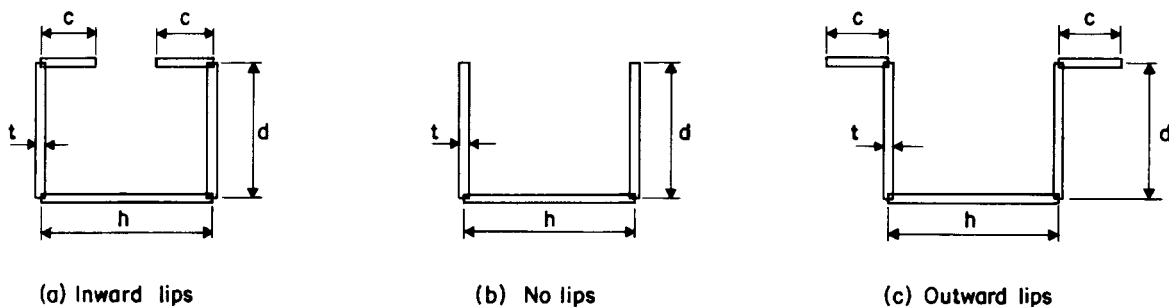


BUCKLING OF STRUTS. LIPPED AND UNLIPPED CHANNEL SECTIONS

1. NOTATION

c	width of lips (see Sketch 1.1)	m	in
d	width of flanges (see Sketch 1.1)	m	in
E	modulus of elasticity of strut material	N/m ²	lbf/in ²
E_T	tangent modulus of strut material	N/m ²	lbf/in ²
f_b	buckling stress at half-wavelength λ	N/m ²	lbf/in ²
f_{be}	elastic buckling stress at half-wavelength λ	N/m ²	lbf/in ²
f_n	stress at which $E_T = \frac{1}{2}E$	N/m ²	lbf/in ²
h	width of web (see Sketch 1.1)	m	in
m	material characteristic for strut material (see Item No.76016)		
t	thickness of strut (see Sketch 1.1)	m	in
η	plasticity reduction factor defined by $f_b = \eta f_{be}$		
λ	half-wavelength of buckle	m	in
ν	Poisson's ratio for strut material		

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

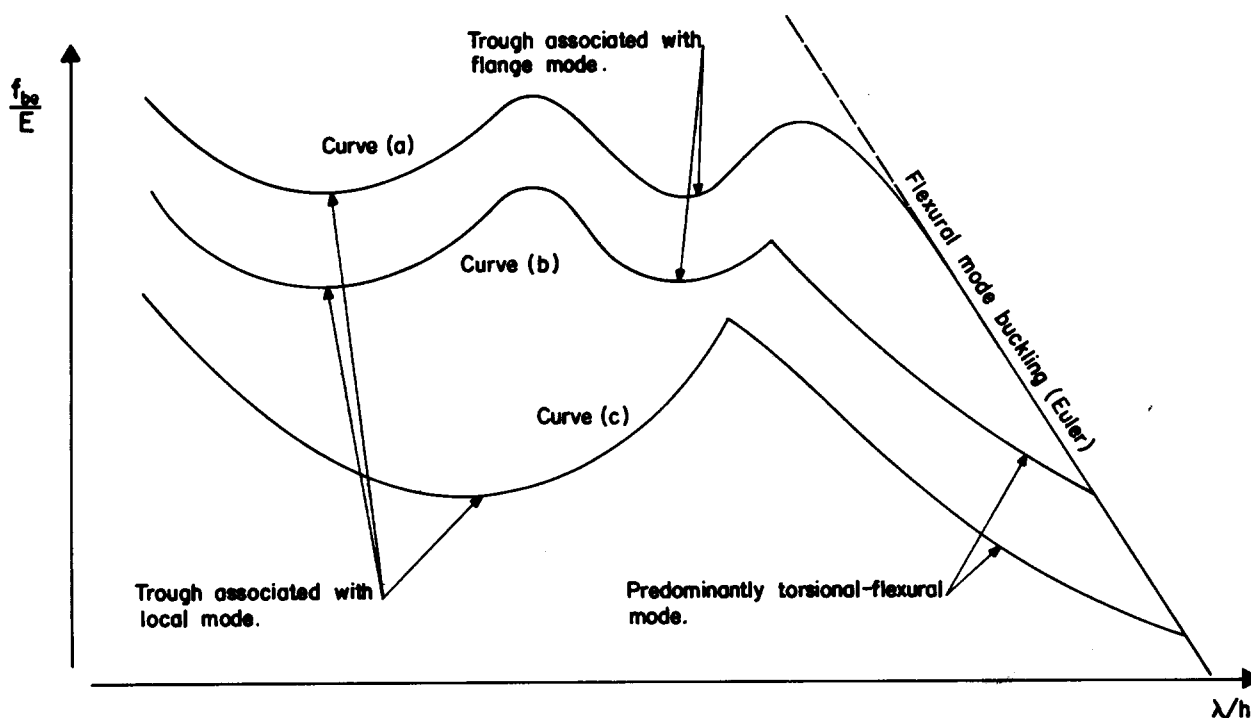


Sketch 1.1

2. NOTES

This Item provides charts that relate the compressive stress at buckling to the associated half-wavelength for lipped and unlipped channel section struts of isotropic material as shown in Sketch 1.1. The data include the effects of translation, rotation and distortion of the strut cross section and cover the practical range of flange and lip proportions and buckle half-wavelengths. Curves giving material plasticity correction factors are also provided.

The charts give the elastic buckling stress, f_{be} , for infinitely long struts which buckle sinusoidally along their length with a half-wavelength λ . Figures 1 to 5 deal with channels without lips. Figures 6 to 15 deal with lipped channels, the left hand set of curves being for channels with inward facing lips and the right hand set for channels with outward facing lips. At low values of λ/h the curves for channels with outward facing lips are identical to those with inward lips (see the note on the charts and the associated scale change). Sketch 2.1 illustrates three typical curves from the charts. The portions of the curves dominated by the basic buckling modes described in Item No. 78021 "Guide to Items on strength and stability of struts" are indicated on the sketch. It should be noted that the four basic modes indicated relate only to the predominant form of deformation and that interaction effects with other modes are included in the data. The basic local, flange and flexural buckling modes of deformation are symmetric in form but the torsional-flexural mode is antisymmetric in form. Because of this, discontinuities in the slope of the curves are usual at the value of λ/h where the change from an antisymmetric to symmetric mode occurs, as shown by curves (b) and (c) on Sketch 2.1. The unlipped channel, see curve (c) of Sketch 2.1, shows only one trough because, for this section, local and flange buckling are one and the same. In some sections, notably struts with outward facing lips, torsional-flexural buckling occurs at a low value of λ thus eliminating flange buckling.



Sketch 2.1

In practice λ may be assumed to be an integral sub-multiple of the strut length. Local and flange type buckles are of short half-wavelength and therefore are unlikely to be influenced significantly by constraints acting at the ends of the strut. They may therefore be determined by inspection by simply locating the lowest trough of the appropriate curve. Torsional-flexural buckling stresses decrease with increasing λ and

therefore for struts whose ends are unrestrained against flexure and warping the critical buckling stress may be taken to occur when λ equals the strut length. If the ends of the strut are fully restrained against flexure and warping λ may be taken to be half the strut length. At the higher values of λ the curves merge with or join the dashed line labelled flexural mode buckling. This is the Euler buckling load for a pin ended strut having no warping restraint. For this mode end restraint effects and strut eccentricity become significant and Item No. Struct 01.01.01 "The strength of struts" should be consulted.

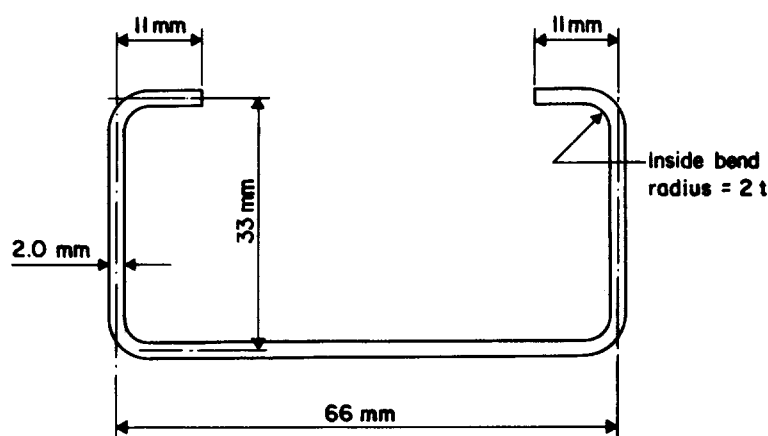
A value of $\nu = 0.3$ has been assumed for calculating the elastic buckling stress associated with λ . It is sufficiently accurate to multiply the buckling stress by $0.91/(1 - \nu^2)$ to obtain values of f_{be} for other values of ν between 0.25 and 0.35. Figure 16 gives values of the plasticity correction factor, η , plotted against f_{be}/f_n for various values of m , which may be used to estimate f_b .

3. DERIVATION

1. GERARD, G.
BECKER, H. Handbook of structural stability. Part I – Buckling of flat plates. NACA tech. Note 3781, October 1954.
2. WITTRICK, W.H. A unified approach to the initial buckling of stiffened panels in compression. *Aeronaut. Q.*, Vol. XIX, Part 3, pp. 265-283, August 1968.
3. WITTRICK, W.H.
WILLIAMS, F.W. Initial buckling of channels in compression. *J. Eng. Mechs Div., Am. Soc. Civil Engrs*, pp. 711-726, June 1971.
4. WILLIAMS, F.W. Initial buckling of lipped channel section struts. *Aeronaut. J.*, Vol. 78, pp. 468-475, October 1974.

4. EXAMPLE

It is required to determine the initial buckling stress of each of two simply-supported lipped channel section struts. Both struts are to be manufactured from the same material and have the cross section shown in Sketch 4.1. One strut is 440 mm long and the other 587 mm. The material properties are $f_n = 260 \text{ MN/m}^2$, $m = 14$, $E = 72\,400 \text{ MN/m}^2$ and $\nu = 0.3$.



Sketch 4.1

From the cross section $\frac{c}{d} = 0.333$, $\frac{t}{h} = 0.030$ and $\frac{d}{h} = 0.5$;

therefore Figures 8 and 13, and for interpolation possibly Figure 3, are appropriate.

For the shorter strut the maximum value of λ is 440 mm which gives

$$\frac{\lambda}{h} = \frac{440}{66} = 6.67.$$

By inspection of the appropriate curves the minimum values of f_{be}/E within the permissible range of $\lambda/h \leq 6.67$ may be tabulated as follows.

Figure	c/d	f_{be}/E	λ/h	Predominant basic mode
3	0	2.35×10^{-3}	1.35	Local
8	1/4	3.65×10^{-3}	3.15	Flange
13	1/2	4.33×10^{-3}	5.40	Flange

Since the buckling mode at $c/d = 0$ is different from that for the other two values it cannot be used with them in the interpolation for a $c/d = 0.333$ value. It therefore becomes necessary to interpolate linearly between the two values for $c/d = 1/4$ and $1/2$. Hence,

$$\frac{f_{be}}{E} = \left\{ \frac{(4.33 - 3.65) \times (0.333 - 0.25)}{(0.5 - 0.25)} + 3.65 \right\} \times 10^{-3} = 3.88 \times 10^{-3}.$$

Thus, $f_{be} = 3.88 \times 10^{-3} \times 72\,400 = 281 \text{ MN/m}^2.$

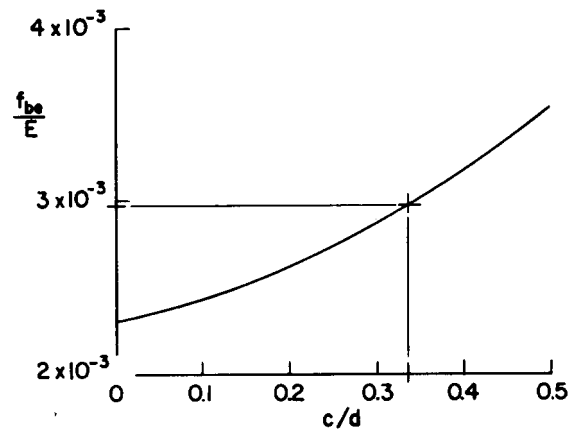
Correcting for material plasticity, using Figure 16 with $m = 14$,

$$\frac{f_{be}}{f_n} = \frac{281}{260} = 1.08$$

giving $\eta = 0.89 = \frac{f_b}{f_{be}}$, so that $f_b = 0.89 \times 281 = 250 \text{ MN/m}^2.$

For the longer strut the maximum permissible value of $\lambda/h = 587/66 = 8.89$. By inspection of the appropriate curves the minimum values of f_{be}/E within the permissible range of $\lambda/h \leq 8.89$ may be tabulated as follows.

Figure	c/d	f_{be}/E	λ/h	Predominant basic mode
3	0	2.21×10^{-3}	8.89	Torsional-flexural
8	1/4	2.73×10^{-3}	8.89	Torsional-flexural
13	1/2	3.55×10^{-3}	8.89	Torsional-flexural



Sketch 4.2

Since the above values of f_{be}/E all relate to one basic mode graphical interpolation using all three values may be employed to obtain a value for $c/d = 0.333$. As Sketch 4.2 shows this leads to a value of f_{be}/E of 2.97×10^{-3} . Thus,

$$f_{be} = 2.97 \times 10^{-3} \times 72\,400 = 215 \text{ MN/m}^2.$$

Then

$$\frac{f_{be}}{f_n} = \frac{215}{260} = 0.827$$

and, from Figure 16 at $m = 14$, $\eta = 0.982$ so that $f_b = 0.982 \times 215 = 211 \text{ MN/m}^2$.

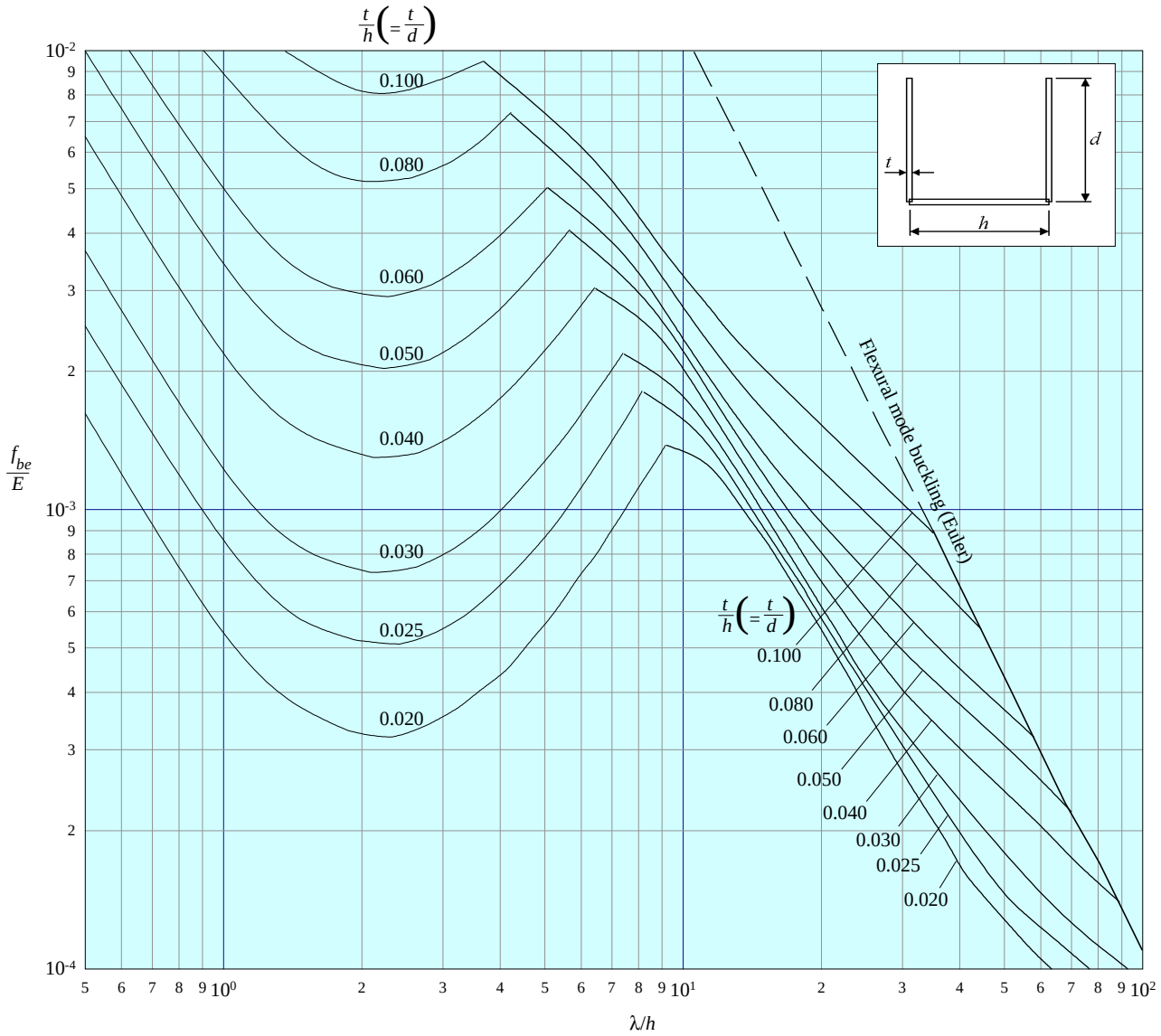


FIGURE 1 $\frac{d}{h} = 1 \left(\frac{c}{d} = 0 \right)$

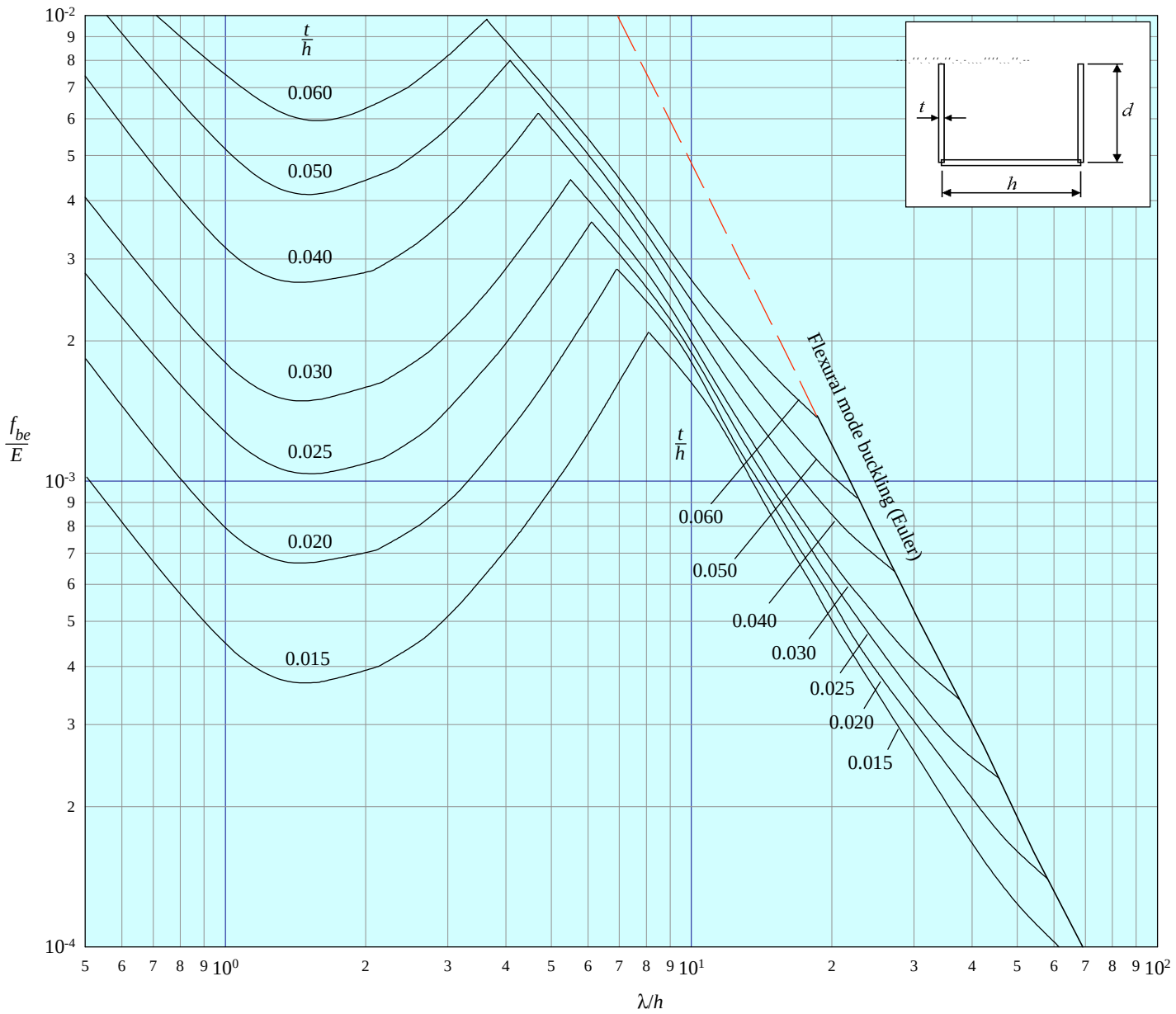


FIGURE 2 $\frac{d}{h} = \frac{2}{3} \left(\frac{c}{d} = 0 \right)$