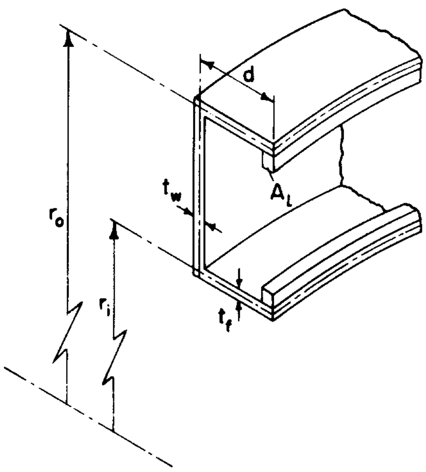
71004

FLANGE EFFICIENCY FACTORS FOR CURVED BEAMS UNDER BENDING IN THE PLANE OF CURVATURE

1. NOTATION

A_e	effective cross-sectional area of flange and lip	in^2	m^2
A_l	cross-sectional area of lip	in^2	m^2
a	reference radial dimension of beam web as shown in Figures 5 and 6	in	m
d	width of flange	in	m
f_i, f_o	circumferential stresses in inner and outer flanges, respectively	lbf/in^2	N/m^2
f_1	maximum transverse bending stress in flange	lbf/in^2	N/m^2
r_i, r_s, r_o	radii of curvature of inner flange, skin and outer flange,respectively	in	m
t_f , t_s, t_w	thickness of flange, skin and web respectively	in	m
η	flange efficiency factor defined by $A_e = \eta(A_l + dt_f)$		
ϕ	parameter to allow for flexibility of web		
ν	Poisson's ratio		

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



Sketch 1.1 Dimensioning for a typical curved beam

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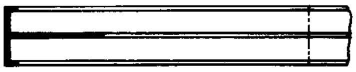
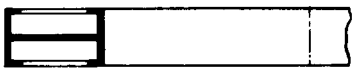
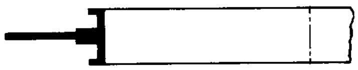
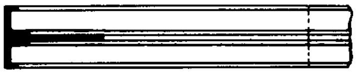
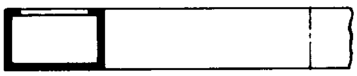
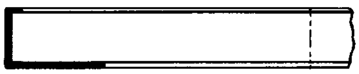
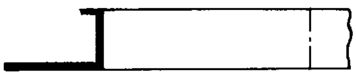
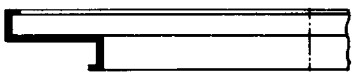
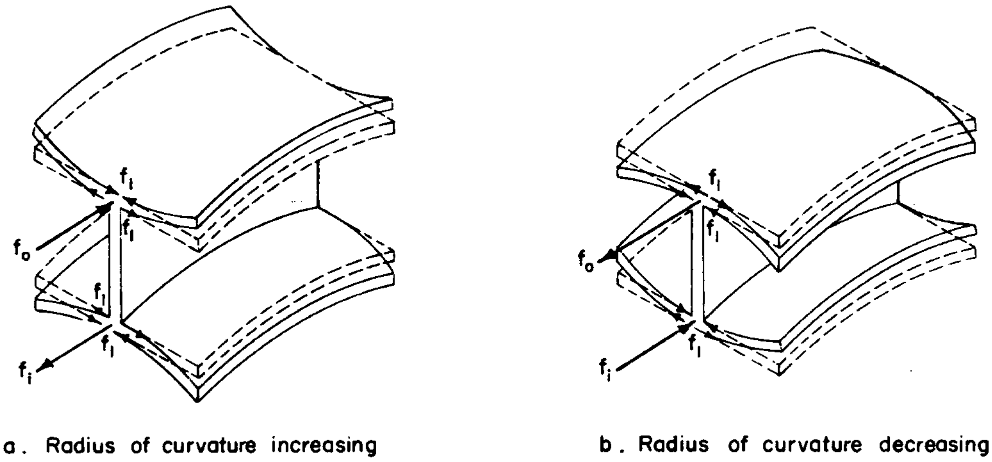
2. NOTES

This Item gives data for the calculation of the elastic stresses in the flanges and the deflections of curved beams subjected to bending in the plane of curvature. The data are provided in the form of flange efficiency factors, η, from which equivalent flanges with cross-sectional areas $A_e = \eta(A_l + dt_f)$ may be obtained for use with beam theory. The Item is based on the behaviour of a complete ring subjected to pure bending. It may be applied to other curved beams and in most such cases it will tend to overestimate the resulting stresses and deflections. The cross sections listed in Table 2.1 are covered specifically and analytical expressions are given in Section 3 for use with other cross sections.

TABLE 2.1

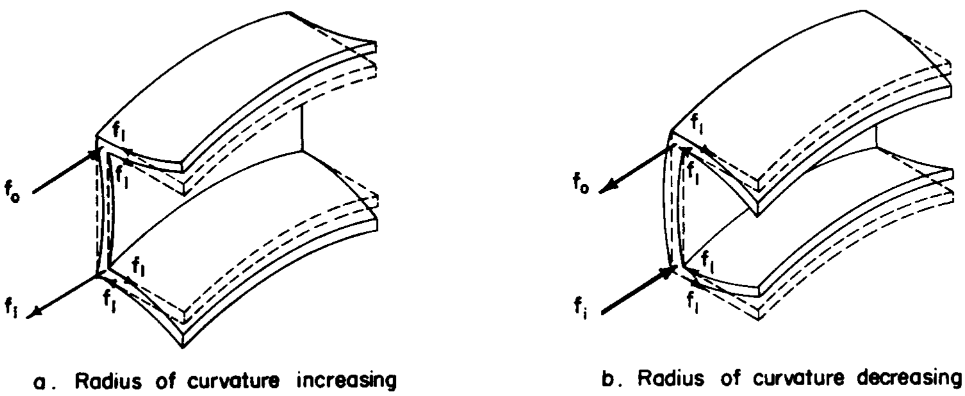
	Type of beam		*Parameter ϕ to allow for flexibility of web*	*Flange efficiency and transverse bending stress*
Symmetric monolithic	T-section with flanges inside		0	Figure 1
	T-section with flanges outside		0	Figure 1
	I-section		0	Figure 1
Symmetric built-up	Built up T-section with flanges inside		Figure 5	Figures 2 to 4
	Built up T-section with flanges outside		Figure 5	Figures 2 to 4
	Built up I-section		Figure 5	Figures 2 to 4
Asymmetric monolithic	Channel		Figure 5	Figures 2 to 4
	L-section with flange outside		Figure 6	Figures 2 to 4
	L-section with flange inside		Figure 6	Figures 2 to 4
	Z-section		Figure 6	Figures 2 to 4

When a curved beam or ring of monolithic section symmetrical about the plane of curvature is subjected to bending in that plane, the free edges of the flanges are able to move radially into positions in which the circumferential stress will be relieved. Relief of circumferential stress reduces the efficiency, η , of the flanges, and the maximum stress and the deflection of the beam are greater than they would have been if it had it been straight. Sketch 2.1 illustrates the distortion induced in the flanges of a curved I-beam. It also shows that the distortion produces additional transverse bending stresses in the flanges. Figure 1 gives η , f_1/f_i and f_1/f_o for a range of values of the governing parameters.



Sketch 2.1 Distortion of the flanges of a curved I-beam

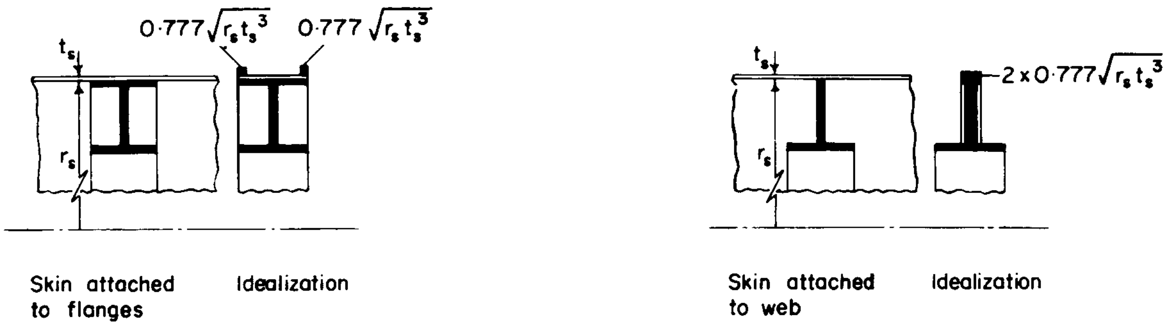
In unsymmetrical curved beams under bending, both the web and the flange are distorted. In built-up symmetrical curved beams under bending, both the web-attached leg of the flange and the flange itself are distorted. Sketch 2.2 illustrates the distortion that occurs in the web of a channel-section curved beam in bending and shows that the flexibility of the web, which is accounted for in this Item by a flexibility parameter, ϕ , leads to a reduction of both f_1 and A_e. It should be noted that, in this unsymmetrical case, the bending moment at the edge of the flange will be balanced by an equal bending moment in the web. Table 2.1 indicates whether ϕ should be taken from Figure 5 or Figure 6. Figures 2 to 4 give η , f_1/f_i and f_1/f_o for a range of values of ϕ and the other governing parameters.



Sketch 2.2 Distortion of the flanges of a curved channel-section beam

Beam theory should be used with the effective areas of the flanges, A_e , to determine f_i and f_o. Straight beam theory may be used if the curvature of the beam is shallow, but if the mean radius of curvature is less than four times the depth of the beam, errors of more than 10 per cent can result, and curved beam theory will give a more accurate answer. The signs of the individual stresses are shown in the sketches.

The effects of the skin overlapping a flange may be allowed for by increasing the area, A_l, of the lip by the amount $0.777\sqrt{r_s t_s^3}$ (see the Sketch 2.3). The effects of a skin attached directly to a web may be allowed for by introducing an effective flange of twice this area.



Sketch 2.3 Effective cross-sectional areas of attached skins

The change in the second moment of area of the cross section due to distortion of the flanges is small and its direct effect on bending stresses and stiffness has been neglected. It has been assumed that changes in curvature due to bending are negligibly small, that stresses do not exceed the elastic limit and that no buckling occurs. The curves apply strictly to flanges with thicknesses that are less than one fifth of their width and less than one tenth of the total depth of the beam. A value of Poisson's ratio of 0.3 has been used throughout.

3. EQUATIONS FOR USE WITH SECTIONS NOT LISTED IN TABLE 2.1

The graphs in this Item apply specifically to the cross sections listed in Table 2.1, though the equations on which they are based may be applied to any cross section built up from the basic elements shown in Table 3.1. Examples of such sections are shown in the accompanying diagrams.