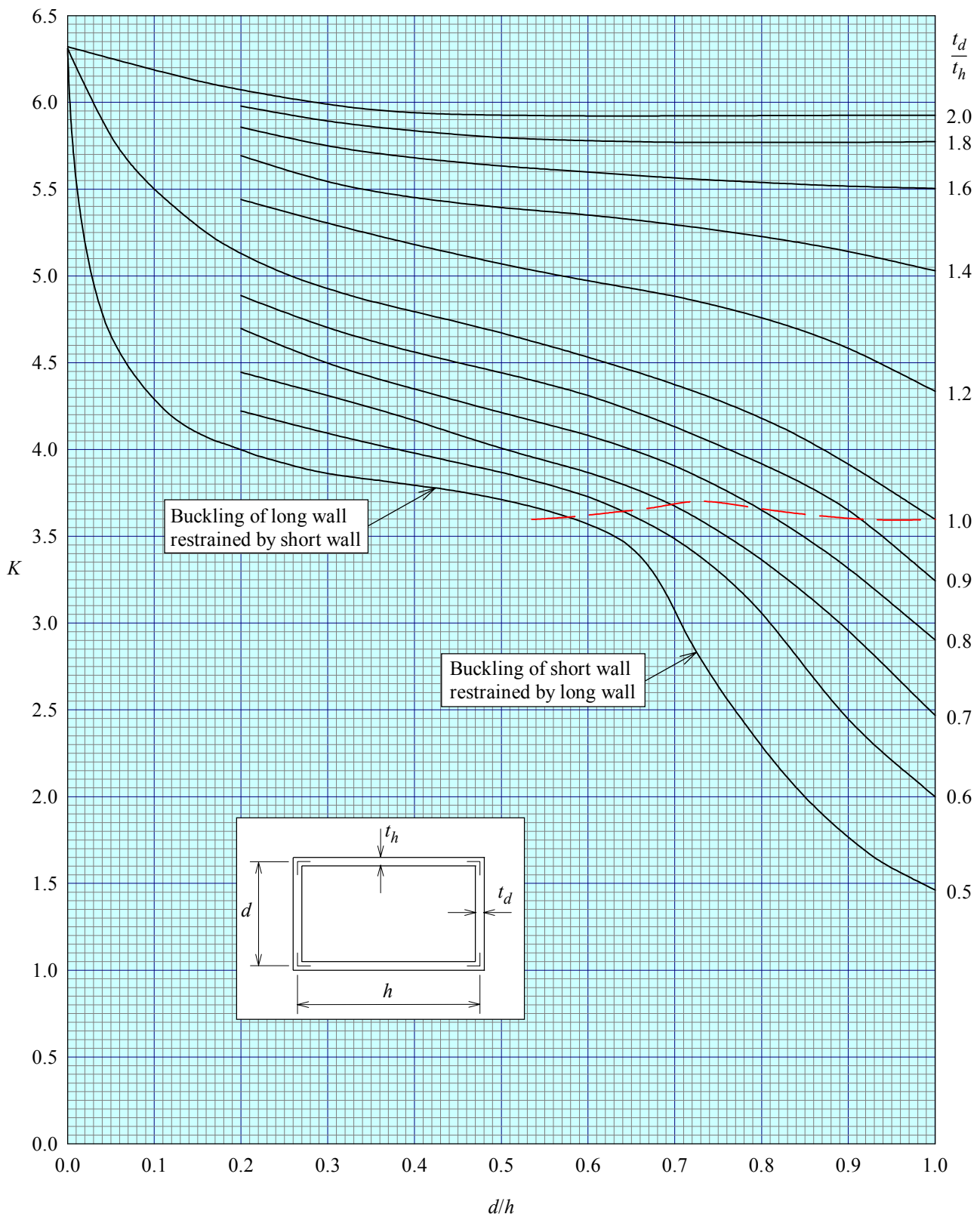


FIGURE 1