CODE OF PRACTICE

CP 118:1969

Incorporating Amendment No. 1

The structural use of aluminium

UDC 669.71:624.014.7

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Structural aluminium
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Contents

Foreword

This Code makes reference to the following British Standards:

BS 153, *Steel girder bridges — Part 3A: Loads.*

BS 275, *Dimensions of rivets (½ in to 1¾ in diameter).*

BS 350, *Conversion factors and tables.*

BS 466, *Electric overhead travelling cranes for general use in factories, workshops and warehouses.*

BS 499, *Welding terms and symbols — Part 1: Welding, brazing and thermal cutting glossary — Part 2: Symbols for welding.*

BS 641, *Dimensions for small rivets for general purposes.*

BS 648, *Schedule of weights of building materials.*

BS 729, *Zinc coatings on iron and steel articles.*

BS 916, *Black bolts, screws and nuts.*

BS 1083, *Precision hexagon bolts, screws and nuts (B.S.W. and B.S.F. threads).*

BS 1161, *Aluminium and aluminium alloy sections.*

BS 1470, *Wrought aluminium and aluminium alloys for general engineering purposes — Plate, sheet and strip.*

BS 1471, *Wrought aluminium and aluminium alloys for general engineering purposes — Drawn tube.*

BS 1472, *Wrought aluminium and aluminium alloys for general engineering purposes — Forging stock and forgings.*

BS 1473, *Wrought aluminium and aluminium alloys for general engineering purposes — Rivet, bolt and screw stock.*

BS 1474, *Wrought aluminium and aluminium alloys for general engineering purposes — Bars, extruded round tube and sections.*

BS 1475, *Wrought aluminium and aluminium alloys for general engineering purposes — Wire.*

BS 1490, *Aluminium and aluminium alloy ingots and castings for general engineering purposes.*

BS 1494, *Fixing accessories for building purposes — Part 1: Fixings for sheet, roof and wall coverings.*

BS 1500, *Fusion welded pressure vessels for general purposes — Part 3: Aluminium.*

BS 1615, *Anodic oxidation coatings on aluminium.*

BS 1768, *Unified precision hexagon bolts, screws and nuts (UNC and UNF threads). Normal series.*

BS 1769, *Unified black, hexagon bolts, screws and nuts (UNC and UNF threads). Heavy series.*

BS 1974, *Large aluminium alloy rivets: ½ in to 1 in nominal diameters.*

BS 2569, *Sprayed metal coatings — Part 1: Protection of iron and steel by aluminium and zinc against atmospheric corrosion.*

BS 2708, *Unified black square and hexagon bolts, screws and nuts (UNC and UNF threads). Normal series.*

BS 2901, *Filler rods and wires for gas-shielded arc welding — Part 4: Aluminium and aluminium alloys and magnesium alloys.*

BS 3019, *General recommendations for manual inert-gas tungsten-arc welding — Part 1: Wrought aluminium, aluminium alloys and magnesium alloys.*

BS 3416, *Black bitumen coating solutions for cold application.*

BS 3451, *Testing fusion welds in aluminium and aluminium alloys.*

BS 3571, *General recommendations for manual inert-gas metal-arc welding — Part 1: Aluminium and aluminium alloys.*

BS 3660, *Glossary of terms used in the wrought aluminium industry.*

BS 3692, *ISO metric precision hexagon bolts, screws and nuts.*

BS 3763, *International System (SI) units.*

BS 3987, *Anodized wrought aluminium for external architectural applications.*

BS 3989, *Aluminium street lighting columns.*

BS 4300-1, *Specification (supplementary series) for wrought aluminium and aluminium alloys. Aluminium alloy longitudinally welded tube.*

BS 4300-14, *HS17 plate, sheet and strip.*

BS 4300-15, *HE 17 bar, extruded round tube and sections.*

CP 3, *Code of basic data for the design of buildings — Chapter V: Loading.*

CP 143, *Sheet roof and wall coverings — Part 7: Aluminium.*

CP 231, *Painting of buildings.*

This Code of Practice was made on the recommendation of the Institution of Structural Engineers, whose report on the structural use of aluminium (1962) it supersedes.

It is assumed that the Code will be interpreted by chartered engineers competent in the fields to which they apply it, and that construction will be entrusted to capable contractors and carried out under competent supervision.

The range of alloys is wider than that of the above report and, although emphasis is laid on the more usual alloys H30, N8 and H9, provision is made for design with other alloys specified in British Standards and also with non-standard tempers and heat-treatment conditions.

The Code does not preclude the use of non-standard alloys, but warns that they should not be used without careful consideration of their relevant physical and chemical properties; consultation with the manufacturer is essential.

Permissible stresses are higher than those of the report, and are in good correspondence with those of foreign specifications; and the internationally accepted 0.2 % proof stress is adopted as a reference datum in place of the 0.1 % proof stress previously used. Useful expressions are given for dealing with torsional and local buckling of thin-walled open sections. Advantage is taken of the post-buckled strength of thin plates and webs. The general increase in static permissible stresses is supported by the inclusion of specific rules for the design of members subject to fluctuating loads.

The welding of aluminium by the inert-gas processes is dealt with comprehensively in regard to both design and fabrication.

Provision is made for the acceptance of a structure by testing should stress-analysis not be feasible; tests more realistic than those hitherto required are prescribed.

Detailed advice is given on the protection of aluminium structures in environments where it is needed.

Consideration was given to the possibility of drafting this Code on limit-state design principles, but to do so in the present state of knowledge was deemed impracticable.

With Amendment Slip No. 1, giving material properties and basic permissible stresses in SI units (for details of which see BS 3763[1)]), the Code becomes substantially a metric document, the conversions (based on BS 350[2)]) of those values still cited first in imperial units being sufficiently accurate for structural purposes.

[1)] BS 3763, *"International System (SI) units"*.

[2)] BS 350, *"Conversion factors and tables"*, Part 1, *"Basis of tables. Conversion factors"*, Part 2, *"Detailed conversion tables"*. Supplement No. 1 to Part 2, *"Additional tables for SI conversions"*.

This Code of Practice represents a standard of good practice and therefore takes the form of recommendations. Compliance with it does not confer immunity from relevant statutory and legal requirements.

Summary of pages

This document comprises a front cover, an inside front cover, pages i to viii, pages 1 to 133 and a back cover.

This standard has been updated (see copyright date) and may have had amendments incorporated. This will be indicated in the amendment table on the inside front cover.

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1 General

1.1 Scope

This Code of Practice covers the use of aluminium for all types of structure except those for which there are specific alternatives; e.g. BS 1500-3[3] for pressure vessels, and BS 3989[4] for lighting columns. It deals with the following materials:

Principal alloys: H30, N8 and H9.

Supplementary alloys: H20, H15, N3, N4, N5 and H17.

Other alloys: Advice is given, conditionally, on the use of alloys not listed above.

1.2 Definitions and symbols

1.2.1 Definitions

For the purposes of this Code, the definitions in BS 3660[5] apply, together with the following.

engineer

the person responsible for the design and satisfactory completion of the structure, as covered by this Code, or a person authorized by him

manufacturer

the producer of the aluminium, in the form of sections, plates or other commodities

strength member

a primary structural member designed to carry important and calculated loads

non-strength member

a secondary part that does not carry important loads; examples are a lower-chord hanger in a roof-truss, a member which only stabilizes a column at mid-length, and a subsidiary attachment like a ladder or a pipe-support (or a connection to such a part)

1.2.2 Symbols. The following symbols, together with those given in Appendix A, are used in this Code:

f_b	Bearing stress
f_{bc}	Bending compressive stress
f_{bt}	Bending tensile stress
f_c	Axial compressive stress
f_q	Maximum shear stress
$f_{q\cdot av}$	Average shear stress (shear force divided by effective area)
f_t	Axial tensile stress
h	Depth to longitudinal stiffener
k	Interaction coefficient
k_b	Buckling coefficient
k_{lat}	Section property
k_t	Section property
k_1	Restraint factor
k_2	Bending-moment-shape factor
k_3	Cross-section-shape factor

[3] BS 1500, "*Fusion welded pressure vessels for general purposes*", Part 3, "*Aluminium*".
[4] BS 3989, "*Aluminium street lighting columns*".
[5] BS 3660, "*Glossary of terms used in the wrought aluminium industry*".

ℓ	Effective length of strut
ℓ_f	Effective unrestrained length of beam
m	Local buckling coefficient
p_b	Permissible bearing stress
p_{bc}	Permissible bending compressive stress
p_{bt}	Permissible bending tensile stress
p_c	Permissible axial compressive stress
p_q	Permissible maximum shear stress
$p_{q\,av}$	Permissible average shear stress
p_t	Permissible axial tensile stress
p_{wc}	Permissible compressive stress in reduced-strength zone at weld
p_{wq}	Permissible shear stress in reduced-strength zone at weld
p_{wt}	Permissible tensile stress in reduced-strength zone at weld
r	Radius of gyration
t	Thickness
t_1	Web thickness
t_2	Flange thickness
A	Cross-sectional area
E	Modulus of elasticity
G	Modulus of rigidity
H	Warping factor
I_p	Polar second moment of area about shear centre
I_x	Second moment of area about x–x axis
I_y	Second moment of area about y–y axis
J	Torsion factor
L	Length of strut or beam between points of lateral support
M	Applied bending moment
$\lambda = \frac{\ell}{r}$	Effective slenderness ratio for column buckling
$\lambda = \frac{L}{r}$	Slenderness ratio for single-bay eccentrically loaded struts
$\lambda = \frac{ma}{t_1}$	Slenderness ratio for local buckling
$\lambda = \frac{mb}{t}$	Slenderness ratio for local buckling
λ_{lat}	Slenderness ratio for lateral buckling
λ_s	Slenderness ratio at junction of straight line and hyperbola
λ_t	Slenderness ratio for pure torsional buckling

2 Materials

2.1 Designation of material

2.1.1 General. The designation of materials is in accordance with the system (see Appendix A) used in the British Standards for wrought aluminium and aluminium alloys for general engineering purposes. Foreign equivalents of these alloys are given in Appendix B.

2.1.2 Durability ratings. In order to formulate rules for the protection of aluminium structures (see Section 7), it has been found convenient to establish durability ratings for different materials and to list them in the appropriate tables of this Code.

2.2 Selection of material

2.2.1 Principal structural alloys. The three aluminium alloys most commonly used in general and structural engineering are listed, with their properties, in Table 1.

For general use, particularly in bolted or riveted framed structures, H30-TF is the normal choice on the grounds of strength, durability and economy; it is supplied as plate, extruded sections (both solid and hollow), sheet, tube and forgings. This material is weldable, but with reduction of strength near the welds.

The alloy N8 is the chief material for welded structures and platework; it is available as plate and may be extruded into simple structural sections. Although less strong, when unwelded, than H30-TF it shows a much smaller reduction in strength after welding, so that welded joints are stronger than those in H30-TF. N8 has exceptional durability, particularly in marine environments.

The alloy H9, produced in the form of extruded solid or hollow sections, combines moderate strength with high durability and a good surface finish that responds well to anodizing; it is particularly adaptable to thin-walled and intricate extruded shapes. It is widely used where appearance is a main requirement. Like H30-TF, this material loses part of its strength on welding.

2.2.2 Supplementary structural alloys. Six further alloys often used in general and structural engineering are described and listed with their properties in Appendix C.

2.2.3 Alloys with non-standard properties. The alloys referred to in **2.2.1** and **2.2.2** are sometimes used in non-standard tempers and conditions (see **4.1.3.3**).

2.2.4 Other alloys. Other alloys are available. The engineer is, however, advised against using any of them without careful consideration, in full consultation with a reputable manufacturer, of all its properties including its durability, its weldability, its resistance to crack propagation and its behaviour in service of the kind envisaged.

2.2.5 Bolts and rivets. Table 2 gives the common bolt and rivet materials, and indicates the alloys with which they may suitably be used. Durability ratings are dependent on the alloys joined, as well as on the bolt or rivet material (see **7.4**).

Steel bolts should preferably be galvanized or sherardized to BS 729[6]. H15-TF bolts may be supplied with anodized finish for improved resistance to corrosion.

H30-TF and H15-TB rivets are more readily driven immediately after solution heat treatment. The period before driving may be extended by cold storage. Special head shapes (see BS 1974[7]) may be necessary for the larger diameters.

Bolts and rivets in N6 are available but must not be used in corrosive or tropical environments; otherwise they carry the same durability rating as the alloys joined.

2.2.6 Filler wires. Filler wires for inert-gas tungsten-arc and metal-arc welding are given in Table 3. For welds between dissimilar alloys, the advice of the manufacturer must be sought.

[6] BS 729, "*Zinc coatings on iron and steel articles*".

[7] BS 1974, "*Large aluminium alloy rivets: ½ in to 1 in nominal diameters*".

Table 1 — Properties of principal alloys

Small figures in parentheses refer to the Notes.

Alloy	(1) Condition	(1) Form	(1) Thickness mm from	(2) Thickness mm to	(3) 0.2 % tensile proof stress N/mm²	(3) Tensile strength N/mm²
H30	TF	Extrusions	—	20	255	295
			20	(9) 150	270	310
		Sheet, plate	0.2	3.0	255	295
			3.0	25	240	295
		Drawn tube	—	6.0	255	310
			6.0	10	240	310
N8	M	Extrusions	—	(9) 150	130	280
		Sheet, plate	3.0	25	—	—
	O	Extrusions	—	(9) 150	125	275
		Sheet, plate	0.2	25		
H9	TF	Extrusions	—	(9) 150	160	185
	TE	Extrusions	—	25	110	150

NOTE 1 For other conditions, forms and thicknesses see BS 1470 to BS 1475
NOTE 2 Each thickness range includes its upper limit
NOTE 3 Minimum value specified in BS 1470, BS 1471 or BS 1474
NOTE 4 For specific elongations see BS 1470, BS 1471 and BS 1474
NOTE 5 Minimum expected value (see Appendix D)

Table 1 — Properties of principal alloys

(3) Elongation % on $5.65\sqrt{S_o}$	(4) Elongation % on 50 mm	(5) 0.2 % compressive proof stress N/mm²	(5) Bearing strength N/mm²	(6) Modulus of elasticity N/mm²	(7) Coefficient of linear expansion per °C	Density kg/m³	(8) Durability rating
8	7	Same as tensile	618	68 900	23×10^{-6}	2 710	B
8	—						
—	8		587				
—	8						
7	7		618				
—	9						
12	11		556		24.5×10^{-6}	2 660	A
—	—						
14	13	118	525				
14	12–16		556				
8	7	Same as tensile	386	65 500	23×10^{-6}	2 710	B
8	7		324				

NOTE 6 For modulus of rigidity multiply by 0.38
NOTE 7 Applies to range 20 °C to 100 °C
NOTE 8 See **2.1.2**.
NOTE 9 For round tube and hollow sections the properties do not apply above 75 mm.

2.3 Relevant standards

2.3.1 Sections, plate, sheet and other forms. Sections, plate, sheet and other forms must comply with the following British Standards as appropriate:

BS 1470, *"Wrought aluminium and aluminium alloys for general engineering purposes" — "Plate, sheet and strip".*

BS 1471, *"Wrought aluminium and aluminium alloys for general engineering purposes" — "Drawn tube".*

BS 1473, *"Wrought aluminium and aluminium alloys for general engineering purposes" — "Rivet, bolt and screw stock".*

BS 1474, *"Wrought aluminium and aluminium alloys for general engineering purposes" — "Bars, extruded round tube and sections".*

BS 1475, *"Wrought aluminium and aluminium alloys for general engineering purposes" — "Wire".*

BS 4300-1, *"Specification (supplementary series) for wrought aluminium alloys for general engineering purposes" — "Aluminium alloy longitudinally welded tube".*

BS 4300-14, *"Specification (supplementary series) for wrought aluminium alloys for general engineering purposes" — "HS17 plate, sheet and strip".*

BS 4300-15, *"Specification (supplementary series) for wrought aluminium alloys for general engineering purposes" — "HE17 bar, extruded round tube and sections".*

2.3.2 Bolts. Aluminium and steel bolts must comply with the following British Standards as appropriate:

BS 916, *"Black bolts, screws and nuts".*

BS 1083, "*Precision hexagon bolts, screws and nuts (B.S.W. and B.S.F. threads)".*

BS 1494, *"Fixing accessories for building purposes"*, Part 1, *"Fixings for sheet, roof and wall coverings".*

BS 1768, *"Unified precision hexagon bolts, screws and nuts (UNC and UNF threads). Normal series".*

BS 1769, *"Unified black hexagon bolts, screws and nuts (UNC and UNF threads). Heavy series".*

BS 2708, *"Unified black square and hexagon bolts, screws and nuts (UNC and UNF threads). Normal series."*

BS 3692, *"ISO metric precision hexagon bolts, screws and nuts".*

Table 2 — Bolt and rivet materials

	Material	Process	Alloys joined		Durability rating
			Principal	Supplementary	
Bolts	H30-WT	—	All	All except H15	Same as alloys joined
			—	H15 and H17	C
	H15-TF[a][b]	—	—	H15 and H17	C
	Steel[b]	—	All	All except H15 and H17 outdoors	[c]
	Corrosion-resisting steel	—	All	All	
Rivets	H30-TB[a]	Cold driven[b]	All	All except H15 and H17	Same as alloys joined
	H15-TB[a]		—	H15 and H17	C
	N5-O	Cold driven[b]	All	All except H15 and H17	Same as alloys joined
		Hot driven			
	Steel	Cold driven	All	All	[c]
		Hot driven	All	All except H15 and H17	

[a] See **4.6.2.1**.
[b] See **2.2.5**.
[c] See **7.4**.

2.3.3 Rivets. Aluminium and steel solid rivets must comply with the following British Standards as appropriate:

BS 275, *"Dimensions of rivets (½ in to 1¾ in diameter)"*.

BS 641, *"Dimensions of small rivets for general purposes"*.

BS 1974, "*Large aluminium alloy rivets: ½ in to 1 in nominal diameters"*.

2.3.4 Filler wire for welding. Filler wire for welding must comply with BS 2901, "*Filler rods and wires for gas-shielded arc welding*", Part 4, "*Aluminium and aluminium alloys and magnesium alloys*".

2.3.5 Forgings and castings. Forgings and castings must comply with BS 1472, "*Wrought aluminium and aluminium alloys for general engineering purposes. Forging stock and forgings*", and BS 1490, "*Aluminium and aluminium alloy ingots and castings for general engineering purposes*" respectively.

2.4 Structural sections

2.4.1 General. Aluminium structural sections are normally produced by extrusion. The low cost of dies gives great flexibility, so that a very large variety of sections is available. Some sections, as noted below, are made by drawing or by forming.

2.4.2 Standard extruded sections. Some 60 standard extruded sections are listed, with properties, in BS 1161[8]. They range in size as follows:

Equal angles	30 × 30	to	120 × 120 mm
Unequal angles	50 × 38	to	140 × 105 mm
Channels	60 × 30	to	240 × 100 mm
I-sections	60 × 30	to	160 × 80 mm
T-sections	50 × 38	to	120 × 90 mm
Equal bulb angles	50 × 50	to	120 × 120 mm
Unequal bulb angles	50 × 37.5	to	140 × 105 mm
Lipped channels	80 × 40	to	140 × 70 mm
Bulb T-sections	90 × 75	to	180 × 150 mm

Other sizes may be obtained by arrangement with the manufacturer.

2.4.3 Non-standard extruded sections. Many other kinds of section, including zeds, double-stemmed tees, top-hats, acute and obtuse angles, and flats, as well as conventional sections of non-standard size, are available.

2.4.4 Hollow sections. Box-sections, twin-web beams and many other hollow sections are available.

2.4.5 Tubes. Tubular sections, not necessarily circular, are produced by extrusion or, alternatively, by cold-drawing from comparatively thick-walled extrusion blooms. The latter process gives greater dimensional accuracy but is more expensive. Both kinds of tube are available to British Standards (see **2.3.1**).

Seam-welded tubes in certain alloys and in sizes up to 2 in (51 mm) diameter, are also available (see BS 4300-1[9]).

2.4.6 Special sections. It is often advantageous to design special extruded sections for a particular structure in order to obtain more economical design and fabrication. The use of special non-circular drawn tubes or special roll-formed sections is less often worth while.

2.4.7 Sections formed from sheet. It is sometimes advantageous to employ sections formed from sheet or strip by roll-forming or by bending.

[8] BS 1161, "*Aluminium and aluminium alloy sections*".

[9] BS 4300-1, "*Specification (supplementary series) for wrought aluminium and aluminium alloys*". "*Aluminium alloy longitudinally welded tube*".

Table 3 — Filler wire for inert-gas welding

Parent alloy	Filler wire (in order of preference)	Durability rating of assembly
H30 H9	NG 21, NG 6[a],	B
N8	NG 6[a]	A
H20	NG 21, NG 6[a]	B
N3	NG 3, G 1C	A
N4 N5	NG 6[a]	
H17	NG61	C

NOTE When welded assemblies in H9, H20 or H30 are to be subsequently anodized, NG6 filler wire should be used, to obtain optimum colour match between weld and parent metal.

[a] NG 61 may be substituted for NG 6.

2.5 Tolerances

In general, the dimensional tolerances given in the relevant British Standards for aluminium material will rule. For special and irregular extrusions, and for sections formed from sheet, the tolerances must be agreed with the supplier.

Closer tolerances than those specified in British Standards may sometimes be of advantage in fabrication, and it may be possible to obtain them by arrangement with the supplier.

3 Loading

3.1 General

The loading that a structure or part of a structure must be designed to resist consists of the dead load, live or imposed loads, impact effects and any other loads and forces, including those due to wind and temperature, to which it will be subject. The loads and forces must be considered both separately and in combination, so that the most severe effects on the structure are taken into account. Particular attention must be given to loading conditions during erection or assembly.

Fluctuating loads must be carefully assessed in regard both to their amounts and to the frequency of their occurrence.

3.2 Dead load

The dead load is the weight of the structure complete. Dead loads for buildings must be calculated in accordance with CP 3:Chapter V-1[10]. For other structures dead loads must be calculated from the unit weights given in BS 648[11] or from the actual known weights of the materials used. The dead load initially assumed for design must be checked after the design is made, and the design then revised as necessary.

3.3 Live or imposed loads, and impact effects

Live or imposed loads, and impact effects if any, must be determined from the appropriate British Standards where these exist. For example, reference must be made to CP 3:Chapter V-1[10] for recommended imposed loads and impact effects on buildings, and to BS 153-3A[12] for live loads and impact effects on bridges. Where no relevant British Standard exists, these loadings must be decided by the engineer.

[10] CP 3, "*Code of basic data for the design of buildings*", Chapter V, "*Loading*", Part 1, "*Dead and imposed loads*".

[11] BS 648, "*Schedule of weights of building materials*".

[12] BS 153, "*Steel girder bridges*", Part 3A, "*Loads*".

3.4 Wind

The forces due to wind must be determined from the appropriate British Standards where these exist (e.g. CP 3:Chapter V for buildings, and BS 153-3A for bridges). Where no relevant British Standard exists, the wind forces must be decided by the engineer. Where the structure is of unconventional size or shape, or in unusual surroundings, it may be desirable to determine wind forces by means of model tests. The possibility of wind-induced vibration must not be overlooked (see **4.7.2**).

3.5 Temperature

Account must be taken of the forces that may arise from overall changes in the temperature of the structure and from temperature differences within it. In the U.K., changes in the temperature of the metal due to climatic variations may be assumed to occur in the range 20 °F to 120 °F (– 7 °C to 49 °C).

3.6 Other loads

Account must be taken of any other loads (e.g. those, if any, due to seismic forces or to foundation settlement) to which the structure may be subject.

4 Design

4.1 General

4.1.1 Factors affecting design. Structural aluminium, like steel, behaves elastically over a large range of stress. The onset of plasticity is roughly defined by the 0.2 % proof stress, corresponding to a permanent strain of 0.002. This stress is analogous to the yield stress of structural steel.

The design procedure for aluminium structures is basically the same as for steel. Consideration must be given to the stability of the structure as a whole, and the lower modulus of elasticity of aluminium makes it necessary to examine closely the stability of parts in compression, and to pay particular attention to deflections and to the likelihood of vibration. The high coefficient of expansion of aluminium should also be borne in mind.

4.1.2 Design requirements. An aluminium structure must be capable of sustaining the most adverse combination of static and dynamic loads referred to in Section 3, and will conform with this Code if the permissible stresses specified in Section 4 are not exceeded or if the requirements of Section 5 are satisfied.

During design, care must be taken to ensure that, as far as possible, all members and connections are readily accessible for maintenance and that pockets and crevices likely to entrap water, dirt or condensation are avoided.

The design of any structure must be examined, preferably at an early stage, to assess the possibility of failure by fatigue (see **4.7**).

4.1.3 Permissible stresses

4.1.3.1 *Principal alloys.* Permissible stresses for the principal alloys in axial tension p_t, axial compression p_c, bending tension p_{bt}, bending compression p_{bc}, shear p_q and bearing p_b (all applying only where there is no buckling) are given in Table 4. The values have been obtained by the procedures in Appendix D and apply to unwelded members under static loading. Slender members tend to buckle and, for these, the permissible stresses must be obtained in accordance with **4.3**, **4.4** and **4.5**; values for flexural and torsional buckling of struts are given in Figure 1 and values for lateral buckling of beams and local buckling of thin plates in Figure 2. The construction of these graphs from the data given in Table 4 is described in Appendix D. The quoted shear stresses are permissible maximum values for use in **4.1.4.3**, **4.1.4.4** and **4.4.3.2**. Permissible average shear stresses for webs and thin plates which tend to buckle are dealt with in **4.4.3.2**, **4.4.7** and **4.5.2**.

The permissible axial and bending stresses must be used in conjunction with the appropriate effective area (see **4.2.1**, **4.2.2** and **4.4.2**).

The permissible bearing stresses listed in Table 4 are for joints in single shear. Increases for joints in double shear, and reductions for small edge distances of bolts or rivets, are described in **4.6.2**.

The effect of welding on permissible stresses is dealt with in **4.6.3**. Permissible stresses for fatigue conditions are given in **4.7.3**.

4.1.3.2 *Supplementary alloys.* The permissible stresses for the supplementary alloys are given in Appendix C.

4.1.3.3 *Alloys with non-standard properties.* Permissible stresses may be obtained as described in Appendix D for any of the principal and supplementary alloys for which a reputable manufacturer either guarantees higher minimum properties than those specified in the relevant British Standards (see **2.3**) or guarantees minimum properties, for a non-heat-treatable alloy, in a temper not so specified (e.g. tempers of NS8 giving minimum proof stresses higher than those of NS8-M). These permissible stresses may, with the engineer's agreement, be used for design.

4.1.3.4 *Other alloys.* The procedure given in Appendix D may be used as a guide to permissible stresses for other alloys (see **2.2.4**).

4.1.3.5 *Joints.* The permissible stresses for bolts, rivets, welded joints and welded members are given in **4.6**.

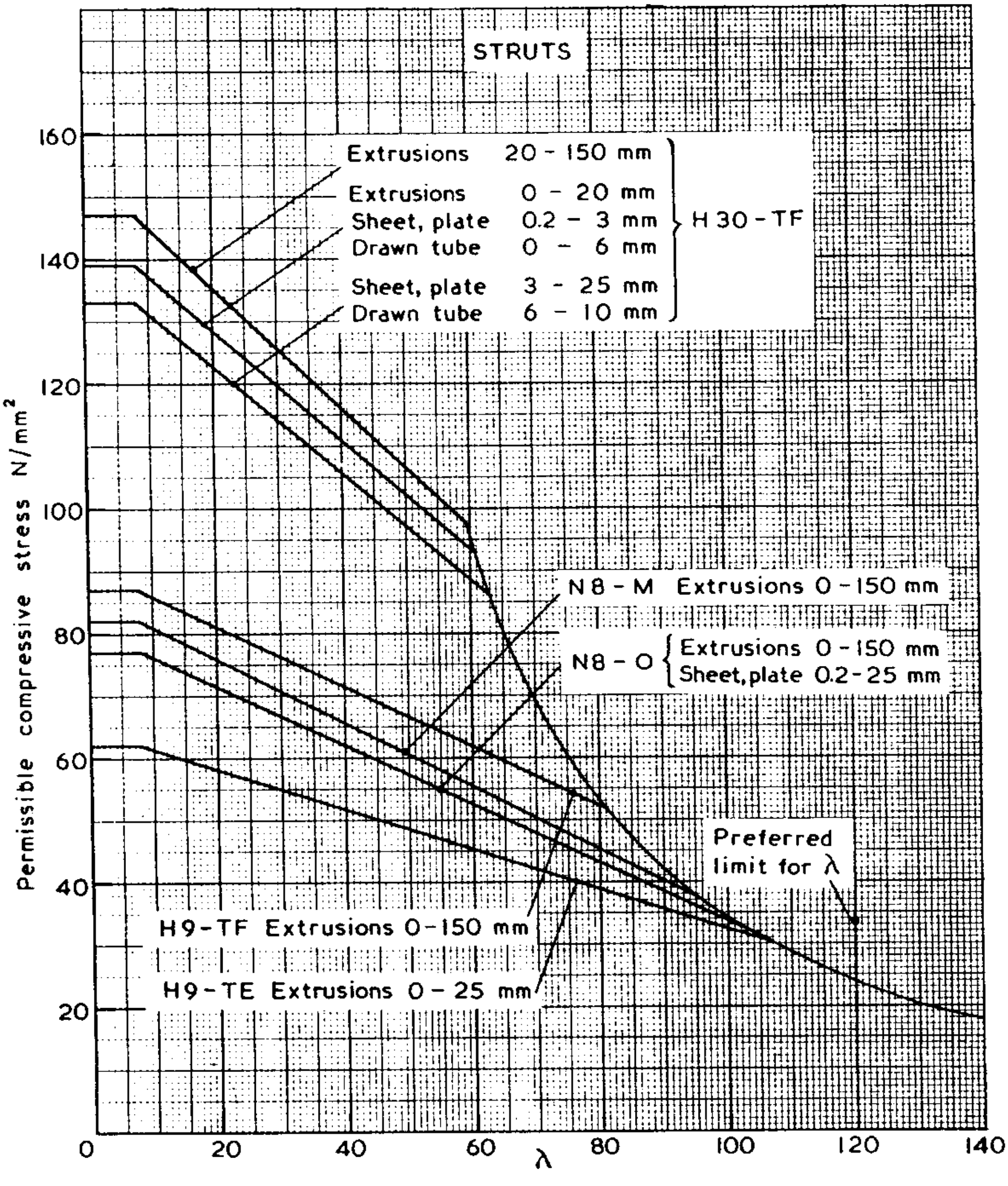
4.1.3.6 *Wind.* Provided fatigue is not a consideration (see **4.7.2**), the permissible stress may be exceeded by 25 % where such excess is due solely to wind. The strength of a member or joint where the stress is thus exceeded must not be less than that needed if the wind load on it be neglected.

Table 4 — Permissible stresses for principal alloys
N/mm^2

Small figures in parentheses refer to the Notes.

<table>
<tr><th rowspan="2">Alloy</th><th rowspan="2">(1)
Condition</th><th rowspan="2">(1)
Form</th><th colspan="2">(1) (2)
Thickness
mm</th><th colspan="2">(3)
Axial</th><th colspan="2">(3)
Bending</th><th>(3)
Shear</th><th>(4)
Bearing</th><th rowspan="2">(5)
λ_s</th></tr>
<tr><th>from</th><th>to</th><th>p_t</th><th>p_c</th><th>p_{bt}</th><th>p_{bc}</th><th>p_q</th><th>p_b</th></tr>
<tr><td rowspan="6">H30</td><td rowspan="6">TF</td><td rowspan="2">Extrusions</td><td>—</td><td>20</td><td colspan="2">139</td><td colspan="2">154</td><td>83</td><td rowspan="2">222</td><td>61</td></tr>
<tr><td>20</td><td>(6)
150</td><td colspan="2">147</td><td colspan="2">162</td><td>88</td><td>59</td></tr>
<tr><td rowspan="2">Sheet, plate</td><td>0.2</td><td>3.0</td><td colspan="2">139</td><td colspan="2">154</td><td>83</td><td rowspan="2">212</td><td>61</td></tr>
<tr><td>3.0</td><td>25</td><td colspan="2">132</td><td colspan="2">147</td><td>79</td><td>63</td></tr>
<tr><td rowspan="2">Drawn tube</td><td>—</td><td>6.0</td><td colspan="2">140</td><td colspan="2">156</td><td>84</td><td rowspan="2">222</td><td>61</td></tr>
<tr><td>6.0</td><td>10</td><td colspan="2">134</td><td colspan="2">149</td><td>80</td><td>63</td></tr>
<tr><td rowspan="4">N8</td><td rowspan="2">M</td><td>Extrusions</td><td>—</td><td>(6)
150</td><td colspan="2">82</td><td colspan="2">96</td><td>49</td><td>201</td><td>96</td></tr>
<tr><td>Sheet, plate</td><td>3.0</td><td>25</td><td colspan="2">(7)</td><td colspan="2">(7)</td><td>(7)</td><td>(7)</td><td>(7)</td></tr>
<tr><td rowspan="2">O</td><td>Extrusions</td><td>—</td><td>(6)
150</td><td rowspan="2">80</td><td rowspan="2">77</td><td rowspan="2">94</td><td rowspan="2">90</td><td rowspan="2">48</td><td rowspan="2">201</td><td rowspan="2">104</td></tr>
<tr><td>Sheet, plate</td><td>0.2</td><td>25</td></tr>
<tr><td rowspan="2">N9</td><td>TF</td><td>Extrusions</td><td>—</td><td>(6)
150</td><td colspan="2">87</td><td colspan="2">96</td><td>52</td><td>139</td><td>81</td></tr>
<tr><td>TE</td><td>Extrusions</td><td>—</td><td>25</td><td colspan="2">62</td><td colspan="2">69</td><td>37</td><td>117</td><td>106</td></tr>
</table>

NOTE 1 For other conditions, forms and thicknesses use procedures of Appendix D: for bolts and rivets see Table 12.
NOTE 2 Each thickness range includes its upper limit: minimum recommended thicknesses are given in **4.1.6**.
NOTE 3 Applies only when buckling is not the criterion: see **4.3**, **4.4** and **4.5**.
NOTE 4 Joints in single shear: see **4.6.2.1**.
NOTE 5 See Appendix D.
NOTE 6 For round tube and hollow sections the permissible stresses do not apply above 75 mm.
NOTE 7 The values given for N8-0 may be used.



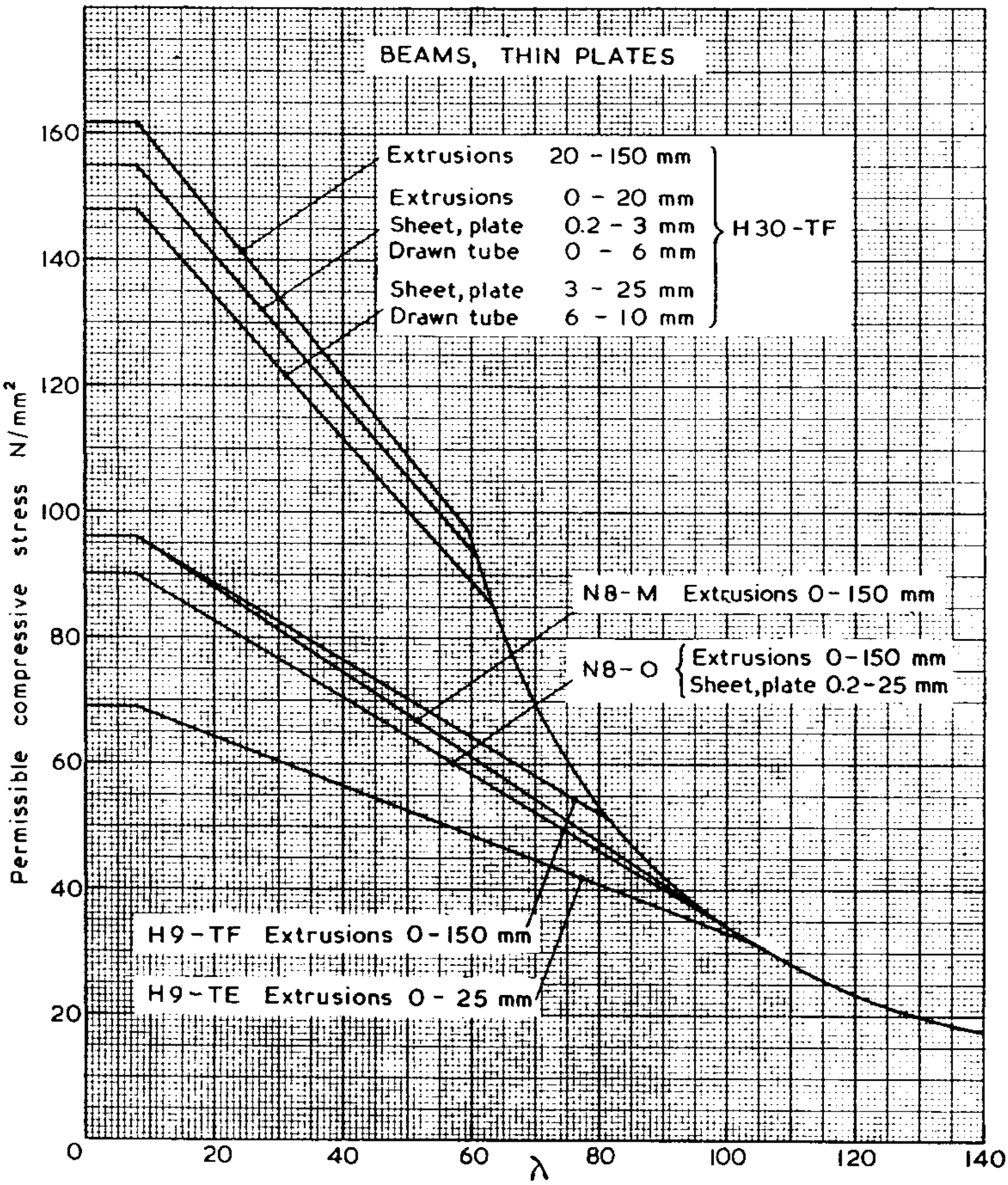
NOTE 1 The graphs do not apply to extruded round tube and hollow sections above 75 mm. thick.

NOTE 2 For clarity, the small differences in properties of thin extrusions and thin drawn tube, and of thicker plate and thicker drawn tube, have been ignored for H30-TF.

NOTE 3 For column buckling, $\lambda = l/r$ (see **4.3.1**).

NOTE 4 For torsional buckling $\lambda = \lambda_t$ (see **4.3.3**).

Figure 1 — Permissible compressive stresses in struts



NOTE 1 The graphs do not apply to extruded round tube and hollow sections above 75 mm. thick.

NOTE 2 For clarity, the small differences in properties of thin extrusions and thin drawn tube, and of thicker plate and thicker drawn tube, have been ignored for H30-TF.

NOTE 3 For beams (lateral buckling) $\lambda = \lambda_{lat}$ (see **4.4.4**).

NOTE 4 For thin plates (local buckling) $\lambda = mb/t$ (see **4.5.1**).

Figure 2 — Permissible compressive stresses in beams and thin plates

4.1.4 Combined stresses

4.1.4.1 *Combined bending and axial tension.* Members subject to bending and axial tension must be so proportioned that

$$\frac{f_t}{p_t} + \frac{f_{bt}}{p_{bt}} \leqslant 1 ,$$

where f_t is the axial tensile stress,

p_t is the permissible axial tensile stress (see Table 4),

f_{bt} is the sum of the tensile stresses due to bending about both axes, and

p_{bt} is the permissible bending tensile stress (see Table 4).

4.1.4.2 *Combined bending and axial compression.* Members subject to bending and axial compression must be so proportioned that

$$\frac{f_c}{p_c} + \frac{f_{bc}}{p_{bc}\left(1 - \dfrac{f_c}{p_e}\right)} \leqslant 1$$

where f_c is the axial compressive stress,

p_c is the permissible axial compressive stress obtained from Table 4 and Figure 1,

f_{bc} is the sum of the compressive stresses due to bending about both axes, ignoring the effects of deflection,

p_{bc} is the permissible bending compressive stress obtained from Table 4 and Figure 2, and

p_e is the Euler critical stress for buckling of the member in the direction of the applied bending moment and equals $\pi^2 E/(\ell/r)^2$,

where E is the modulus of elasticity, and

ℓ/r is the ratio of the effective length to the appropriate radius of gyration.

4.1.4.3 *Combined bending and shear.* Members subject to bending and shear must be so proportioned that $f_{eq} \leqslant 0.9$ times the minimum 0.2 % proof stress,

where f_{eq} is the equivalent stress, equal to

either $\sqrt{(f_{bt}^2 + 3f_q^2)}$ or $\sqrt{(f_{bc}^2 + 3f_q^2)}$,

f_q is the maximum shear stress, and

f_{bt} and f_{bc} have the same meanings as in **4.1.4.1** and **4.1.4.2** respectively.

The values of f_{bt}, f_{bc} and f_q must not, however, exceed the appropriate values for permissible stresses given in Table 4.

For webs of built-up beams and for thin plates, reference must also be made to **4.4.7** and **4.5**.

4.1.4.4 *Combined bearing, bending and shear.* Members subject to bearing, bending and shear must be so proportioned that $f_{eq} \leqslant 0.9$ times the minimum 0.2 % proof stress,

where f_{eq} is the equivalent stress, equal to

either $\sqrt{(f_{bt}^2 + f_b^2 + f_{bt}f_b + 3f_q^2)}$ or

$\sqrt{(f_{bc}^2 + f_b^2 - f_{bc}f_b + 3f_q^2)}$,

f_b is the bearing stress, and

f_{bt}, f_{bc} and f_q have the same meanings as in **4.1.4.1**, **4.1.4.2** and **4.1.4.3** respectively.

The values of f_{bt}, f_{bc} and f_q must not, however, exceed the appropriate values for permissible stresses given in Table 4.

For webs of built-up beams and for thin plates, reference must also be made to **4.4.7** and **4.5**.

4.1.5 Temperature limitations

4.1.5.1 *Ordinary and low temperatures.* The design requirements of this Code apply without modification to structures subject to temperatures in the range – 330 °F to 150 °F (– 201 °C to 66 °C).

4.1.5.2 *High temperatures.* In the design of structures whose temperature will consistently exceed 150 °F (66 °C) or which will ever exceed 200 °F (93 °C), the engineer must obtain expert advice on such modifications to design as may be necessary. For materials N8 and H17 design modifications may, under certain conditions of stress and corrosion, be required at lower temperatures, and similarly the engineer must obtain expert advice. Some information on the high-temperature properties of certain materials is to be found in BS 1500-3[13].

4.1.6 Thicknesses. Structural sections should not be thinner than 0.048 in (1.2 mm) and stressed-skin elements (e.g. diaphragms, webs and sheet panels) not thinner than 0.035 in (0.9 mm). Thicknesses should be sufficient to give reasonable resistance to accidental damage.

4.2 Ties

4.2.1 Axially loaded ties. The permissible axial load in a tie is the permissible tensile stress (see Table 4) multiplied by the effective area.

The effective area is the gross area (as calculated from nominal or actual dimensions) minus deductions, as follows, for holes and for loss of strength due to welding:

1) *The deduction for holes* is the larger of:

the sum of the cross-sectional areas of the holes in a straight line across the member and at right angles to the direction of stress, the line being the one for which the sum is largest, and

the sum of the cross-sectional areas of holes in a zig-zag line from hole to hole across the member or part thereof less $s^2t/4g$ for each pitch space in the chain of holes, the zig-zag line being the one for which this net quantity is largest,

where

s is the hole pitch,

g is the hole gauge, and

t is the thickness of the holed material.

These definitions are illustrated with an example in Appendix E.

2) *The deduction for loss of strength due to welding* is the sum of the areas of the reduced-strength zones (see **4.6.3.2**) in a cross section multiplied by $(p_t - p_{wt})/p_t$, the governing cross section being the one with the largest reduced-strength area, where p_t is the permissible axial tensile stress (see Table 4) and p_{wt} is the permissible axial tensile stress in reduced-strength zones (see Table 14).

4.2.2 Eccentrically loaded ties. Single-bay ties of single and double angles may be designed as axially loaded members, and the variation in stress in the outstanding leg or legs ignored, provided that the effective area is obtained by deducting part of the area of the outstanding leg from the gross area, in addition to any deduction called for in **4.2.1**. The proportions of outstanding leg area to be deducted are given in Table 5.

The deductions given in Table 5 apply equally to other sections with outstanding legs, such as tees and web-fastened channels.

[13] BS 1500, "*Fusion welded pressure vessels for general purposes*", Part 3, "*Aluminium*".

Table 5 — Outstanding-leg deductions for single-bay ties

Alloy	Deduction per outstanding leg	
	Single angle connected through one leg	Two angles back-to-back connected to both sides of gusset
H30 H9	0.6 *A*	0.2 *A*
N8	0.4 *A*	nil
NOTE *A* is the gross area of the outstanding leg that lies clear of the connected leg, but disregarding any fillet; e.g. for a 4 × 4 × ½ in angle, $A = 1.75\ \text{in}^2$, and for a 100 × 100 × 10 mm angle, $A = 900\ \text{mm}^2$		

For end bays of multiple-bay angles, channels and tees, the effective area must be calculated in the same way as for single-bay ties.

For intermediate bays of multiple-bay angles, channels and tees, the effective area is the gross sectional area minus the deductions given in **4.2.1**.

4.3 Struts

4.3.1 Axially loaded struts. With struts, the main requirement is resistance to column buckling (i.e. overall flexural buckling), for which the permissible average stress on the gross area is obtained from the appropriate graph in Figure 1 at $\lambda = \ell/r$, where ℓ is the effective length estimated from Table 6 and r is the appropriate radius of gyration.

Two further requirements, applying more particularly to struts of thin-walled section, are resistance to torsional buckling and to local buckling. The permissible stresses for struts subject to these types of buckling must be obtained from **4.3.3** and **4.5.1** respectively.

The permissible stress for a strut is the least of the three permissible stresses obtained as above.

Table 6 — Effective lengths of struts

End conditions	Effective length of strut
Effectively held in position and restrained in direction at both ends	0.7 *L*
Effectively held in position at both ends and restrained in direction at one end	0.85 *L*
Effectively held in position at both ends, but not restrained in direction	*L*
Effectively held in position and restrained in direction at one end, and partially restrained in direction but not held in position at the other end	1.5 *L*
Effectively held in position and restrained in direction at one end, but not held in position or restrained at the other end	2.0 *L*
NOTE *L* is the length of strut between points of lateral support.	

4.3.2 Eccentrically loaded struts

4.3.2.1 *Single-bay struts.* For single-bay struts consisting of a single angle connected by one leg only, a single channel connected by its web only, or a single tee connected by its table only, the average stress must not exceed $0.4\ p_c$. The value of p_c is the permissible stress obtained from Figure 1 at $\lambda = L/r$, taking r as the radius of gyration about the axis parallel to the gusset. The reduction of p_c to $0.4\ p_c$ is necessary to take into account the eccentricity of connection. In checking for torsional buckling, the eccentricity of connection may be ignored.

4.3.2.2 *Struts of two components back-to-back.* Struts consisting of two angles, channels (web-connected), or tees (table-connected), connected to both sides of end gussets, may be taken as axially loaded and designed as in **4.3.1** provided that they satisfy the following requirements.

They must be designed as integral members and must be connected together so that the slenderness ratio of each component between connections is not greater than 0.7 times the most unfavourable slenderness ratio of the composite strut. Each individual component, in contact or separated by a small distance, must be designed to carry its share of the load as a strut between adjacent fastenings.

The components must at each end of the strut be connected together with not less than two rivets or close-fitting bolts, or the equivalent in welding, and there must not be fewer than two additional connections equally spaced in the length of the strut. Where the connected legs are 4½ in (114 mm) or more wide, not less than two rivets or close-fitting bolts must be used in each connection and must be spaced as far apart as practicable (they may be staggered) across the connected-leg width. The diameters of the bolts or rivets in each intermediate connection must be the same as those in the end-connections. Where the connections are welded, both pairs of edges at the connection must be welded together, the strength of the welds being at least equal to that of the bolts or rivets specified above.

If the components are separated back-to-back, the bolts or rivets must pass through solid washers or packings; welds must be made to full-width solid packings.

Struts of two components back-to-back must not be subjected to transverse loading normal to the plane of contact of the components unless all forces are calculated and provided for.

4.3.2.3 *Others.* Any other eccentrically loaded strut must be designed for the combined axial load and bending moment (see **4.1.4.2**).

4.3.3 Torsional buckling. Torsional buckling is the type of failure in which the middle part of a strut rotates bodily relative to the ends. It may be critical for thin-walled open sections, particularly at low slenderness ratios. Closed hollow sections are free from it.

The permissible stress for a strut in torsional buckling must be read from Figure 1 at $\lambda = \lambda_t$. Values of λ_t for certain sizes of some common sections are given in Table 7; these expressions, which for channels depend on the factor k_t presented in Figure 3 and Figure 4, take account of interaction with column buckling. Torsional buckling will not be critical if λ_t is less than ℓ/r. For channels, it will not be critical if λ_y is greater than $k_t b/t_2$, where the symbols are as defined in Table 7.

For other sections the torsional properties must be obtained by reference to Appendix F, and the values of λ_t by reference to Appendix G. Use of the same Appendices may lead to slightly higher permissible stresses for the sections specifically dealt with in Table 7.

4.3.4 Battened struts

4.3.4.1 *General.* Struts composed of two main components battened must have the slenderness ratio for the axis perpendicular to the battens not more than 0.8 times that for the axis parallel to the battens.

Battens and their fastenings must be proportioned to resist a total transverse shear load S equal to 2½ % of the total compressive load on the strut, divided equally between the two parallel batten systems.

Where there is eccentricity of loading, applied end moments or lateral loads (including the 2½ % transverse shear load S) acting in the plane parallel to the battens, all forces resulting from deformation must be provided for in the battens and their fastenings.

4.3.4.2 *Spacing.* The spacing between battens must be such that the slenderness ratio of each strut component measured between the centres of battens does not exceed either 0.7 times the slenderness ratio of the complete strut with respect to the axis perpendicular to the battens, or 50.

Battens must be in pairs, placed opposite each other on the two sides of the main components, and must be spaced uniformly throughout the length of the strut.

Table 7 — Values of λ_t for struts

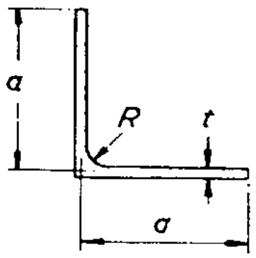
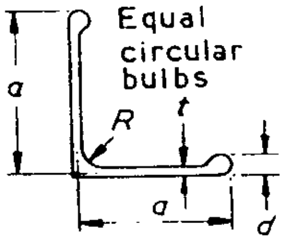
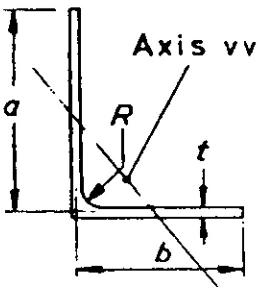
<table>
<tr><th>Section</th><th>Limits</th><th>Value of λ_t</th></tr>
<tr><td>
</td><td>$\frac{R}{t} \leqslant 3$</td><td>$\frac{5.2\,a}{t} - 1.3\left(\frac{R}{t}\right)^2$</td></tr>
<tr><td>
</td><td>$\frac{R}{t} \leqslant 3$
$\frac{d}{t} \leqslant 2.5$</td><td>$\frac{5.2\,a}{t} - 1.3\left(\frac{R}{t}\right)^2 - 2\left(\frac{d}{t} - 1\right)^3$
$+ 1.5\left(\frac{d}{t} - 1\right)\left(\frac{R}{t}\right)$</td></tr>
<tr><td>
</td><td>$\frac{R}{t} \leqslant 3$
$1 < \frac{a}{b} < 2$</td><td>$\sqrt{\lambda_o^2 + \lambda_v^2\sqrt{\frac{a}{b} - 1}}$
where $\lambda_o = 2.6\left(\frac{a+b}{t}\right) - 1.3\left(\frac{R}{t}\right)^2$
$\lambda_v = \frac{\ell}{r_v}$</td></tr>
<tr><td colspan="3">NOTE ℓ is the effective length
r_v is the radius of gyration about the axis vv (i.e. the minimum value of r).</td></tr>
</table>

Table 7 — Values of λ_t for struts

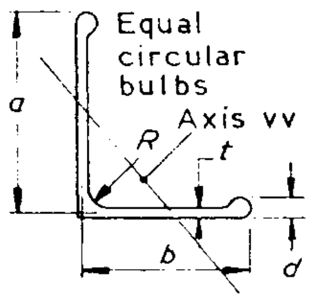
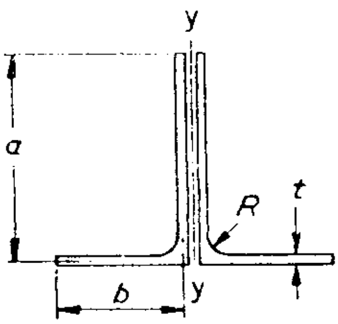
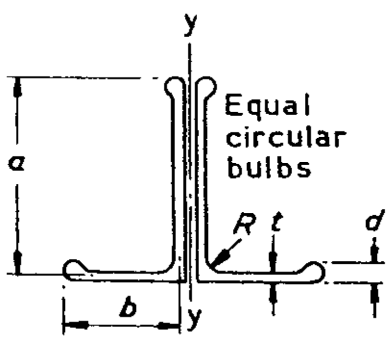
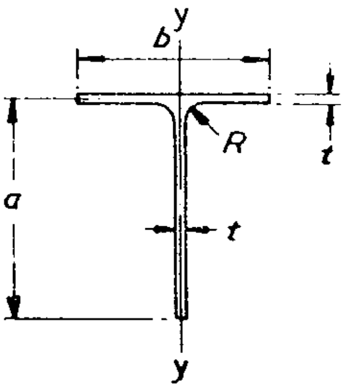
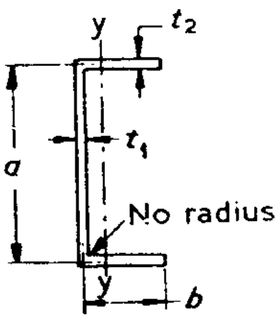
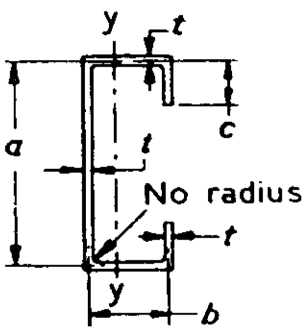
<table>
<tr><th>Section</th><th>Limits</th><th>Value of λ_t</th></tr>
<tr><td>
</td><td>$\frac{R}{t} \leqslant 3$
$1 < \frac{a}{b} < 2$
$\frac{d}{t} \leqslant 2.5$</td><td>$\sqrt{\lambda_o^2 + \lambda_v^2 \sqrt{\frac{a}{b} - 1}}$
where $\lambda_o = 2{\cdot}6\left(\frac{a+b}{t}\right) - 1{\cdot}3\left(\frac{R}{t}\right)^2 - 2\left(\frac{d}{t} - 1\right)^3 + 1{\cdot}5\left(\frac{d}{t} - 1\right)\left(\frac{R}{t}\right)$
$\lambda_v = \frac{\ell}{r_v}$</td></tr>
<tr><td>
</td><td>$R \leqslant 3$
$0.5 < \frac{a}{b} < 2$</td><td>$\sqrt{\lambda_o^2 + \lambda_y^2\left(\frac{a}{2b}\right)}$
where $\lambda_o = 1{\cdot}9\left(\frac{a+2b}{t}\right) - 1{\cdot}3\left(\frac{R}{t}\right)^2$
$\lambda_y = \frac{\ell}{r_y}$</td></tr>
<tr><td>
</td><td>$\frac{R}{t} \leqslant 3$
$0.5 < \frac{a}{b} < 2$
$\frac{d}{t} \leqslant 2.5$</td><td>$\sqrt{\lambda_o^2 + \lambda_y^2\left(\frac{a}{2b}\right)}$
where $\lambda_o = 1{\cdot}9\left(\frac{a+2b}{t}\right) - 1{\cdot}3\left(\frac{R}{t}\right)^2 - 2\left(\frac{d}{t} - 1\right)^3 + 1{\cdot}5\left(\frac{d}{t} - 1\right)\left(\frac{R}{t}\right)$
$\lambda_y = \frac{\ell}{r_y}$</td></tr>
<tr><td colspan="3">NOTE ℓ is the effective length
r_y is the radius of gyration about the axis yy
r_v is the radius of gyration about the axis vv (i.e. the minimum value of r).</td></tr>
</table>

Table 7 — Values of λ_t for struts

Section	Limits	Value of λ_t
	$\frac{R}{t} \leqslant 2$ $0.5 < \frac{a}{b} < 1$	$\sqrt{\lambda_o^2 + \lambda_y^2\left(\frac{0.8\,a}{b}\right)}$ where $\lambda_o = \left(\frac{3.2\,a + b}{t}\right) - 2\left(\frac{R}{t}\right)^2$ $\lambda_y = \frac{\ell}{r_y}$
	$R = 0$ $1 < \frac{a}{b} < 3$ $1 < \frac{t_2}{t_1} < 2$	$0.5\left(\frac{k_t b}{t_2} + \lambda_y\right)$ where k_t is obtained from Figure 3 $\lambda_y = \frac{\ell}{r_y}$ The presence of small fillets ($R \leqslant 2\,t$) has negligible effect on λ_t
	$R = 0$ $1 < \frac{a}{b} < 3$ $\frac{c}{a} \leqslant 0.3$	$0.5\left(\frac{k_t b}{t} + \lambda_y\right)$ where k_t is obtained from Figure 4 $\lambda_y = \frac{\ell}{r_y}$ The presence of small fillets ($R \leqslant 2\,t$) has negligible effect on λ_t

NOTE ℓ is the effective length
r_y is the radius of gyration about the axis yy.

Table 7 — Values of λ_t for struts

Section	Limits	Value of λ_t
Symmetrical I-section	None for: plain section, lipped section and bulb section with $\frac{d}{t} \leqslant 2.5$	Torsional buckling may be ignored
Closed hollow section		Torsional buckling may be ignored
Others		See Appendix G

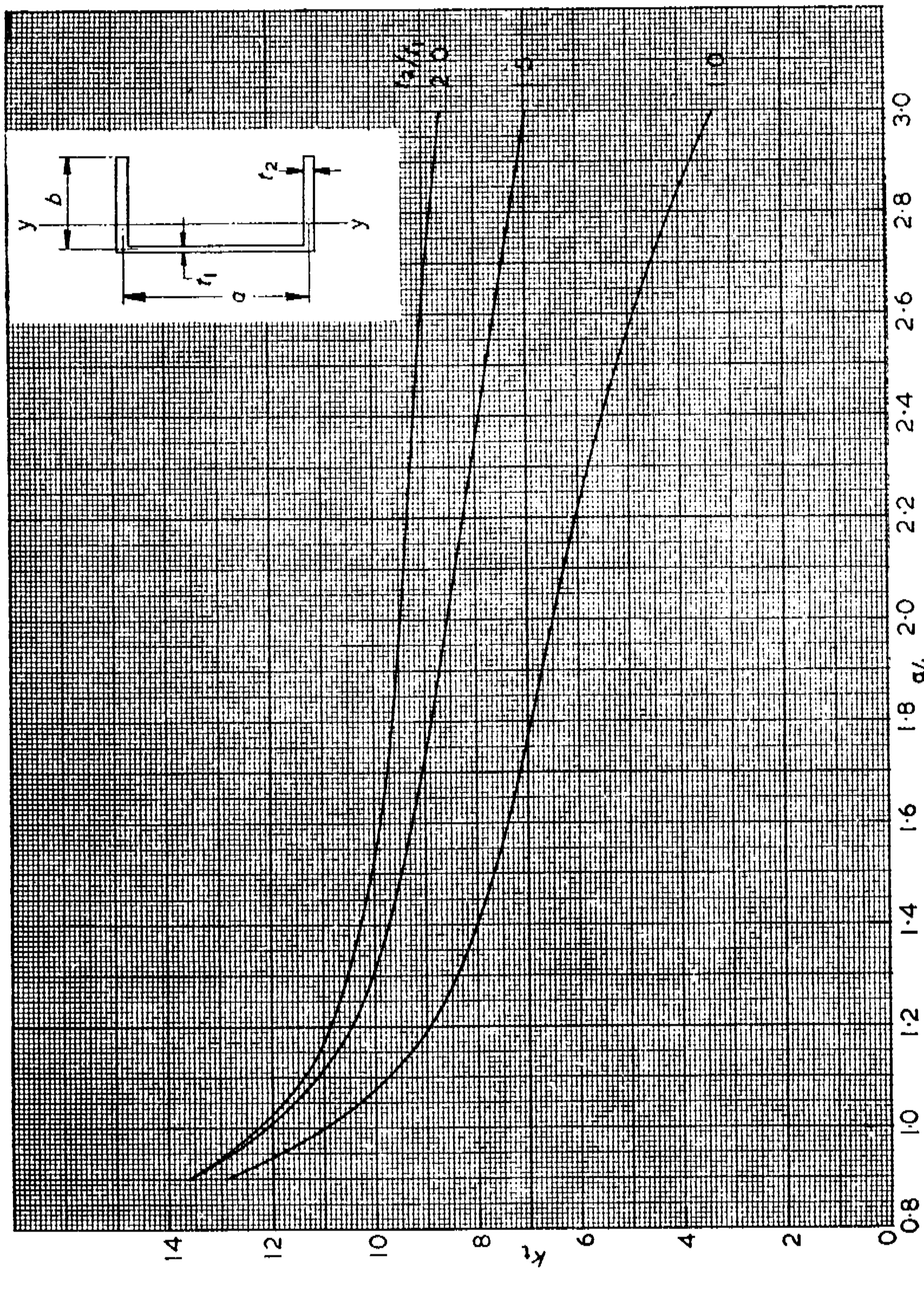


Figure 3 — Values of k_t for plain channels

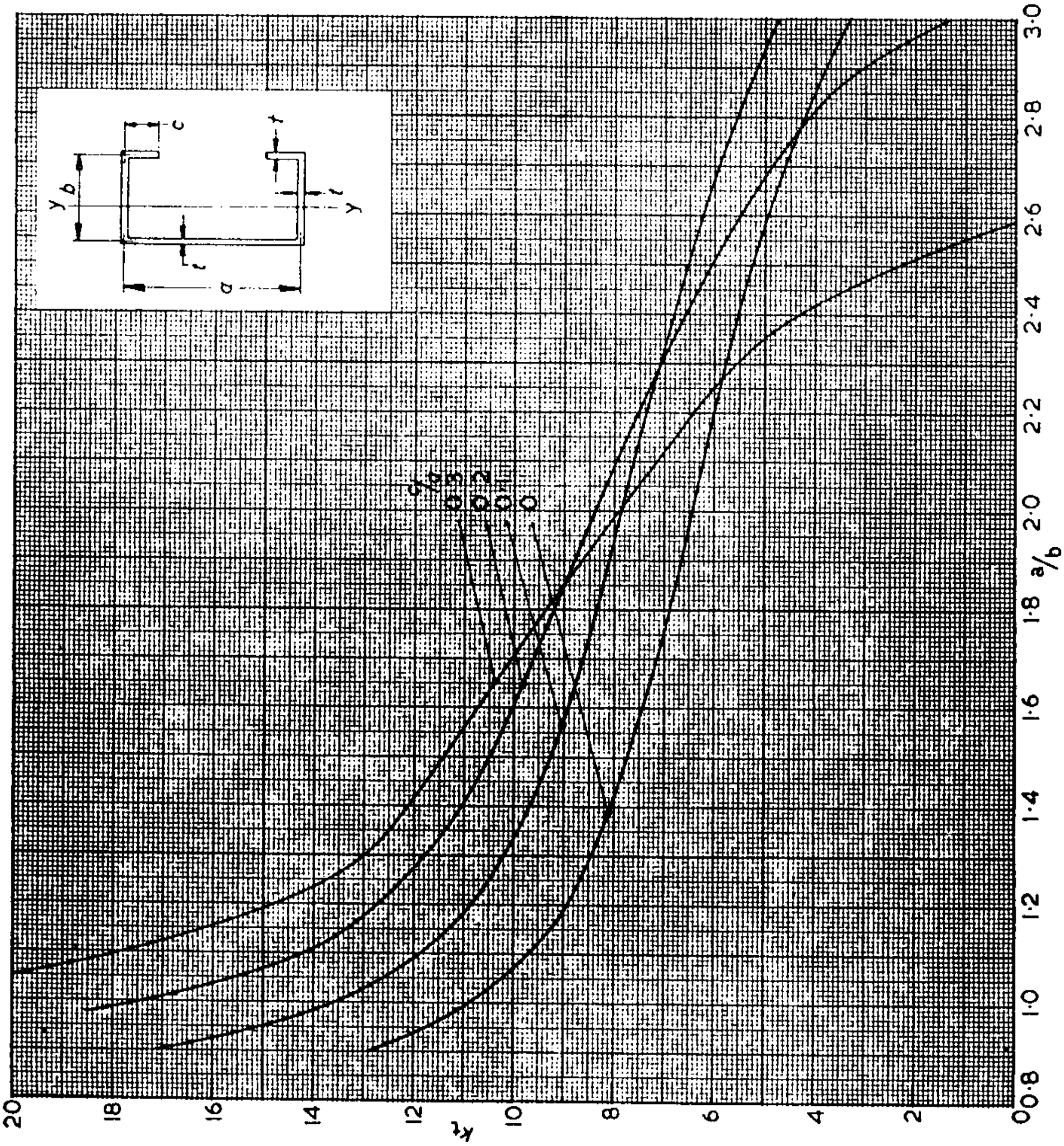


Figure 4 — Values of k_t for lipped channels

4.3.4.3 *Length.* The effective length of a batten, measured along the strut, must be not less than three quarters the distance a between the centroids of the bolt or rivet groups, or of the welds (see Figure 5).

4.3.4.4 *Thickness.* The thickness of a batten plate must be not less than either $a/36$ or 0.10 in (2.5 mm), whichever is larger. Alternatively, if the free edges of the batten plate are turned over to make effective flanges of gross width not less than $a/12$ or if a channel section is used, the thickness of the plate or section web must be not less than either $a/50$ or 0.10 in (2.5 mm), whichever is larger. The symbol a has the same meaning as in **4.3.4.3**.

4.3.4.5 *Fastening.* Each batten must be fastened to the main components by at least two rivets or close-fitting bolts, or by welding. Each fastening must be designed to resist simultaneously a longitudinal shear force of $Sd/(2a)$ and a moment of $Sd/4$, together with any other forces due to bending of the struts, where S is the shear load (see **4.3.4.1**),

d is the distance between centres of battens (see Figure 5), and

a has the same meaning as in **4.3.4.3**.

4.3.5 Laced struts

4.3.5.1 *General.* Struts composed of two main components laced and tied must, where possible, have the slenderness ratio for the axis perpendicular to the lacing planes not greater than that for the axis parallel to the lacing planes.

Laced struts must be provided with tie plates at the ends of the lacing system. If the system is interrupted, intermediate tie plates must be used.

Lacing bars and their fastenings must be proportioned to resist a total transverse shear load S equal to 2½ % of the total compressive load on the strut, divided equally between the two parallel lacing systems.

Where there is eccentricity of loading, applied end moments or lateral loads (including the 2½ % transverse shear load S) acting in a plane parallel to the lacing system, all forces resulting from deformation must be provided for in the lacing system and its fastenings.

Single-laced systems opposed in direction on the two sides of the main components, and all double-laced systems, must not be combined with cross members (except end tie plates) perpendicular to the longitudinal axis of the strut, unless all forces resulting from deformation of the strut members are calculated and provided for in the lacing bars and tie plates and their fastenings.

Connections of lacing bars and tie plates must be opposite to each other on the two sides of the main components, and must be spaced uniformly throughout.

4.3.5.2 *Lacing bars.* Single or double lacing systems must have the lacing bars inclined at angles not less than 40° nor more than 70° to the longitudinal axis. Each lacing bar must be fastened to each main component by one or more rivets or close-fitting bolts, or by welding.

4.3.5.3 *Tie plates.* Tie plates and their fastenings must be designed as for battens (see **4.3.4**). An intermediate tie plate must have an effective length of not less than $3a/4$, where a has the same meaning as in **4.3.4.3**.

4.3.6 Welded struts. Welded struts in materials in the O and M condition (e.g. N8-O, N8-M) may be designed as though they were unwelded.

With heat-treated materials (e.g. H30-TF) and work-hardened materials (e.g. N5-H2) the effect of reduced-strength zones (see **4.6.3.2**) depends on the extent and position of the zones in relation both to the cross-section and to the length of the strut. In the present state of knowledge, only approximate rules for design (see below) can be given. Greater economy may be effected by making use of published research[14] and by testing.

[14] e.g. "Strength of welded aluminium columns" (Brungraber and Clark. *Trans. Am. Soc. C. E.* Vol. 127. Part II, 1962).

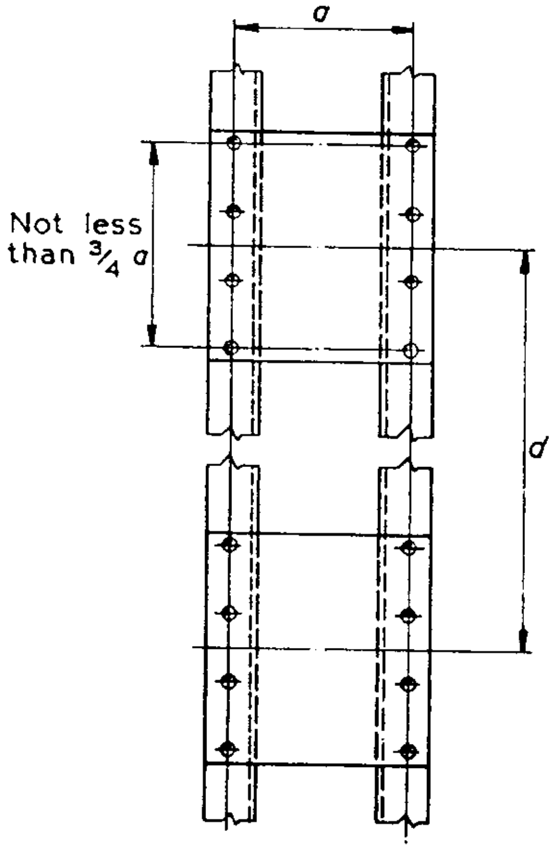


Figure 5 — Batten dimensions and spacing

The rules are as follows:

1) An empirical graph giving permissible compressive stresses for struts consisting wholly of reduced-strength zones may be set up for any material, as follows. On the axes of Figure 1 draw a straight line from a point with ordinate p_{wt} (see Table 14) at λ = 8 to a point on the existing hyperbola with ordinate $p_{wt}/3$.

The permissible stress may then be read from the new graph at the appropriate value of λ.

2) For a symmetrical strut with one or more longitudinal welds (e.g. welds by which a member is built up from plates or sections), and with the reduced-strength zones disposed symmetrically with respect to the principal axes of the cross-section, the permissible stress is equal to $p_c - n(p_c - p_{wc})$,
where p_c is the permissible compressive stress for unwelded material, obtained from Figure 1 or Figure 2 as appropriate.

p_{wc} is the permissible compressive stress obtained as in 1) above, and

n is the fraction of the cross-section consisting of reduced-strength zones.

For any other strut with longitudinal welds extending over one-tenth of its length or more, the permissible stress is p_{wc}.

3) For a strut with one or more transverse welds (e.g. butt welds, or welds connecting other members or attachments), the permissible stress is obtained as in 1) above.

4) Notwithstanding 2) and 3) above, a strut with a weld or welds within one-tenth of its length from either end may be designed as though it were unwelded, provided that the affected ends be taken as unrestrained in direction.

4.3.7 Maximum slenderness ratio. The effective slenderness ratio of a strut (see **4.3.1**) must not normally exceed 120. However, it may exceed 120 but not 180 provided that the strut is not subject to shock or vibratory loads, and provided that account is taken of incidental lateral loads. The limit of 180 also applies to ties that may become struts by reversal of stress, even where the reversal is due only to wind.

4.4 Beams

4.4.1 Beams in general: deflection. Because the modulus of elasticity of aluminium is about one third that of steel, the design of beams is often governed by deflection. Some deflection is of course acceptable, but it is limited by the requirement that it must not be such as to impair the strength, function or appearance, or to cause damage to the finish, of any part of the structure. For buildings the following limits must not be exceeded:

1) Beams carrying plaster finish	span/360
2) Purlins and sheeting rails	
under dead load only	span/200
under worst combination of dead, imposed, wind and snow loads	span/100
3) Curtain wall mullions	span/175
4) Members carrying glass direct	(span, in)^2/11 000 in (span, mm)^2/280 000 mm

For other members the limit of deflection, unless specified in an appropriate British Standard (e.g. BS 466[15)]), must be established by the engineer.

In calculating the deflection of a beam, the gross value of the second moment of area must be used; the effects of bolt and rivet holes, and of reduced-strength zones due to welding, may be ignored.

4.4.2 Beams in general: section properties

4.4.2.1 *Flanges.* The gross area of the flange of an extruded beam without additional flange plates is the product of the flange width and its average thickness.

The gross area of the flange of a beam of bolted or riveted construction is the sum of the gross areas of the extruded flange (including its web or webs if any) and flange plates if any, or the sum of the gross areas of the flange angles, the flange plate or plates and those parts of the web, including side plates if any, between the flange angles.

The gross area of the flange of a beam of welded construction is the sum of the gross areas of the extruded flange and flange plates if any, or the sum of the gross areas of the flange plate or plates and the tongue plate if any; in this computation the depth of the tongue plate is limited to 8 times its thickness, which must not be less than twice that of the web.

The effective area of a tension flange is the gross area with deductions for holes and welds (see **4.2.1**).

The effective area of a compression flange is the gross area with deductions as for a tension flange but ignoring holes filled by rivets or close-fitting bolts.

4.4.2.2 *Webs.* The effective area of the web of an extruded beam is the product of the web thickness and the overall depth of the section.

The effective area of the web of a built-up beam is the product of the overall depth and the thickness of the actual web plate.

Where a beam section is not symmetrical about the neutral axis of bending, or where the web varies in thickness (e.g. by the use of tongue plates), or where the depth of web included in a flange area (see **4.4.2.1**) is greater than one quarter of the overall depth, the above approximations are not permissible, and the web stresses must be computed with due regard to the distribution of bending stresses.

4.4.2.3 *Flanges and webs with large holes.* Flanges and webs having holes larger than those normally required for bolts or rivets must be the subject of special analysis, and the provisions of **4.4.2.1** and **4.4.2.2** do not apply.

4.4.2.4 *Use in design.* Beams must be designed on the basis of the second moment of area of the gross cross section about the neutral axis. In calculating the maximum bending stresses, the stress calculated on the basis of the gross second moment of area must, for each flange, be increased in the ratio of its gross area to its effective area.

[15)] BS 466, "*Electric overhead travelling cranes for general use in factories, workshops and warehouses*".

4.4.3 Beams in general: permissible stresses

4.4.3.1 *Flanges.* The bending tensile stress in the extreme fibre of a beam, calculated on the effective section (see **4.4.2**) must not exceed the permissible value given in Table 4.

The bending compressive stress, calculated on the effective section (see **4.4.2**), must not exceed the permissible value, either for lateral buckling or local buckling, obtained from Figure 2.

4.4.3.2 *Webs.* Provided that the ratio d/t does not exceed C_1 in Table 8, the average shear stress, taken as the shear force divided by the effective web area (see **4.4.2.2**), must not exceed the permissible value given in Figure 6. In using Figure 6, values of b/d greater than 2 must be considered as infinite. The requirements of **4.1.4.3**, **4.1.4.4** and **4.4.7.3** must also be met.

If d/t exceeds C_1, stiffeners are required (see **4.4.6.4**).

Table 8 — Values of C_1 and C_2 for webs

Alloy	C_1		C_2	
H30-TF sheet plate	65 67		120 124	
N8-O, N8-M plate	84		156	
Others	$150/\sqrt{p_q}$	p_q in tonf/in^2	$280/\sqrt{p_q}$	p_q in tonf/in^2
	$590/\sqrt{p_q}$	p_q in N/mm^2	$1\,100/\sqrt{p_q}$	p_q in N/mm^2

NOTE p_q is the permissible maximum shear stress of the alloy (see Table 4).

4.4.4 Beams in general: lateral buckling

4.4.4.1 *General.* Lateral buckling is the mode of failure of a beam in which twisting is combined with sideways deflection.

4.4.4.2 *Beams bent about major axis.* An unrestrained beam, subject to bending about the major axis only, must be so proportioned that the bending compressive stress in any part between points of support shall not exceed the permissible stress obtained from Figure 2 at $\lambda = \lambda_{lat}$ where λ_{lat} for that part is calculated as below:

1) *I-sections and channels.*

$\lambda_{lat} = k_{lat}\sqrt{(\ell_f/t_2)}$,

where t_2 is the flange thickness, and

k_{lat} is obtained from Figure 7.

2) *Rectangular sections, solid or hollow.*

$\lambda_{lat} = k_{lat}\sqrt{(\ell_f/b)}$,

where b is the width of the section, and

k_{lat} is obtained from Figure 8.

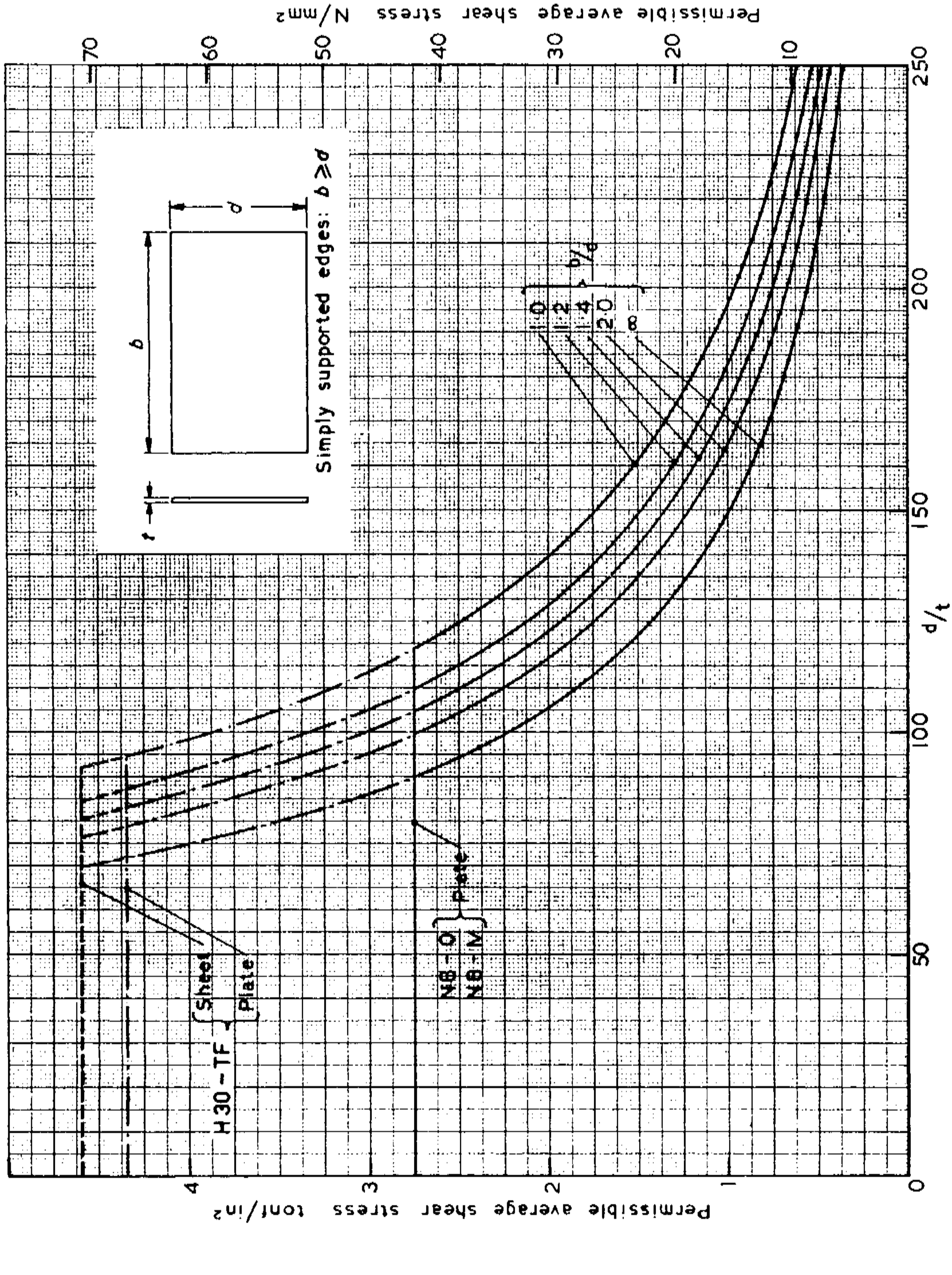


Figure 6 — Permissible average shear stresses in unstiffened webs and thin plates

3) *Other doubly-symmetrical sections.*

$$\lambda_{lat} = 2{\cdot}3\left\{I_x\,(I_x - I_y)/JI_y\right\}^{1/4}(\ell_f/y)^{1/2},$$

where I_x and I_y are the second moments of area about the major and minor axes,

J is the torsion factor (see Appendix F), and

y is the distance from the extreme compression fibres to the neutral axis.

4) *Singly-symmetrical sections.*

Sections symmetrical about the minor axis only are dealt with in Appendix H.

In the above formulae, provided that the beam receives lateral support at all points of application of load,

$\ell_f = k_1 k_2 L$,

where L is the distance between points of lateral support,

k_1 is a factor depending on the conditions of restraint at those points (see Table 9), and

k_2 is a factor depending on the shape of the bending-moment diagram between those points (see Table 10).

If lateral support is not present at the points of application of load, the rules of Appendix H may be applied.

The effect of warping resistance, which is ignored above, may be appreciable for thin-walled open sections, and greater economy may derive from a more precise analysis[16]. An approximate treatment for doubly-symmetrical sections supported laterally at load points is given in Appendix H.

Table 9 — Condition-of-restraint factor k_1

Condition of restraint at points of lateral support	k_1
Full restraint against twisting and minor-axis bending	0.7
Full restraint against twisting, but minor-axis bending unrestrained	1.0
Restraint against twisting confined to that due to continuity; minor-axis bending unrestrained	1.2

[16] "Buckling strength of metal structures", F. Bleich, McGraw-Hill, 1952.

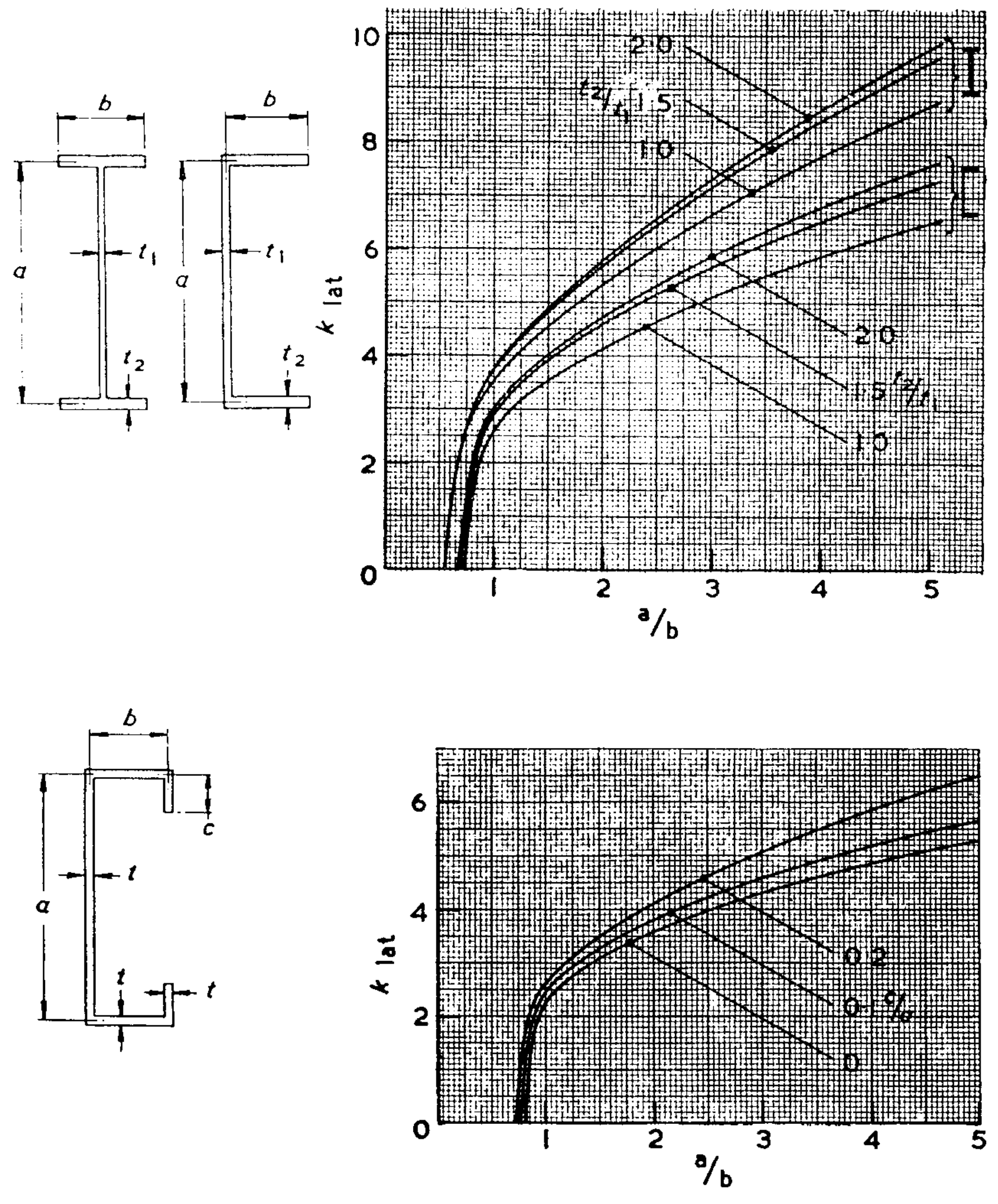


Figure 7 — Values of k_{lat} for I-sections and channels

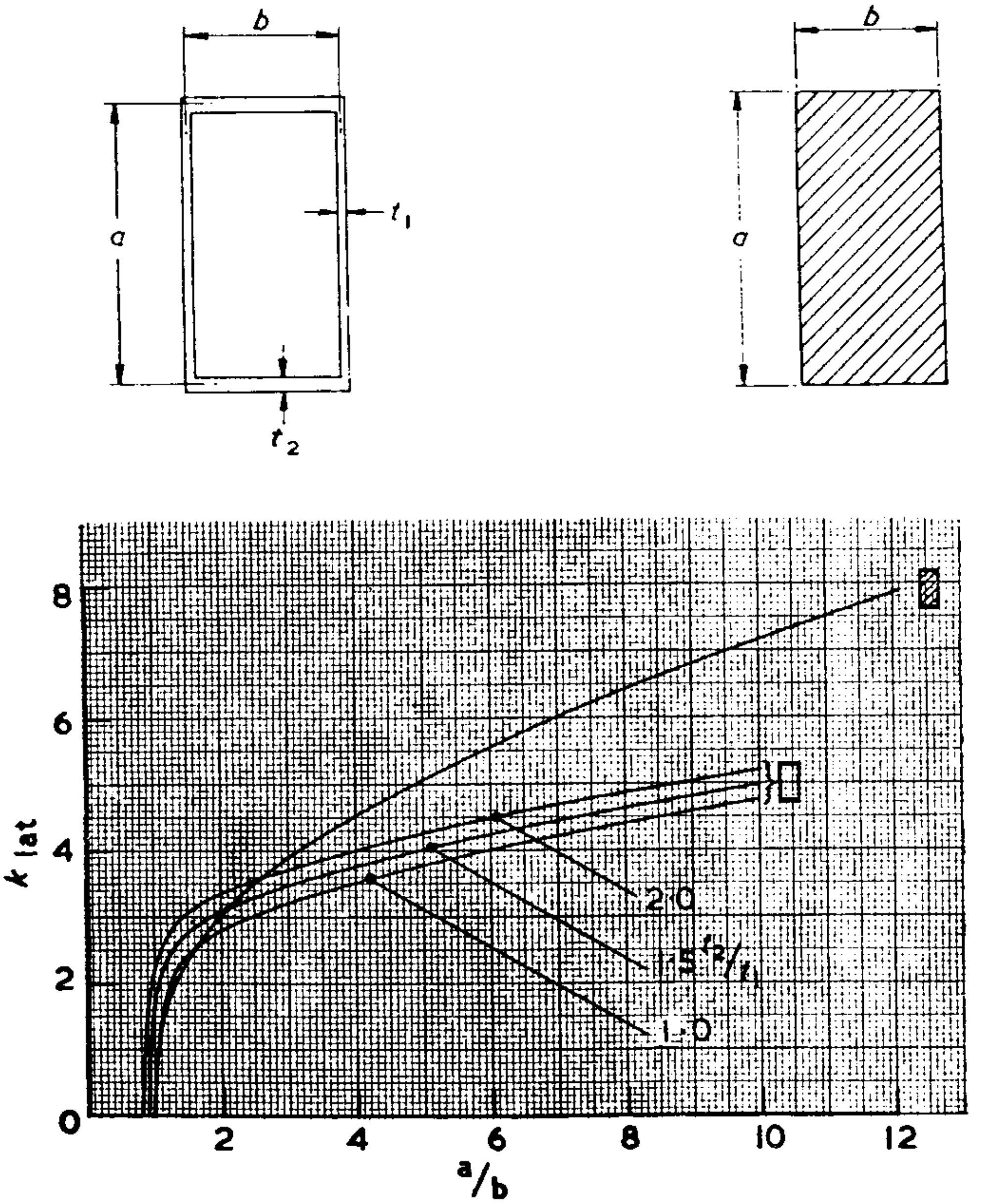
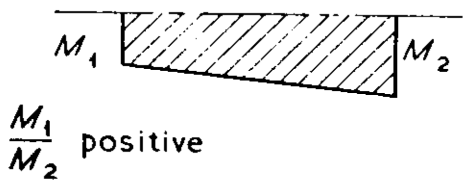
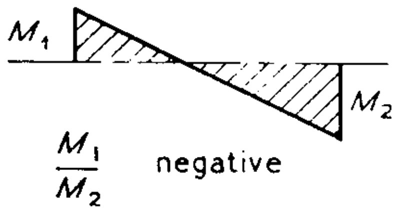


Figure 8 — Values of k_{lat} for rectangular sections

Table 10 — Bending-moment-shape factor k_2

Type of loading	Bending moment diagram between points of lateral support	k_2
		$\left(0.6 + 0.4\,\dfrac{M_1}{M_2}\right)$ or 0.4, whichever is greater M_2 is numerically greater than, or equal to, M_1
		

4.4.4.3 *Beams bent about both axes.* An unrestrained beam subject to bending about both axes must be proportioned for major axis bending alone in accordance with **4.4.4.2** and also that

$$\frac{f_x}{p_{bc}} + \frac{f_y}{p_{bt}} \leqslant 1\,,$$

where f_x is the extreme fibre compressive stress due to major-axis bending,
f_y is the extreme fibre stress (tensile or compressive) due to minor-axis bending,
p_{bc} is the permissible bending compressive stress obtained from **4.4.4.2**,
p_{bt} is the permissible bending tensile stress (see Table 4).

In addition, the tensile stress due to major-axis and minor-axis bending combined must not exceed p_{bt}.

4.4.5 Beams in general, with end loads. A beam in which bending is combined with axial tension or compression must be designed in accordance with **4.1.4.1** or **4.1.4.2** respectively.

4.4.6 Built-up beams: construction details

4.4.6.1 *Flanges.* In any built-up beam, each flange (see **4.4.2.1**) must be connected to the web by enough bolts, rivets or welding to transmit the horizontal shear forces together with any vertical applied forces on the flange except that, where the web is in continuous contact with the flange plate, it may be assumed that such vertical forces are transmitted by direct bearing. Such vertical forces may be considered to act uniformly on the flange-web joint over a length defined by the intercept on the joint line of two diverging lines drawn from the extremities of the load area at 30° to the plane of the flange.

In a bolted or riveted beam, flange angles must form as large a part (preferably not less than one third) of the flange area as practicable, and the number of flange plates must be kept to a minimum. Flange plates should preferably all be of the same thickness, and one of the top flange plates must extend over the full length of the beam unless the top of the web is finished flush with the flange angles. Each flange plate must extend beyond its theoretical cut-off points, and be connected by enough bolts or rivets to develop its calculated load at those points.

In a welded beam, local increase of flange area should be effected by inserting a flange plate of heavier section. The ends of such a plate must be butt-welded to the lighter flange plate (see Table 29) to give a continuous flange. The heavier plate must extend beyond its theoretical cut-off points and must be connected by enough welding to develop its calculated load at those points.

Flange joints should preferably not be located at points of maximum moment. Where a flange of a bolted or riveted beam is spliced, the area of cross-section of the splice plate must be not less than that of the part spliced, and its centroid must be as close as possible to that of the part spliced. Enough bolts or rivets must be used on each side of the splice to develop the load on the part spliced. In a welded beam, flange splices must be made with butt welds.

4.4.6.2 *Webs.* Where a built-up beam without full-length top flange plates is exposed in a severe environment, the top edge of the web plate must be finished either flush with or above the flange angles.

A web joint must be designed to resist the shear and bending forces in the web at the joint. In bolted or riveted construction, splice plates must be provided on both sides of the web. In welded construction, web joints should preferably be butt-welded.

4.4.6.3 *Bearing stiffeners.* Bearing stiffeners must be provided at all points of concentrated load or reaction, including points of support, where the concentrated load or reaction exceeds $p_c\,tb$,

where p_c is the permissible compressive stress obtained from Figure 1 at $\lambda = 1.73\ d/t$

t is the thickness of the web, and

b is the length of the stiff portion of the bearing plus half the depth of the beam, including any flange plates, at the bearing. The stiff portion of a bearing is that length which cannot deform appreciably in bending; it must not be taken as greater than half the depth of the beam, and

d is the depth of web between root fillets or between toes of flange angles.

Bearing stiffeners must, where possible, be symmetrical about the web and, at points of support, must project as nearly as practicable to the outer edges of the flanges. Each stiffener assembly must be designed as a strut to carry the whole concentrated load, the strut being assumed to consist of the pair of stiffeners together with a length of web on each side of the centre line of the assembly equal to twenty times the web thickness, provided that such length is actually available. The radius of gyration must be taken about the axis parallel to the web of the beam, and the permissible stress must be that for a strut of effective length equal to 0.7 times the length of the stiffener (see **4.3.1**; note that torsional buckling need not be considered).

The outstanding leg of each stiffener must be so proportioned that the bearing stress on that part of its area clear of the root of the flange or flange angle or clear of the flange-to-web weld does not exceed the permissible bearing stress given in Table 4. Sufficient rivets, welds or close-fitting bolts must be provided to transmit to the web that portion of the concentrated load carried by the stiffener.

Where a bearing stiffener at a support is the sole means of providing restraint against torsion, the second moment of area of the stiffener assembly about the centre line of the web must be not less than

$$\frac{d_o^3 t_o R}{250W},$$

where d_o is the overall depth of the beam,

t_o is the maximum thickness of the compression flange,

R is the reaction at the bearing, and

W is the total load on the beam.

In addition, either the beam must be securely bolted down at the bearings or the width of the seating under the stiffener must be not less than $d_o/3.5$.

The ends of bearing stiffeners must be fitted to provide tight and uniform bearing on the loaded flange unless welds, designed to transmit the full reaction, are provided between flange and stiffener. Bearing stiffeners must not be joggled and must be solidly packed throughout.

4.4.6.4 *Transverse stiffeners.* Intermediate transverse stiffeners must be provided throughout the length of a beam where the ratio d/t exceeds the quantity C_1 in Table 8,

where d is the depth of web between root fillets or between toes of flange angles, and

t is the thickness of the web.

Transverse stiffeners may be single, in which case they should preferably be placed alternately on opposite sides of the web (but see **4.4.6.5**), or may consist of pairs of stiffeners arranged one on each side of the web. They must extend substantially from flange to flange but need not be connected to either flange.

Transverse stiffeners must be so designed that the second moment of area of a single stiffener about the face of the web, or of a pair of stiffeners about the centre line of the web, is not less than

$1.3\, d^3t^3/b^2$,

where d and t have the meanings given above, and

b is the spacing of the stiffeners (with stiffeners on one side only, b must be taken to the lines of attachment of them; with stiffeners both sides, b may be taken as the clear distance between them provided that they are at least as thick as the web).

If the spacing of the stiffeners is made smaller or the web thickness is made greater than required above or in **4.4.3** or **4.4.7** respectively, the second moment of area of the stiffener or pair of stiffeners need not be correspondingly increased. Normally, it will be neither economical nor necessary to have stiffeners at spacings greater than 1.5 d.

4.4.6.5 *Longitudinal stiffeners.* Where the ratio d/t exceeds the quantity C_2 in Table 8, the symbols d and t having the same meanings as in **4.4.6.4**, a longitudinal stiffener must be provided in addition to intermediate transverse stiffeners. Figure 9 gives, for various $f_{q\cdot av}/f_1$ and b/d ratios, values of the ratio h/d such that the panels above and below the longitudinal stiffener are of equal strength,

where $f_{q\cdot av}$ is the average shear stress,

f_1 is the maximum total compressive stress due to combined bending and axial compression (usually occurring in an upper panel adjacent to the compression flange),

b is the transverse stiffener spacing (see **4.4.6.4**), and

h is the distance from compression flange (root fillet or toes of flange angles) to longitudinal stiffener (line of attachment for single stiffener, top edge for stiffeners both sides).

A longitudinal stiffener may be single, in which case it may be conveniently placed on the opposite side of the web to a series of single transverse stiffeners, or it may consist of a pair of stiffeners arranged one on each side of the web. A longitudinal stiffener must extend fully between intermediate transverse stiffeners, but may be interrupted at each of them.

Longitudinal stiffeners must be so designed that the second moment of area of a single stiffener about the face of the web, or of a pair of stiffeners about the centre line of the web, is not less than $4\, dt^3$.

4.4.6.6 *Thickness of transverse and longitudinal stiffeners.* The outstanding leg of a plate stiffener or a web-attached angle stiffener must be such that the ratio of its width to thickness does not exceed 12, unless its outer edge is continuously stiffened by a bulb or lip of which the effect is to give at least the equivalent strength in local buckling (see **4.5.1**).

The distance between the centre line of the attachments of a stiffener and the further face of the outstanding leg of the stiffener must be not more than

$13.5\, t_s^2/t$,

where t_s is the thickness of the attached leg of the stiffener, and

t is the thickness of the web.

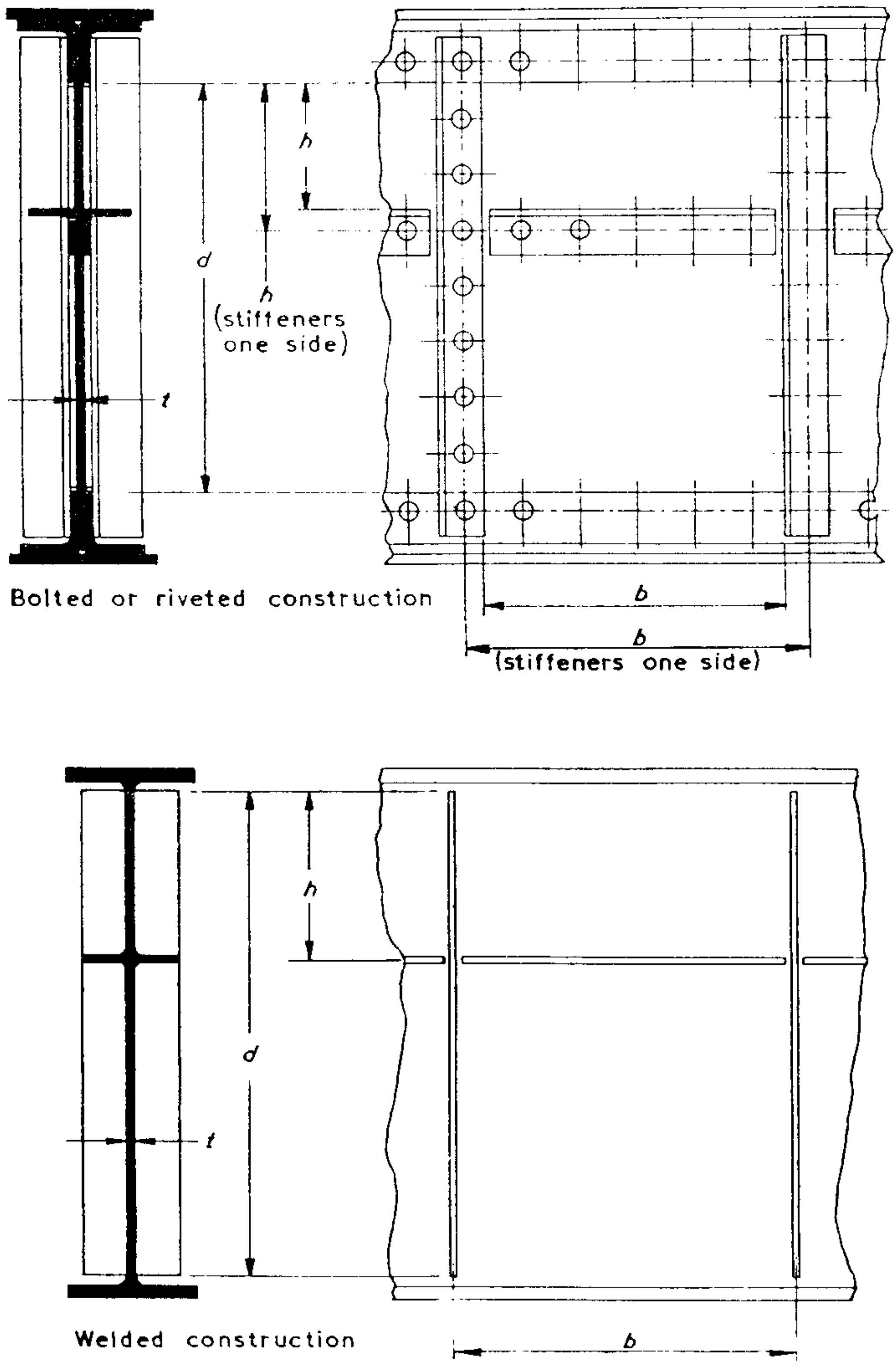
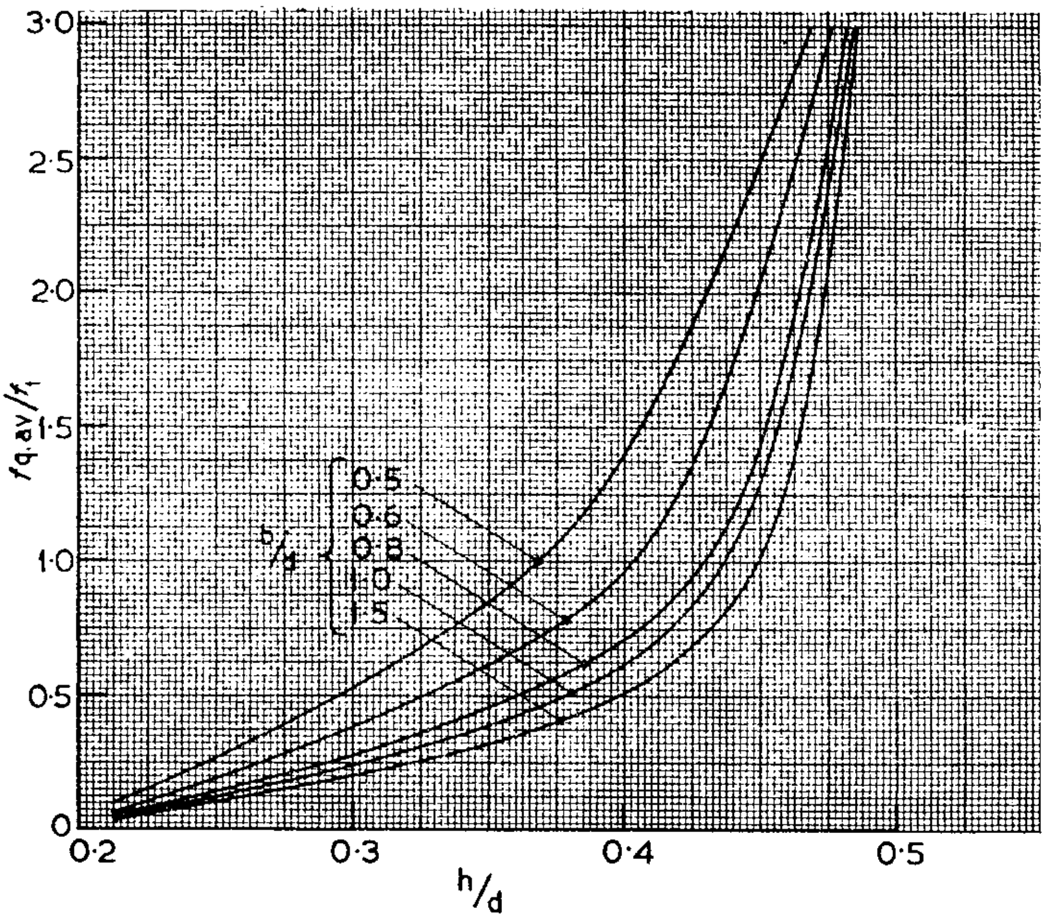


Figure 9 — Optimum spacing of longitudinal stiffeners



Symbols are defined in 4.4.6

Figure 9 — Optimum spacing of longitudinal stiffeners *(continued)*

4.4.6.7 *Connection of transverse and longitudinal stiffeners.* A transverse or longitudinal stiffener, not subject to external loads, must be connected to the web so as to withstand a shear force between stiffener and web, per unit length of stiffener, of not less than

$8\ t^2/s$ tonf/in (t and s in inches), or $123\ t^2/s$ N/mm (t and s in mm),

where t is the thickness of the web, and

s is the unsupported width of the outstanding leg of the stiffener.

For a stiffener subject to external loads, the shear force between stiffener and web due to such loads must be added to the above value.

4.4.7 Built-up beams: permissible stresses

4.4.7.1 *Section properties.* The effective areas of flanges and webs, and the basis for determining flange stresses, are given in **4.4.2**.

4.4.7.2 *Flanges.* Permissible stresses for flanges are given in **4.4.3.1**.

4.4.7.3 ***Unstiffened webs*** ($d/t \leqslant C_1$ in *Table 8*)

1) *In shear.* Permissible average shear stresses for unstiffened webs are dealt with in **4.4.3.2**.

2) *In pure bending.* The bending compressive stress must not exceed the permissible value obtained from the curve $h/d = 0$ in Figure 10, where h and d have the meanings given in **4.4.6.5** and **4.4.6.4** respectively.

3) *In combined bending and axial compression.* The total compressive stress due to combined bending and axial compression must exceed neither the permissible compressive stress obtained from Figure 2 nor a value equal to $k_b t^2/d^2$, where k_b is a buckling coefficient dependent on the distribution of total longitudinal stress as given in Figure 11, and d and t have the meanings given in **4.4.6.4**.

4) *In combined bending, axial compression and shear*. The following expression must be satisfied:

$$(f_1/p_1)^n + (f_{q \cdot av}/p_{q \cdot av})^2 \leqslant 1,$$

where f_1 is the maximum total compressive stress due to combined bending and axial compression,

p_1 is the permissible total compressive stress obtained from 3) above,

$f_{q \cdot av}$ is the average shear stress,

$p_{q \cdot av}$ is the permissible average shear stress obtained from 1) above, and

n is an exponent, dependent on the distribution of total longitudinal stress, as given in Figure 12, where the above equation with the left-hand side equal to unity is plotted.

4.4.7.4 *Webs with transverse stiffeners ($C_1 < d/t \leqslant C_2$ in Table 8).* The permissible stresses given in 1) to 4) below are applicable provided that the stiffeners satisfy the conditions of **4.4.6.4**, and that I_f/bt^3 is not less than 0.00035,

where I_f is the second moment of the gross area of the compression flange

(see **4.4.2.1**) about its axis normal to the web, and

b and t have the meanings given in **4.4.6.4**.

1) *In shear*. Permissible average shear stresses are given in Figure 13 for various stiffener spacings and d/t ratios, where d and t have the meanings given in **4.4.6.4**.

2) *In pure bending*. Permissible stresses are obtained as in **4.4.7.3** 2).

3) *In combined bending and axial compression.* Permissible stresses are obtained as in **4.4.7.3** 3).

4) *In combined bending, axial compression and shear.* The requirements of **4.4.7.3** 4), but with $p_{q \cdot av}$ as obtained from **4.4.7.4** 1), must be satisfied.

4.4.7.5 *Webs with longitudinal and transverse stiffeners* ($d/t > C_2$ in *Table 8*). The permissible stresses given in 1) to 4) below are applicable provided that the stiffeners satisfy the conditions of **4.4.6.4** and **4.4.6.5**, and that I_f/bt^3 is not less than 0.00035, where I_f, b and t have the meanings given in **4.4.7.4**.

1) *In shear.* The average shear stress in any panel must not exceed the permissible value obtained from Figure 13 where d is taken either as h, the ratios in the figure being read as b/h and h/t, or as $(d-h)$, the ratios being read as $b/(d-h)$ and $(d-h)/t$. The symbols d and t have the meanings given in **4.4.6.4**, and h has the meaning given in **4.4.6.5**.

2) *In pure bending*. The bending compressive stress in any panel must not exceed the permissible value obtained, by interpolation if necessary, from Figure 10 at the appropriate h/d ratio, where h and d have the meanings given in **4.4.6.5** and **4.4.6.4** respectively.

3) *In combined bending and axial compression.* The total compressive stress in any panel due to combined bending and axial compression must exceed neither the permissible value obtained from Figure 2 nor a value equal to $k_b t^2/h^2$ for an upper panel nor $k_b t^2/(d-h)^2$ for a lower panel, where k_b, d, h and t have the meanings given in **4.4.7.3**.

4) *In combined bending, axial compression and shear*. The requirements of **4.4.7.3** 4), but applying to any panel and with $p_{q \cdot av}$ and p_1 obtained respectively from 1) and 3) of **4.4.7.5**, must be satisfied.

4.4.7.6 *Webs with torsionally strong stiffeners*. The requirements of **4.4.7.4** and **4.4.7.5** are based on the conservative assumption that the flanges and stiffeners provide no torsional restraint to the web. In many cases, more economical beams can be designed by taking such restraint into account (see Appendix J).

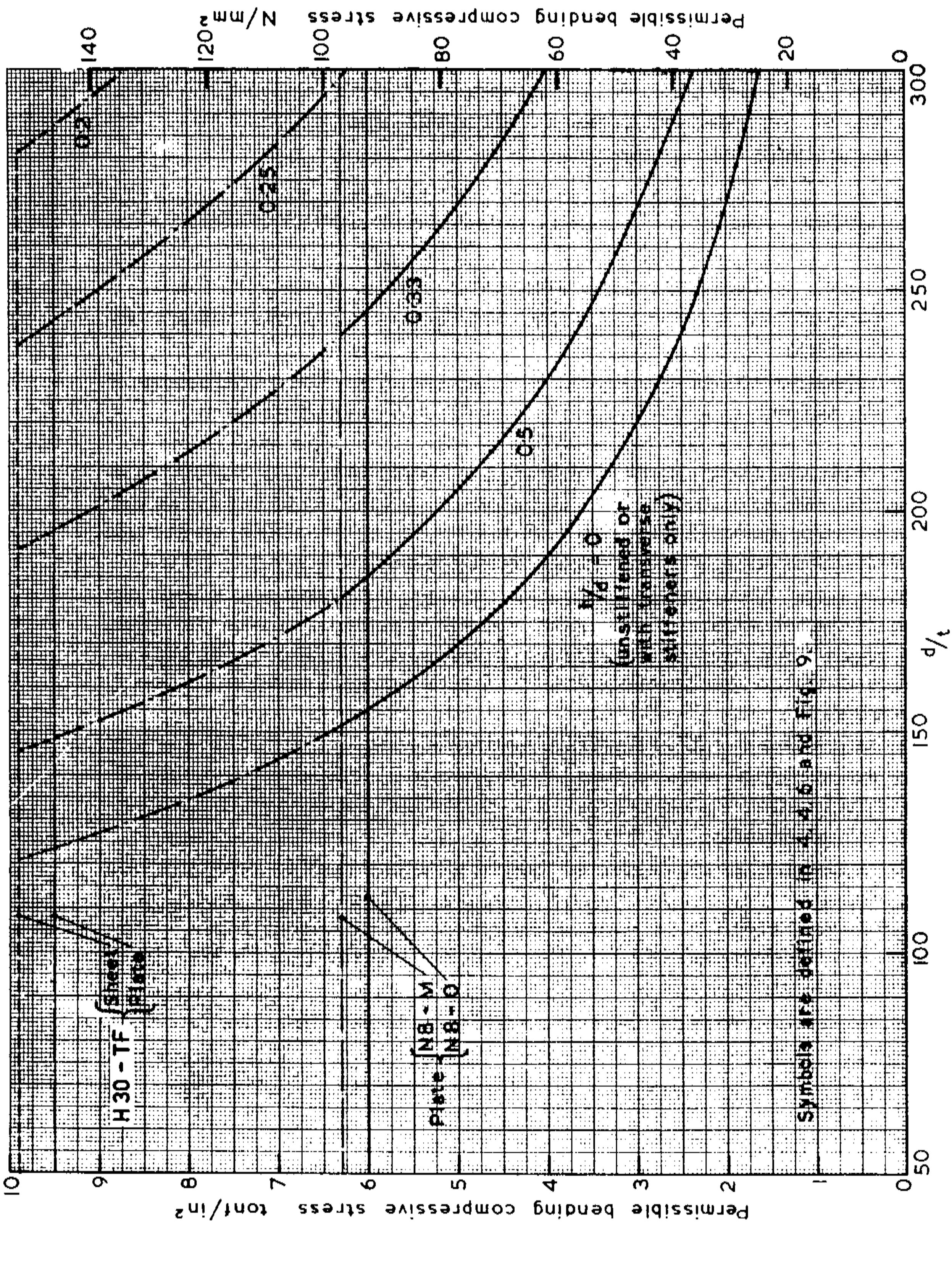


Figure 10 — Permissible bending compressive stresses for webs in pure bending

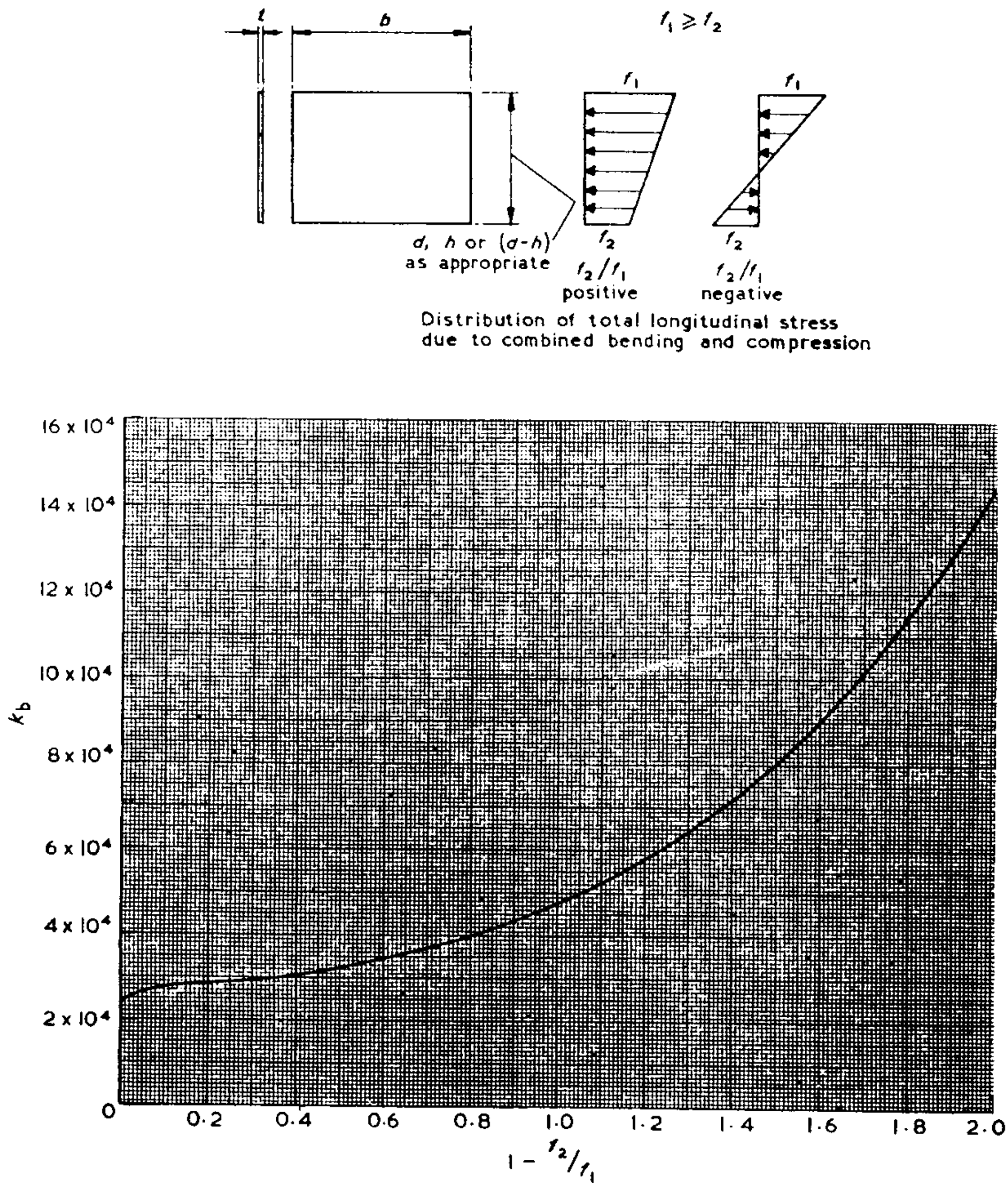


Figure 11 — Buckling coefficient k_b for combined bending and axial compression

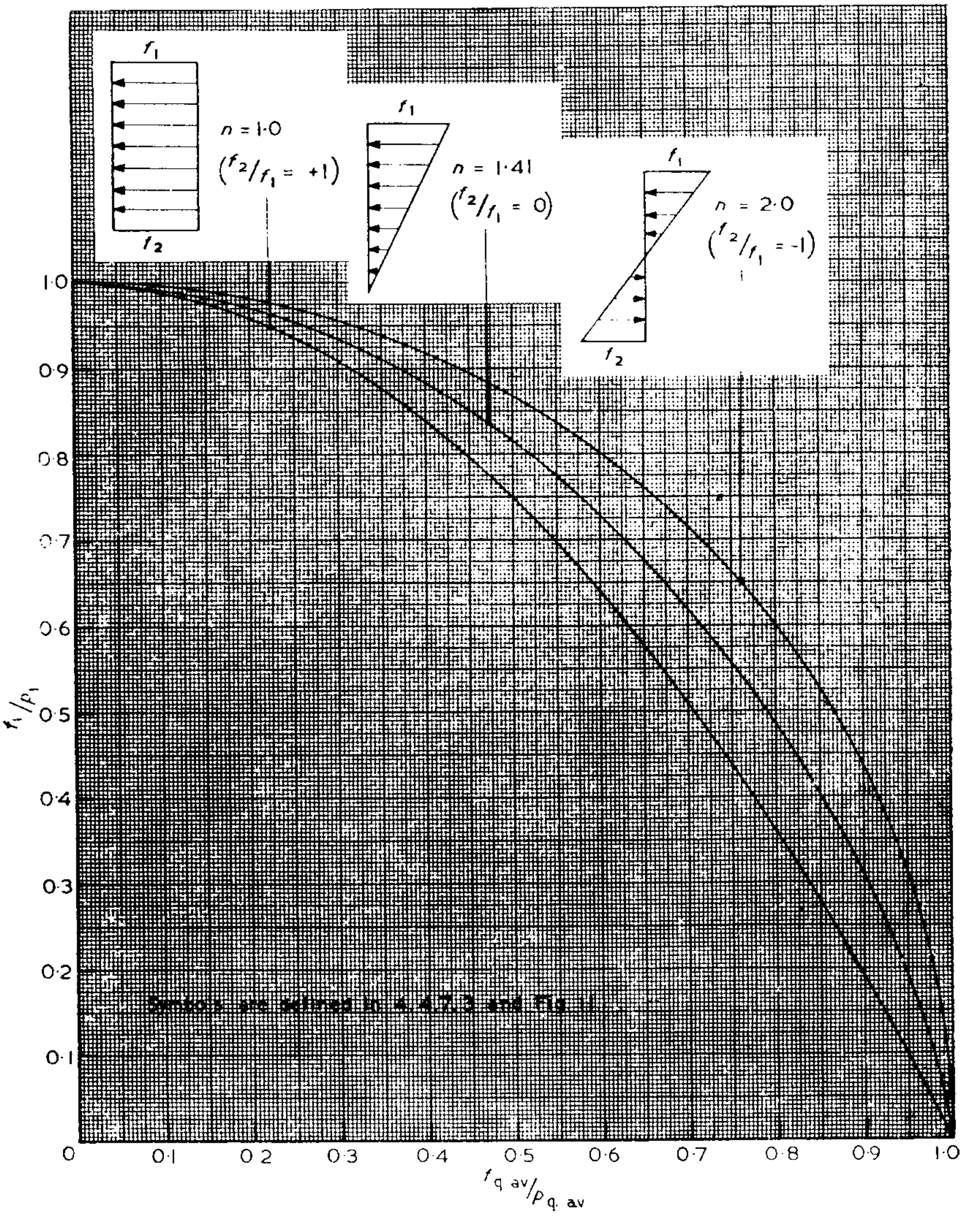


Figure 12 — Limiting ratios of compressive and shear stresses

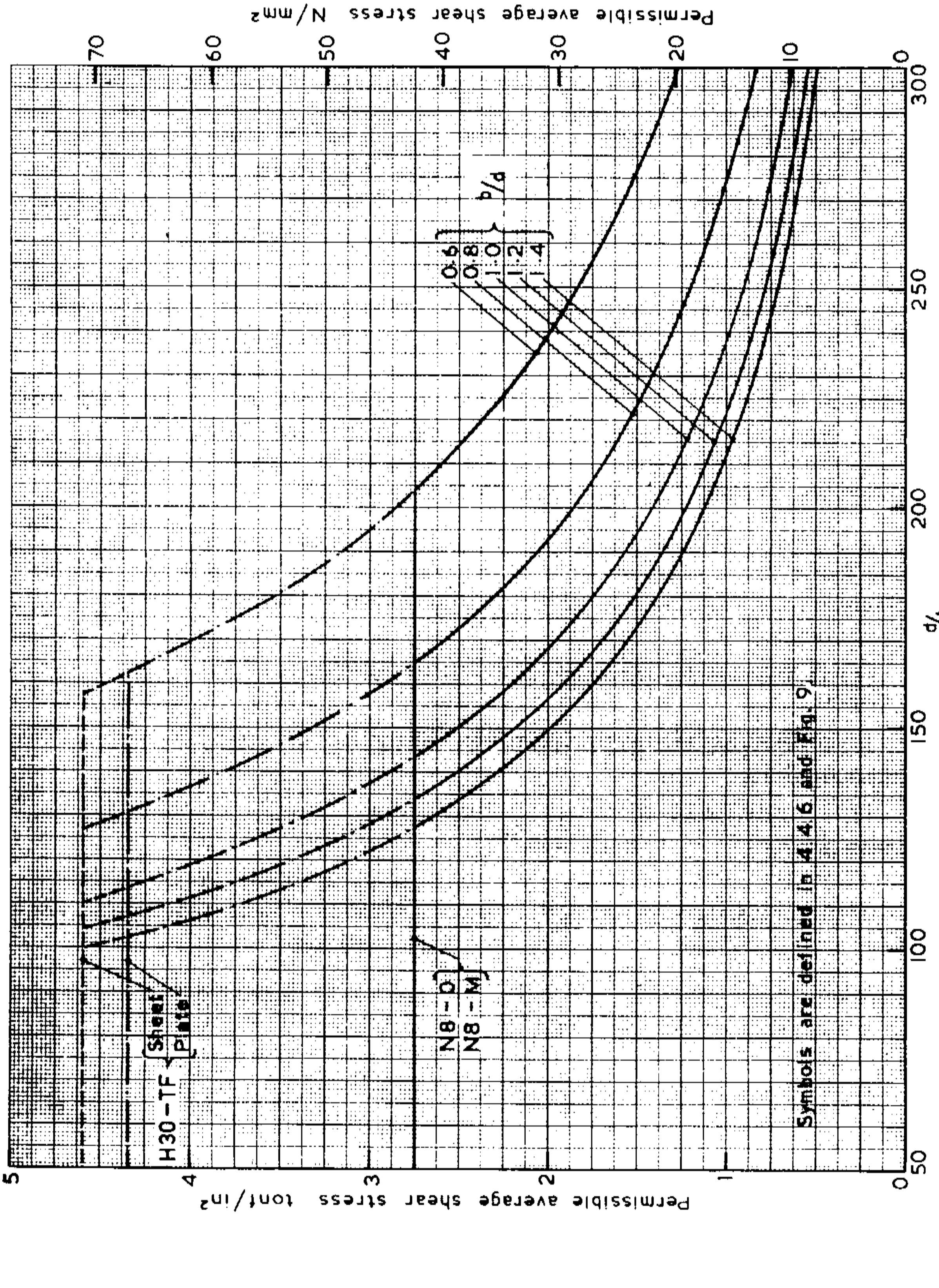


Figure 13 — Permissible average shear stresses in stiffened webs

4.5 Thin plates, webs and flanges

4.5.1 Local buckling in compression

4.5.1.1 *General.* Local buckling is the type of failure in which one or more of the component elements of a cross-section deform into a series of waves.

For sections such as angles, double angles and tees, in which the component elements have a common junction, separate calculations for local buckling are unnecessary since this type of failure is effectively the same as torsional buckling and is therefore covered by the requirements of **4.3.3**.

4.5.1.2 *Unreinforced webs and flanges.* The permissible stresses in local buckling for unreinforced webs and flanges must be obtained from Figure 2 at $\lambda = mb/t$. The value of mb/t to be used is the largest of those obtained by separate calculation for each element of the section which is wholly or partly in compression, where m is the local buckling coefficient (see Table 11), and b and t are the

width and thickness respectively of the element (see Table 11).

For thin-walled channels and I-sections in uniform axial compression the more exact treatment given in Appendix K may be used.

4.5.1.3 *Flanges reinforced with lips.* The permissible stress in local buckling for a thin flange reinforced with a lip of the same thickness as the flange must be obtained from Figure 2 at $\lambda = mb/t$. The value of mb/t to be used is the largest of those obtained by:

1) Calculation for the flange as a web element (see **4.5.1.2**),

where $m = 1.6$

2) Calculation for the lip as a flange element (see **4.5.1.2**),

where $m = 5.1$

3) Calculation for the flange-lip combination,

where $m = 5.1\ (1 - c^2/80\ t^2)$, and

c and t are the width and thickness respectively of the lip (see Table 11).

For thin-walled channels and I-sections in uniform axial compression the more exact treatment given in Appendix K may be used.

4.5.1.4 *Flanges reinforced with bulbs.* The permissible stress in local buckling for a thin flange reinforced with a bulb must be obtained from Figure 2 at $\lambda = mb/t$. The value of mb/t to be used is the larger of those obtained by:

1) Calculation for the flange as a web element (see **4.5.1.2**),

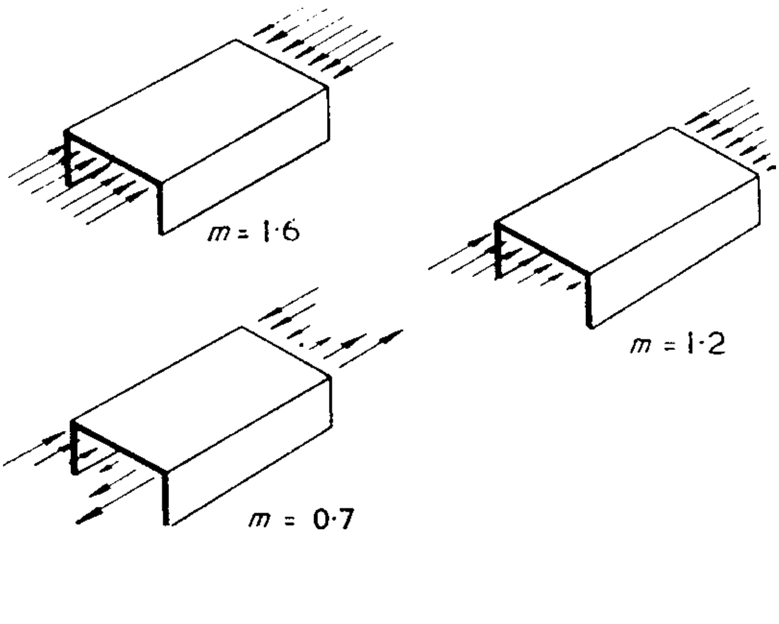
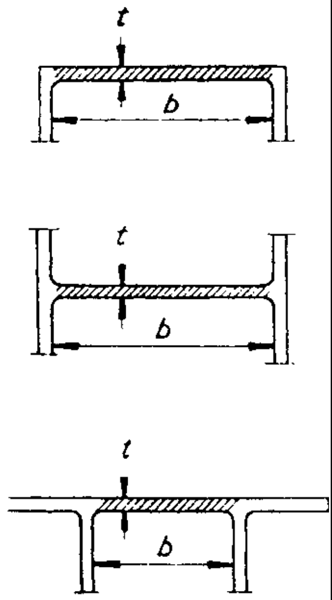
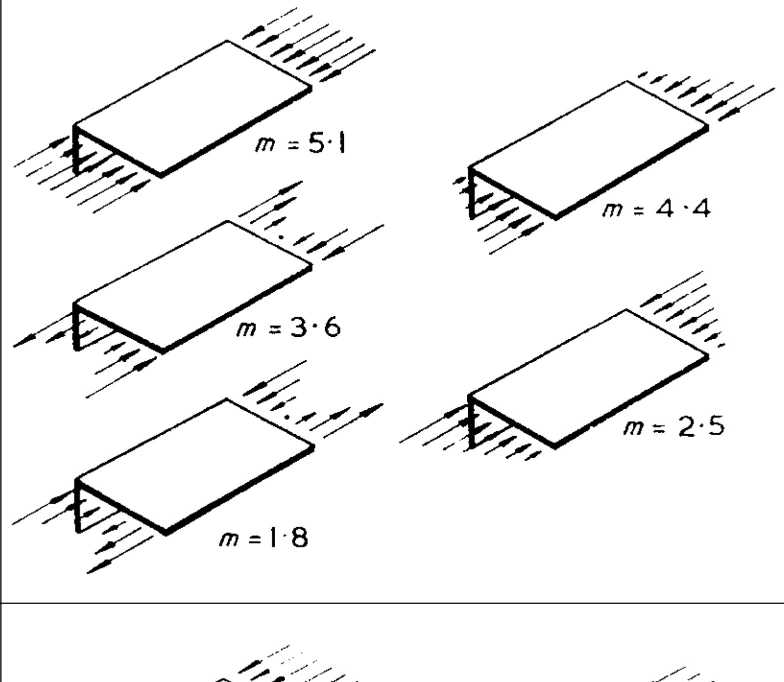
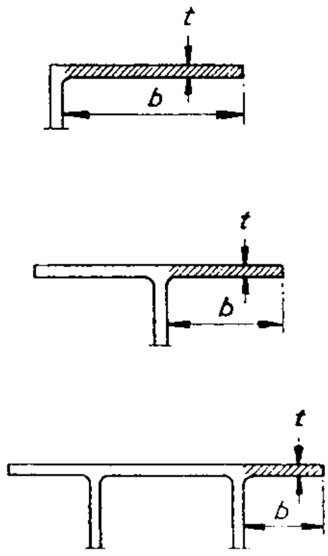
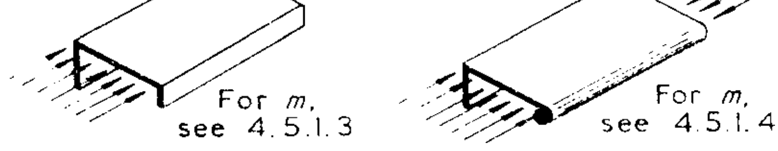
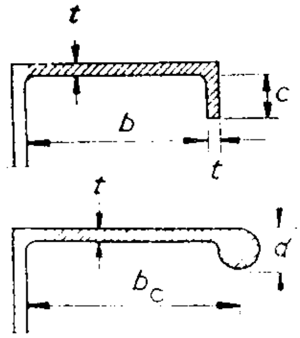
where $m = 1.6$, and the width $b = b_c + t/2$ (see Table 11)

2) Calculation for the flange-bulb combination,

where $m = 5.1\ (1 - d^2/256\ t^2)$, and

d and t are the bulb diameter and flange thickness respectively (see Table 11).

Table 11 — Local buckling coefficient m

<table>
<tr><td>Both edges supported; (e.g. a web)</td><td>
</td><td>
</td></tr>
<tr><td>One edge supported; one edge free (e.g. a flange)</td><td>
</td><td>
</td></tr>
<tr><td>One edge supported; one edge with lip or bulb</td><td>
</td><td>
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</table>

4.5.1.5 *Welded thin-walled members.* Welded thin-walled members in materials in the O and M condition (e.g. N8-0, N8-M) may be designed as though they were unwelded.

With heat-treated materials (e.g. H30-TF) and work-hardened materials (e.g. N5-H2) the effect of reduced-strength zones (see **4.6.3.2**) depends on the extent and position of the zones, and in the present state of knowledge design rules cannot be given. Where appropriate, the performance of a welded thin-walled member may be established by test. Otherwise, the permissible compressive stress may be obtained from a graph drawn in accordance with **4.3.6** 1).

4.5.1.6 *Very thin plates.* Where λ as obtained from **4.5.1.2** to **4.5.1.4** exceeds both λ_s and ℓ/r, the permissible compressive stress may be increased by multiplying it by the following factor, which takes post-buckled strength into account:

$$\{1 + [\lambda/\lambda_s - 1][1 - \ell/(r\lambda)]\},$$

where λ_s is the slenderness ratio corresponding to the junction of straight line and hyperbola in Figure 2 (see Table 4), and

ℓ/r is the effective slenderness ratio of the entire cross-section as a strut in ordinary column buckling (see **4.3.1**).

4.5.2 Shear buckling. For a thin rectangular panel simply supported on all four edges the permissible average shear stress must be obtained from Figure 6.

For webs of built-up beams, see **4.4.7.4**.

4.5.3 Buckling due to bending, axial compression and shear. For thin plates in combined bending, axial compression and shear see **4.4.7.3**.

4.6 Joints

4.6.1 General. To avoid eccentricity, members meeting at a joint must, as far as is practicable, be arranged with their centroidal axes intersecting at a point, so that the centre of resistance of the joint lies on the line of action of the load.

Where there is eccentricity, the members and joints must be designed to resist adequately the bending moments arising therefrom.

Joints of a type liable to produce indeterminate distributions of stress must only be used if the engineer is satisfied as to their load-carrying capacity.

Rivets and close-fitting bolts may be assumed to act together to resist the forces at a joint. Otherwise, sufficient of one type of fastening (bolting, riveting, welding, gluing or other) must be provided to resist the forces.

4.6.2 Bolted and riveted joints

4.6.2.1 *Permissible stresses.* Permissible stresses in shear and in tension for close-fitting bolts (see **4.6.2.2**) and solid rivets of certain materials are given in Table 12. Values for aluminium alloys not tabulated may be established by the procedures given in Appendix D.

The use of cold-driven aluminium rivets in tension is not recommended.

The use of H15-TF bolts in tension is not permitted.

The permissible stress in shear for a bolt in a clearance hole (see **4.6.2.2**) is 0.9 times that for a close-fitting bolt of the same size.

Permissible bearing stresses for bolted or riveted joints in the principal and supplementary alloys are given in Table 4 and Table 24. The figures listed refer to joints in single shear; for joints in double shear, the permissible bearing stresses on inner plies are 1.1 times the tabulated values. Other alloys may be dealt with as in Appendix D. If the edge distance on the bearing side of a bolt or rivet is less than the appropriate limit given in **4.6.2.2** the permissible bearing stress must be reduced by multiplying it by the edge distance and then dividing by the appropriate limit.

With bolts, the shear and bearing areas must be based on the shank diameter and the tension area on the diameter at the root of the thread. With solid rivets, the shear, bearing and tension areas may be based on the hole diameter provided that clearances are in accordance with Table 13.

4.6.2.2 ***Details***

1) *Diameter*. The diameter of a bolt or solid rivet in tension should generally be not less than ½ in (13 mm) and must not be less than ⅜ in (9.5 mm).

The diameter of a bolt or solid rivet in shear should generally be not less than $^{5}/_{16}$ in (7.9 mm) and must not be less than ¼ in (6.4 mm).

2) *Minimum spacing*. The spacing between centres of bolts and rivets must be not less than 2½ times the bolt or rivet diameter.

3) *Maximum spacing*. In tension members the spacing of adjacent bolts or rivets on a line in the direction of stress must exceed neither 16t, where t is the thickness of the thinnest outside ply, nor 8 in (203 mm); in compression or shear members it must exceed neither 8t nor 8 in (203 mm). In addition, the spacing of adjacent bolts or rivets on a line adjacent and parallel to an edge of an outside ply must exceed neither 8t nor 4 in (102 mm). Where bolts and rivets are staggered on adjacent lines and the lines are not more than 3 in (76 mm) apart the above limits may be increased by 50 %.

In any event the spacing of adjacent bolts or rivets, whether staggered or not, must exceed neither 32t nor 12 in (305 mm) in tension members and neither 20t nor 12 in (305 mm) in compression and shear members.

4) *Edge distance*. With extruded, rolled or machined edges, the edge distance (measured from the centre of the bolt or rivet) must be not less than 1½ times the bolt or rivet diameter. If, on the bearing side, it is less than twice the diameter the permissible bearing stress must be reduced as in **4.6.2.1**.

With sheared edges, the above limits must be increased by ⅛ in (3.2 mm).

Table 12 — Permissible stresses for bolts and rivets

tonf/in^2 (N/mm^2)

	Material	Process	Diameter[a] in (mm)	Shear	Tension
Bolts[b]	H30-TF	—	Up to, but excluding, ½ (13)	4.0 (62)	4.5 (69)
			½ (13) or more	4.5 (69)	5.7 (88)
	Steel	—	Up to, but excluding, 7/8 (22)	6.0 (93)	6.0 (93)
			7/8 to 1⅛ (22 to 29) inclusive	6.0 (93)	7.0 (108)
Rivets[b]	H30-TB	Cold driven	Any	4.0 (62)	[c]
	N5-O	Cold driven		3.5 (54)	
		Hot driven		3.2 (49)	[d]
	Steel	Power driven (shop)		6.5 (100)	6.0 (93)
		Power driven (field)		6.0 (93)	

[a] Permissible diameters are given in **4.6.2.2**.
[b] Close-fitting bolts and solid rivets. For bolts in clearance holes see **4.6.2.1**.
[c] Not recommended.
[d] Information not available. Permissible stress must be obtained in accordance with Appendix D.

Table 13 — Hole clearances for bolts and rivets

	Type	Material	Diameter in (mm)	Maximum clearance on diameter in	(mm)
Bolts	Close-fitting	—	Any	0.005[a]	(0.13)[a]
	Not close-fitting		Up to, but excluding, ½ (13)	1/64[a]	(0.4)[a]
			½ (13) or more	1/32[a]	(0.8)[a]
Rivets	Solid	Aluminium	Up to, but excluding, ½ (13)	1/64	(0.4)
			½ (13) or more	1/32	(0.8)
		Steel or corrosion-resisting steel	Up to, but excluding, ½ (13)	1/32	(0.8)
			½ (13) or more	1/16	(1.6)
	Tubular	As recommended by manufacturer			

[a] From measurements of actual bolt and hole diameters; the clearance must not be increased on account of irregular or excess zinc coating on the bolts. For metal-sprayed parts the clearance before spraying may, at the discretion of the engineer, be increased by 0.005 in (0.13 mm) except where the hole is deep and the spraying consequently non-uniform.

5) *Hole clearance.* The hole clearance must be in accordance with Table 13. Bolts that transmit fluctuating loads, other than those caused by wind, must be close-fitting.

6) *Washers and locking devices.* Washers must be used in accordance with **6.2.1**.

Locking devices approved by the engineer must be used on nuts liable to work loose because of vibration or stress fluctuation.

4.6.2.3 *Tubular and other special rivets.* The permissible load on a tubular or other special rivet is one third of the minimum expected rivet strength obtained from a sufficient number of tests made, under competent supervision and to the satisfaction of the engineer, on joints made with rivets the same type and size as, and similarly loaded to, those in the actual structure.

4.6.2.4 *Packing.* The number of bolts or rivets carrying shear through a packing must be increased above that required by normal calculation by 2 % for each 1/16 in (1.6 mm) of the total thickness of the packing beyond ¼ in (6.4 mm). For double-shear joints packed on both sides the number of additional bolts or rivets must be determined from the thickness of the thicker packing. The additional bolts or rivets may be placed in extensions of the packing.

4.6.2.5 *Countersinking.* One half of the depth of any countersinking of a bolt or rivet must be neglected in calculating its length in bearing. No reduction need be made in shear. The permissible tensile load of a countersunk bolt or rivet must be taken as two thirds of that of a plain one of the same diameter. The depth of countersinking must not exceed the thickness of the countersunk part less 0.15 in (4 mm).

4.6.2.6 *Long-grip bolts and rivets.* Where the grip of a bolt or rivet in a strength joint exceeds four times the diameter, the number of bolts or rivets must be increased above that required by normal calculation by 1 % for each additional 1/16 in (1.6 mm) of grip. The total grip must not exceed five times the diameter.

4.6.3 Welded joints

4.6.3.1 *Exchange of information.* Drawings and specifications must be provided, giving the following information about every weld:

1) Parent and filler material.

2) Dimensions of weld (see BS 499-2[17]).

3) Edge preparation, welding position.

4) Welding process.

[17] BS 499, "*Welding terms and symbols*", Part 2, "*Symbols for welding*".

5) Any special requirements, such as smoothness of weld profile, precautions against excessive temperature, and special quality control (as required, for example, in **4.7.4**).

4.6.3.2 *Effect of welding.* Welding can reduce the strength of the metal in the vicinity of the weld.

Aluminium already in, or substantially in, the annealed condition (e.g. N8-O and N8-M) will, after welding, still have tensile properties close to or equal to the specified ones.

Aluminium in other than the annealed condition (e.g. H30-TF, H9-TF, and N8 in a temper harder than N8-M), must, irrespective of its thickness, be assumed in design to have reduced-strength zones extending over a distance of 1 in (25 mm) in all directions from the centre line of a butt weld and from the root of a fillet weld. If, however, it can be shown that a reduced-strength zone extends for less than 1 in (25 mm), an appropriate smaller distance may be assumed.

4.6.3.3 *Permissible stresses.* Permissible stresses for welded joints, and for cross-sections consisting entirely of reduced-strength zones, in the recommended combinations of parent and filler material (see Table 3) are given in Table 14; they apply only to welds made in accordance with **6.3**.

Permissible stresses for other combinations of parent and filler material may be established by the procedure given in Appendix D (**D.2.6**).

The permissible stress in compression may be taken as equal to that in tension, except where buckling may occur; in such cases design must be in accordance with **4.3.6** and **4.5.1**.

Table 14 — Permissible stresses for welded joints and reduced-strength zones

tonf/in^2 (N/mm^2)

Parent metal	Butt-welded joints and reduced-strength zones		Fillet-welded joints[a] (weld metal)	
	Tension p_{wt}	Shear p_{wq}	Transverse	Longitudinal
H30	3.3 (51)	2.0 (31)	3.5 (54)	2.0 (31)
N8	5.3 (82)	3.1 (48)	4.7 (73)	3.0 (46)
H9	2.0 (31)	1.2 (19)	3.5 (54)	2.0 (31)
H20 N4	3.3 (51)	2.0 (31)	3.5 (54)	2.0 (31)
N5	4.0 (62)	2.4 (37)	4.2 (65)	2.3 (36)
H17	8.0 (124)	4.8 (74)	4.5 (70)	3.0 (46)

[a] Values apply to the effective throat area of weld metal. Filler wire must be in accordance with Table 3.

The permissible load on a butt-welded joint is the permissible stress multiplied by the product of the effective length and the effective thickness of the weld.

The effective length of a butt weld is the total length, provided that end imperfections are avoided by the use of run-on and run-off plates; otherwise it is the total length less twice the weld width. The effective thickness is the thickness of the thinner parent metal at the joint.

The permissible load on a fillet-welded joint is the lesser of:

1) The permissible stress for the weld metal, transverse or longitudinal as the case may be, multiplied by the product of the effective length and the effective throat thickness of the weld, and

2) The permissible stress for the heat-affected parent metal, in tension (p_{wt}) or in shear (p_{wq}) as the case may be, multiplied by the effective length and 1.1 times the nominal leg length of the weld.

The effective length of a fillet weld is the total length less, for each beginning and end of the weld, a distance equal to the nominal leg length. The effective throat thickness of a fillet weld is 0.7 times the nominal leg length.

The strength of each connected member at a fillet-welded joint must be ascertained, in tension or in shear as may be appropriate, by taking into account the effect of reduced-strength zones. For tension the procedure in **4.2.1** 2) must be followed. For shear the same procedure, but using the permissible shear stresses p_q and p_{wq} (see Table 4 and Table 14) must be followed.

Reference may be made to BS 499-1[18] for definitions of terms used above.

4.6.3.4 *Details.* General recommendations for the design of welded joints are given in Appendix L. The following specific requirements apply:

1) *Intermittent butt welds.* Intermittent butt welds must not be used.

2) *Intermittent fillet welds.* The distance along the edge of a part between adjacent welds in an intermittent fillet weld, whether the welds are in line or staggered on alternative sides of the part, must not exceed 10 times the thickness of the thinner parent material if it is in compression or shear and 24 times that thickness if it is in tension, and must not exceed 12 in (305 mm).

3) *Longitudinal fillet welds.* If longitudinal fillet welds alone are used in an end connection, the length of each must be not less than the distance between the welded edges.

4) *Edge preparations.* Appendix M gives guidance on the choice of edge preparations for welded joints. The actual preparation used for a joint must be approved as part of the welding procedure (see **6.3.5**).

4.6.4 Glued joints. Structural joints in aluminium may be made with thermosetting or other adhesives. Such joints may be economical for the attachment of stiffeners to thin sheet.

A thermosetting adhesive should preferably be in accordance with DTD 775[19] Its suitability in all respects for use on, and for the life of, a particular structure must be demonstrated to the satisfaction of the engineer.

The permissible shear stress on a glued joint is one quarter of the minimum expected shear strength determined from a sufficient number of tests made, under competent supervision and to the satisfaction of the engineer, of joints with size, geometry and direction of loading similar to those in the actual structure.

Glued joints must not be used in tension or where the loading causes forces tending to open the joint.

4.6.5 Other joints. A joint made by means other than those dealt with in **4.6.2** to **4.6.4** may be used provided that its load-carrying capacity can be demonstrated to be satisfactory.

4.7 Fatigue

4.7.1 General. Structures subjected to fluctuations of load may be liable to suffer fatigue failure which, if the number of applications of load is large, may occur at stresses much lower than the permissible static stress. Fatigue failure is usually initiated in the vicinity of a stress concentration and appears as a crack which subsequently propagates through the connected or fabricated members. Discontinuities such as bolt or rivet holes, welds and other local or general changes in geometrical form set up stress concentrations. Details must be designed to avoid, as far as possible, stress concentrations which may give rise to excessive reduction of the fatigue strength of members or connections. Advice on the design of welded joints is given in Appendix L.

4.7.2 Loads and stresses. When designing against fatigue failure, stresses due to all combinations of loads (see Section 3), and secondary stresses such as result from eccentricity of connections and loading, must be considered. Members subject to wind loading may be liable to fluctuating stress and therefore must be examined for fatigue.

Elements of a structure may be subject to stress cycles varying both in stress ratio and in maximum stress. The number of cycles of each combination of stress ratio and maximum stress to which any element is liable to be subjected must be estimated as accurately as possible. The accumulation of all these stress cycles must be used in design against fatigue failure (see **4.7.3.3**).

Fatigue information is not given for numbers of stress cycles less than 10^5. For situations where repetitions of high-strain loading are likely to occur, consideration should be given to the possibility of low-cycle fatigue, and expert advice should be sought.

[18] BS 499, "*Welding terms and symbols*", Part 1, "*Welding, brazing and thermal cutting glossary*".
[19] Ministry of Technology, aerospace material specification, "Adhesive suitable for joining metals".

The stresses to be considered in fatigue are principal stresses; e.g. in the design of webs and web-to-flange joints in built-up beams the combined effect of shear and bending must be considered, and in butt joints the effect of any eccentricity must be included[20].

The terms used above to describe fluctuating loads are defined as follows (see Figure 14):

Minimum stress (f_{min})	The lower numerical value of the stress in a stress cycle.
Maximum stress (f_{max})	The higher numerical value of the stress in a stress cycle.
Stress ratio (f_{min}/f_{max})	The ratio of the minimum to the maximum stress in a stress cycle, tensile stress being considered positive, and compressive stress negative.
Stress cycle	A portion of the stress-time function between successive minima of stress.

4.7.3 Permissible stresses

4.7.3.1 *General.* The permissible stresses, to which no additional safety factor need be applied, for 9 classes of member (see **4.7.4**) are given in Figure 15 to Figure 23. These show for each class the interrelations between stress ratio, maximum stress and number of cycles. The permissible value of any one of the three quantities can be obtained where the other two are known.

The permissible stresses are the same for several alloys, as follows, in all heat-treatment and strain-hardening conditions:

for unwelded members (Class 1 *and* (i) *of Class* 3), the stresses apply to H30, N8, H20, H15, N4, N5 and H17; they do not apply to H9, as there are no experimental data.

For welded members (*all other classes*), the stresses apply to the above alloys except H15, and also to H9.

In the sets of curves for maximum stress tensile (Figure 15 *a* to Figure 23 *a*) the parts of the curves corresponding to values of the stress ratio in excess of 0.5 are shown by broken lines. The precise values of f_{max} in this range may be calculated from

$$f_{max} = f_{0.5}/2(1 - f_{min}/f_{max},)$$

where $f_{0.5}$ is the maximum stress corresponding to the stress ratio 0.5,

f_{max} is the maximum stress, and

f_{min}/f_{max} is the stress ratio.

Interpolation between adjacent curves must be done logarithmically.

The permissible stress for a joint comprising more than one class of member is that appropriate to the weakest class.

It is recognized that the presentation of permissible stresses adopted in Figure 15 to Figure 23 may not be the most convenient for some design procedures. The information is therefore repeated, in Appendix N, in tabular form.

4.7.3.2 *Uniform load fluctuations.* For uniform load fluctuations, the permissible stress may be obtained by entering the appropriate family of curves at the values of the stress ratio and the number of cycles likely to occur in the life of the structure. If the maximum stress is smaller than that permissible for 10^8 cycles, fatigue failure is unlikely.

[20] An approximate method of allowing for eccentricity in the thickness direction, whether due to misalignment, eccentricity or variation of thickness (see Table 29) is to multiply the nominal stress by $(1 + 3\ e/t)$,

where e is the distance between centers of thickness of the two abutting members; if one of the members is tapered, the centre of the untapered thickness must be used, and

t is the thickness of the thinner member.

With connections which are supported laterally (e.g. the flanges of a beam which are supported by the web: see Table 29), eccentricity may be neglected.

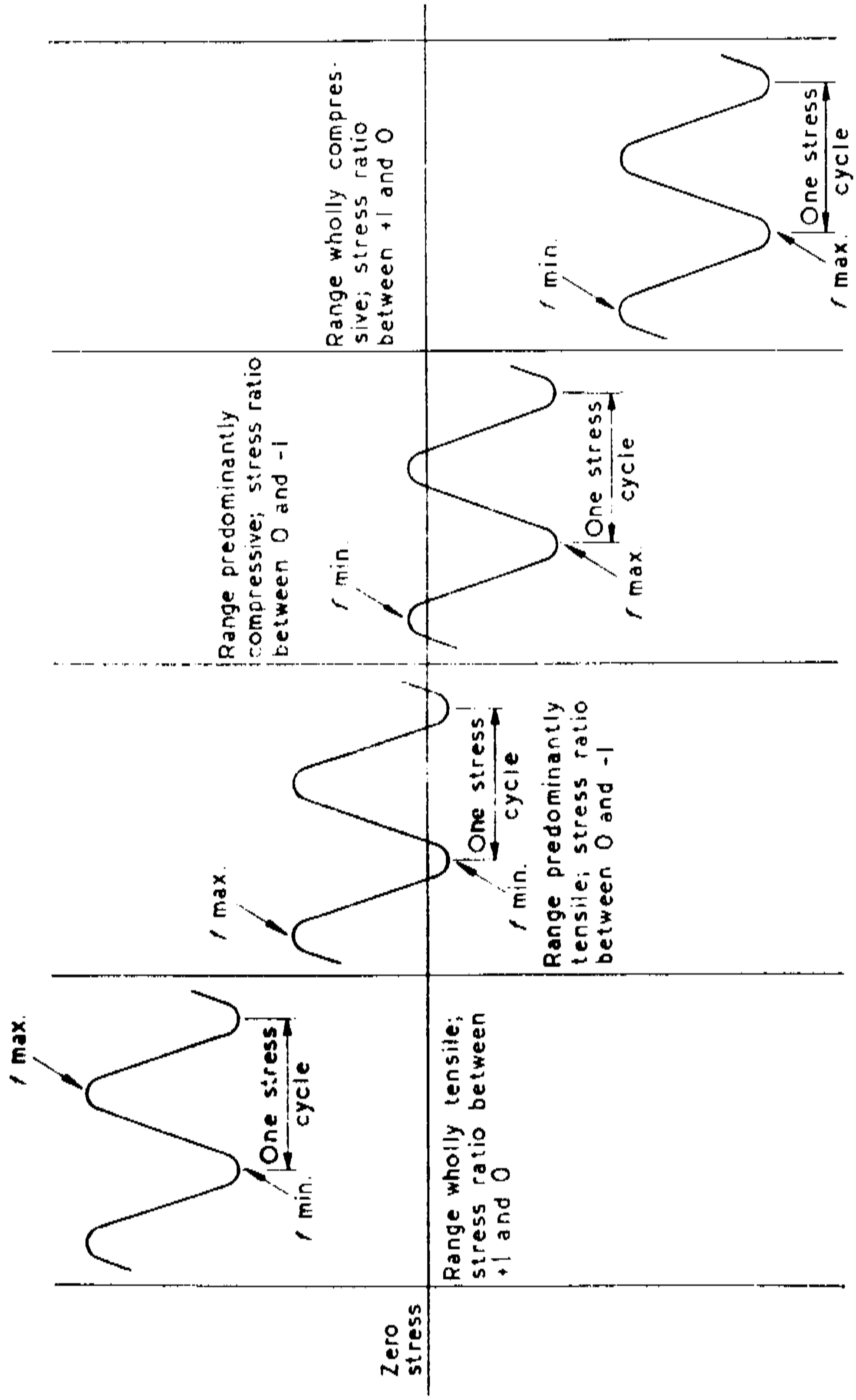


Figure 14 — Maximum and minimum stresses, and stress cycle

4.7.3.3 *Non-uniform load fluctuations.* In the general case of members subjected to a stress spectrum, i.e. to numbers of cycles $n_1, n_2 \ldots\ldots n_n$ of different maximum stresses at different stress ratios, the following design method must be used:

1) All cycles with a maximum stress equal to or lower than the permissible stress given for members of Class 9 in Figure 23 for 10^8 cycles and for the relevant stress ratio may be ignored.

2) Where the loading conditions do not give rise to clearly defined groups of stress cycles, all stress cycles with a maximum stress greater than the permissible stress obtained as in 1) above must be divided into at least five groups defined by maximum stresses equally spaced between the algebraically smallest and largest.

3) For the above groups, the corresponding permissible numbers of cycles $N_1, N_2 \ldots\ldots N_n$ must be determined, if necessary by logarithmic interpolation, from the figure appropriate to the class of member (see **4.7.4**). If, however, f_{max} is smaller than the appropriate permissible stress for 10^8 cycles or larger than that for 10^5 cycles, the value of N must be extrapolated as follows:

$$\log N = \log (2 \times 10) \frac{(\log p_C - \log f_{max})}{(\log p_A - \log p_C)} + \log (2 \times 10^6)$$

where p_C and p_A are the appropriate permissible stresses for 2×10^6 and 10^5 cycles respectively.

4) The member must then be designed so that:

$$\frac{n_1}{N_1} + \frac{n_2}{N_2} + \ldots\ldots + \frac{n_n}{N_n} \leqslant 1$$

4.7.4 Classification of structural members

4.7.4.1 *Classes.* The 9 classes of member, in descending order of fatigue strength, are:

Class 1 Members consisting of plain wrought material with edges as-extruded or carefully machined or filed in the direction of the stress.

Class 2 Members with continuous full-penetration longitudinal or transverse butt welds, with the reinforcement dressed flush with the surface and the weld proved free from defects by specified quality-control requirements (see **6.3.7**). To qualify for Class 2, this type of member must comply with **4.7.4.2**.

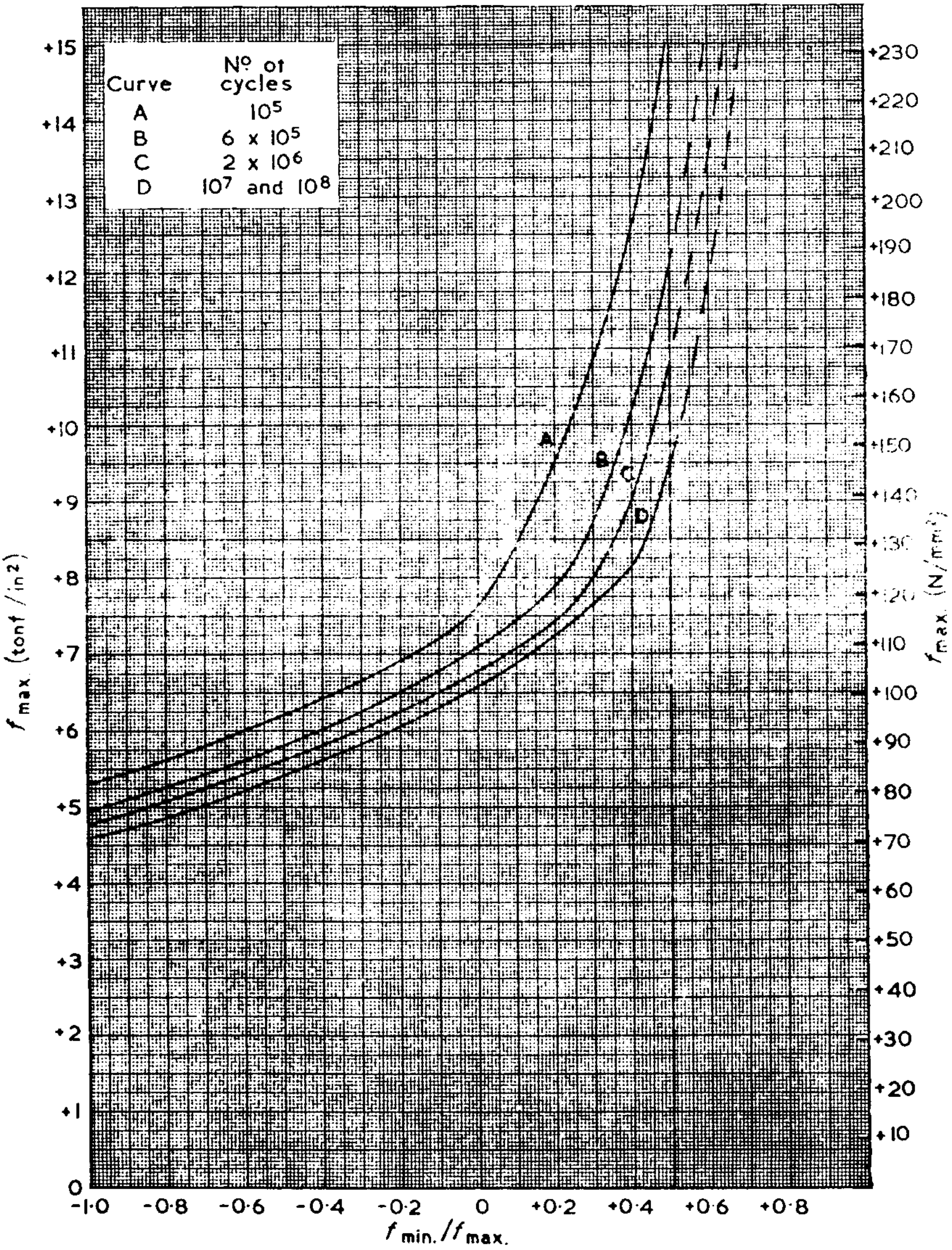
Class 3 (i) Members fabricated or connected by close-fitting bolts or by cold-driven aluminium rivets and designed so that secondary bending stresses are not introduced (e.g. single-lap joints should not be used, except in special circumstances such as the joining of tubes). Members connected by hot-driven steel rivets are not included, as there is no experimental data. To qualify for Class 3, this type of member must comply with **4.7.4.3**.

(ii) Members with full-penetration transverse butt welds made from both sides with the reinforcement on each side having a maximum height above the parent metal of ⅛ in (3.2 mm) or one-fifth of the thickness, whichever is smaller, and blending smoothly with the parent metal. To qualify for Class 3, this type of member must comply with **4.7.4.4**.

(iii) Members with full-penetration continuous longitudinal automatic butt welds, free from transverse surface irregularities, and with no interruptions in welding either the root pass or the final pass. To qualify for Class 3, this type of member must comply with **4.7.4.5**.

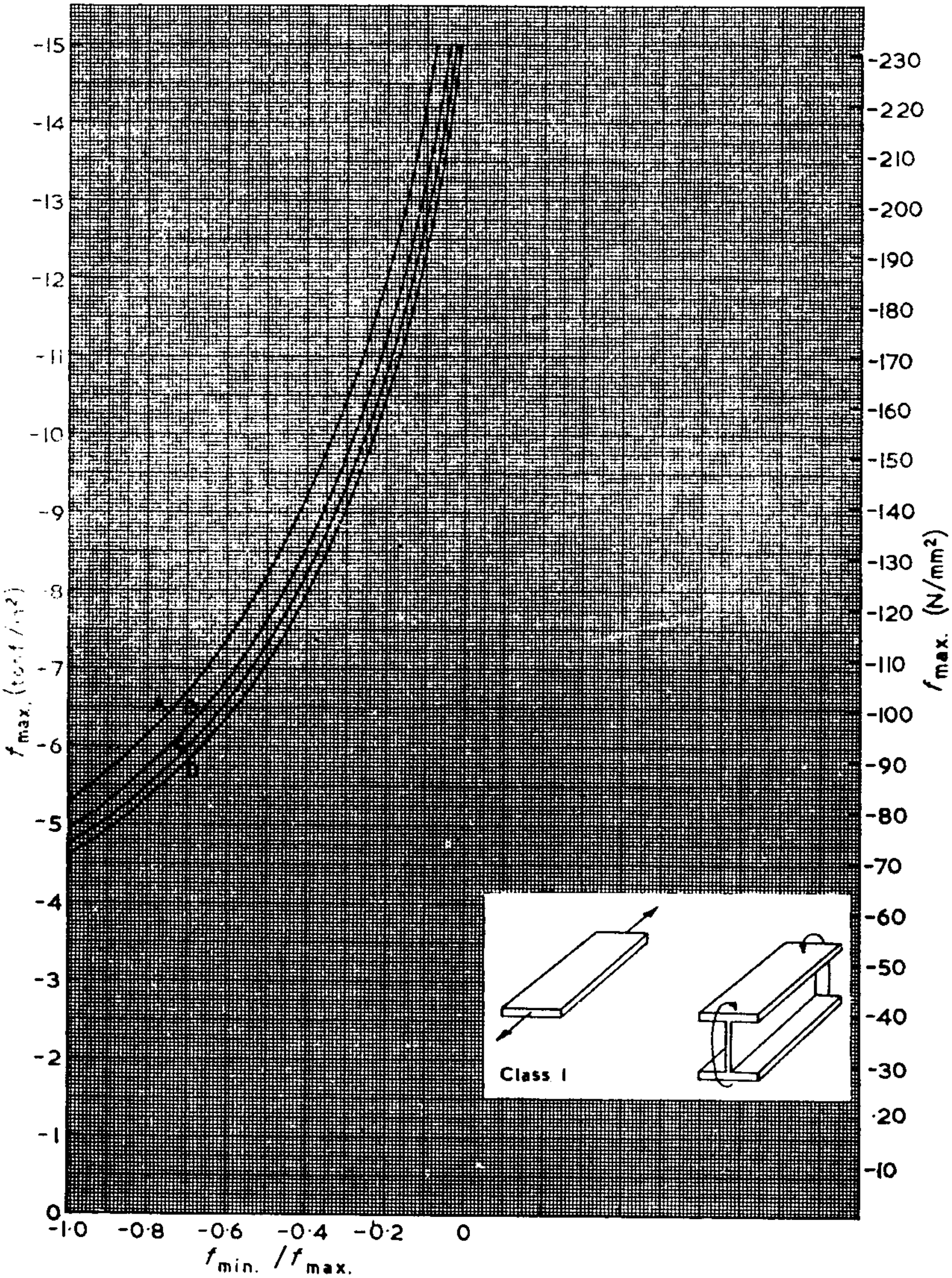
Class 4 (i) Members with continuous longitudinal fillet welds, with no interruptions in welding either the root pass or the final pass. To qualify for Class 4, this type of member must comply with **4.7.4.5**.

(ii) Members with transverse butt welds made from both sides, but with the height of the reinforcement above the parent metal greater that permitted in (ii) of Class 3. To qualify for Class 4, this type of member must comply with **4.7.4.4**.



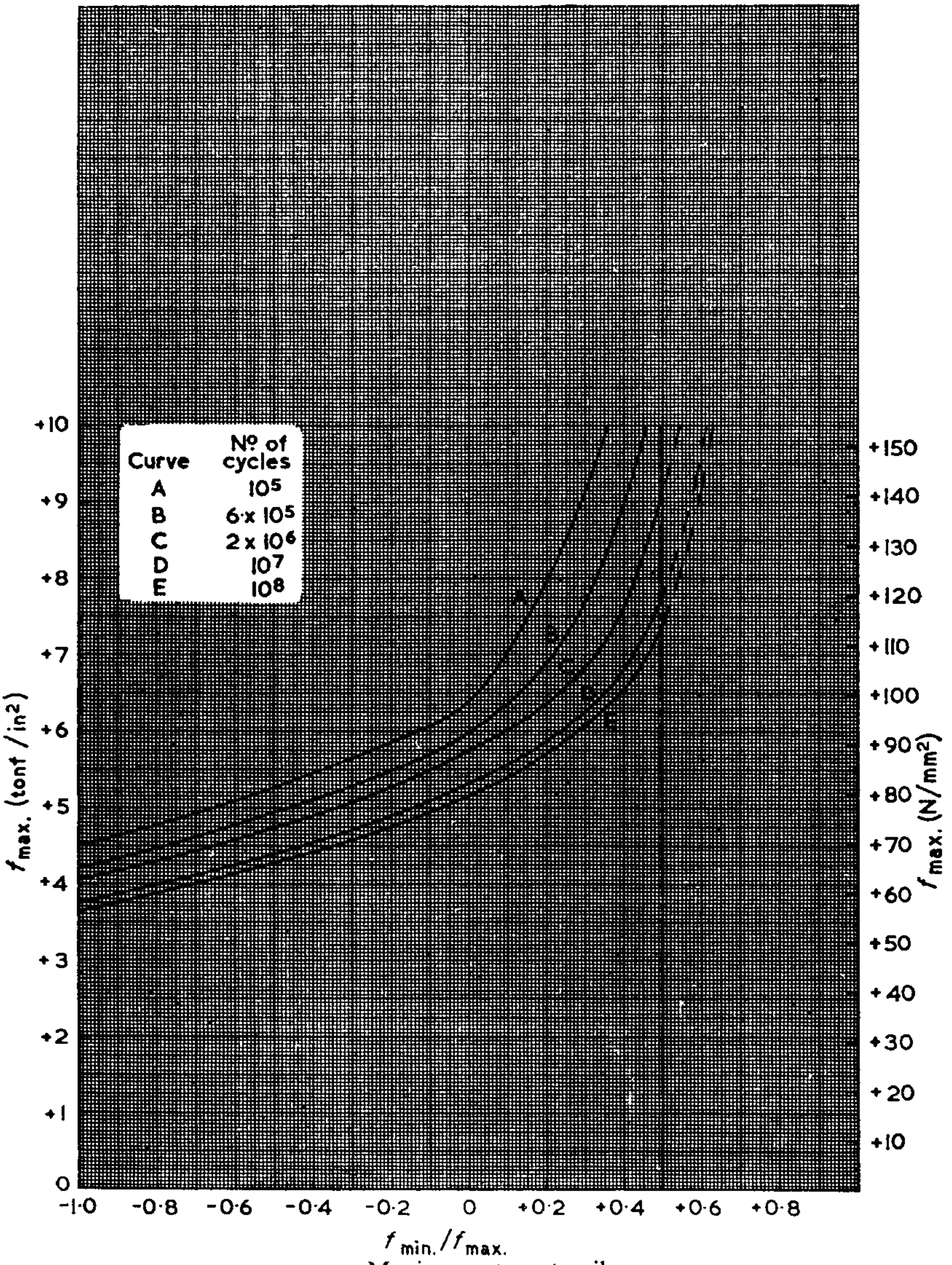
a. Maximum stress tensile

Figure 15 — Curves relating maximum stress, stress ratio and numbers of cycles for Class 1 members



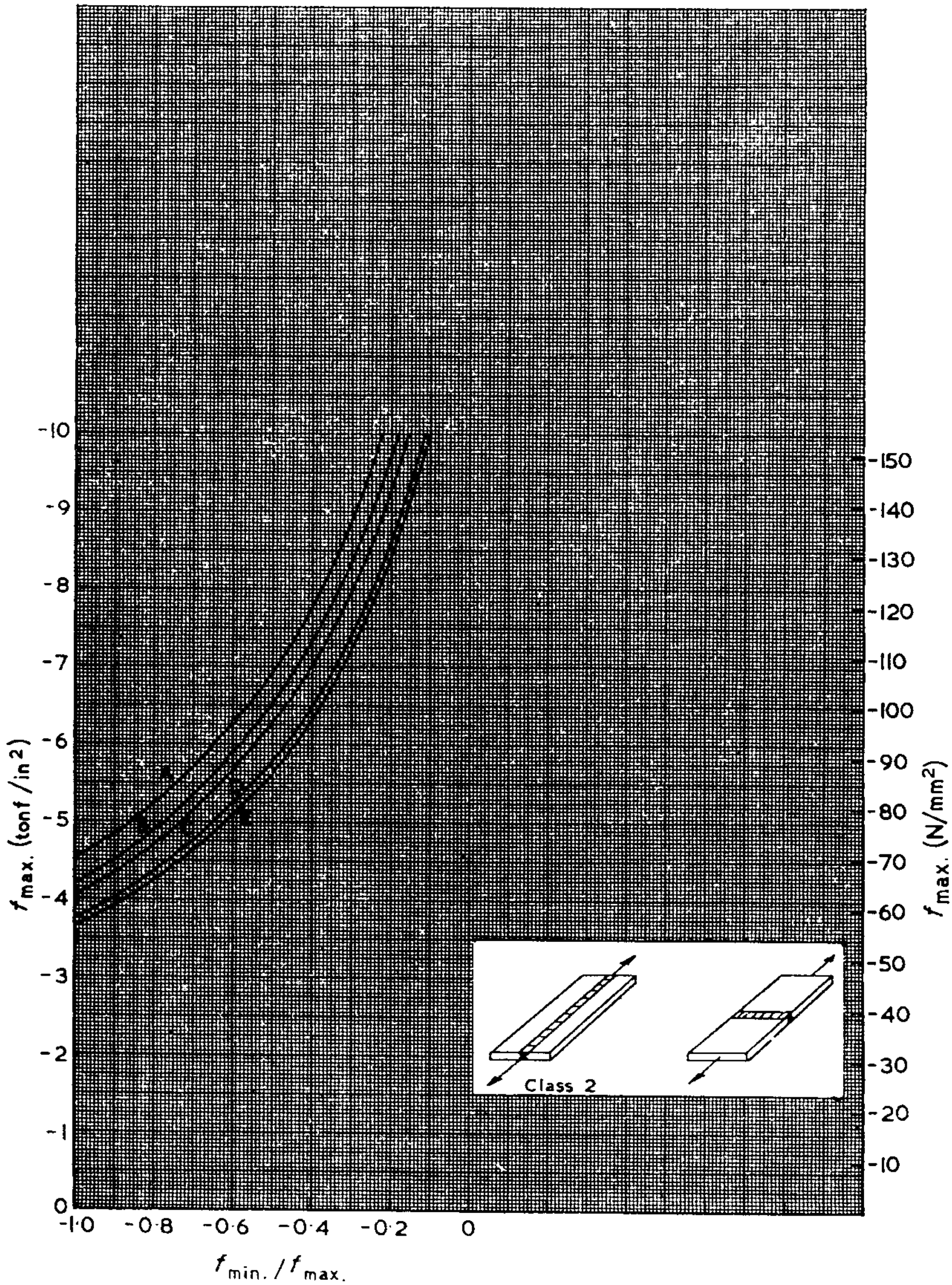
b. Maximum stress compressive

Figure 15 — Curves relating maximum stress, stress ratio and numbers of cycles for Class 1 members



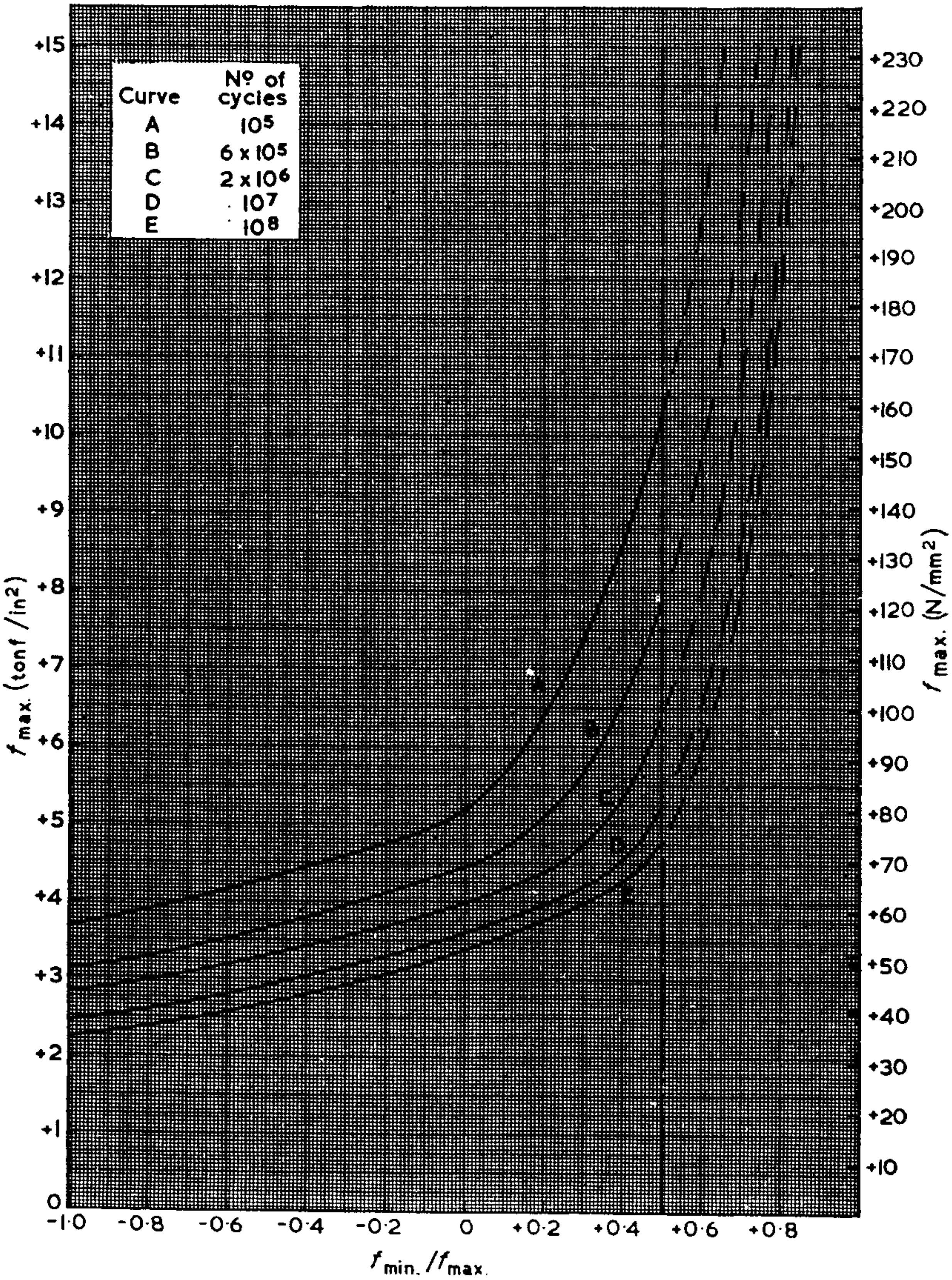
a. Maximum stress tensile

Figure 16 — Curves relating maximum stress, stress ratio and number of cycles for Class 2 members



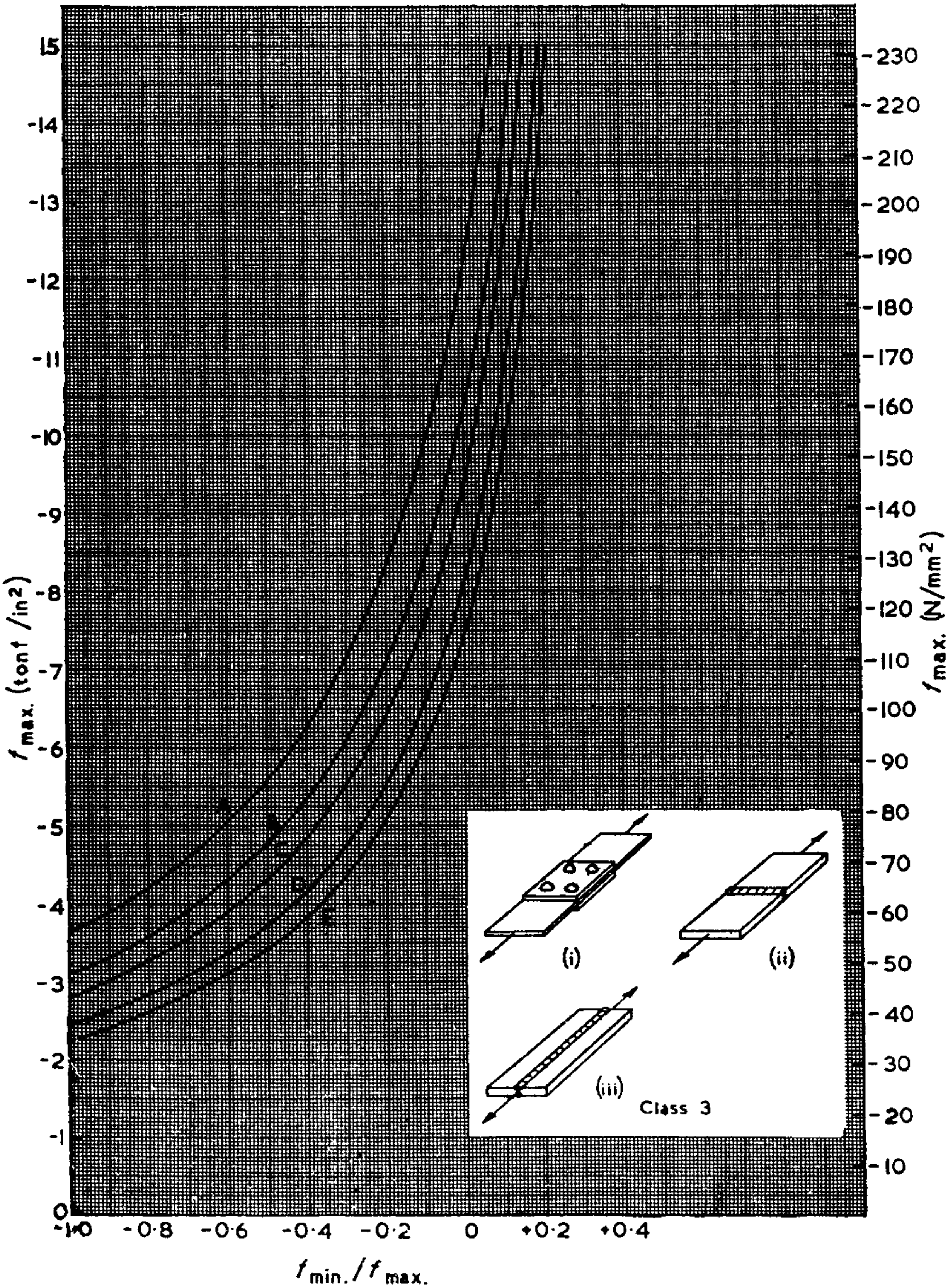
b. Maximum stress compressive

Figure 16 — Curves relating maximum stress, stress ratio and number of cycles for Class 2 members



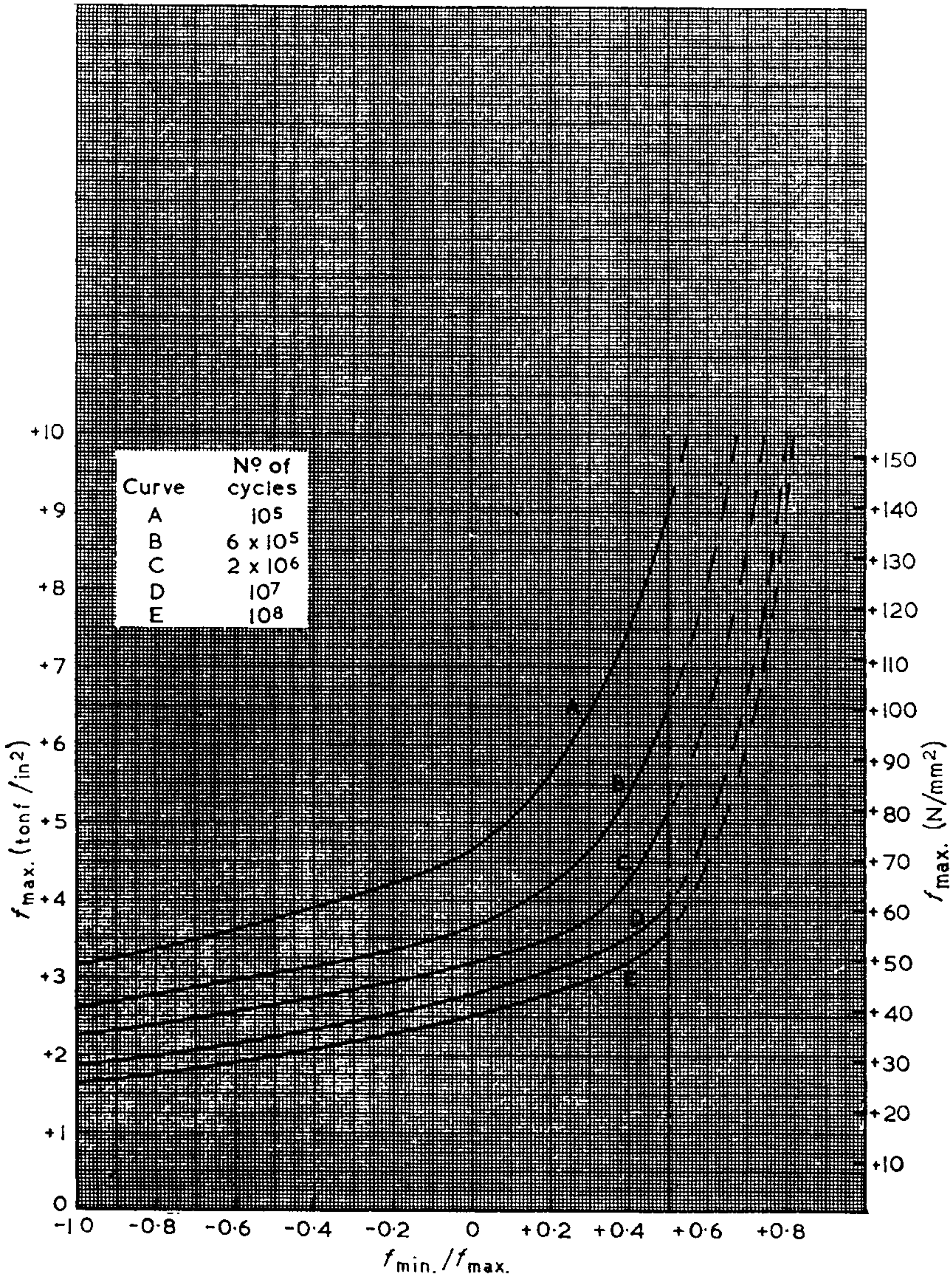
a. Maximum stress tensile

Figure 17 — Curves relating maximum stress, stress ratio and number of cycles for Class 3 members



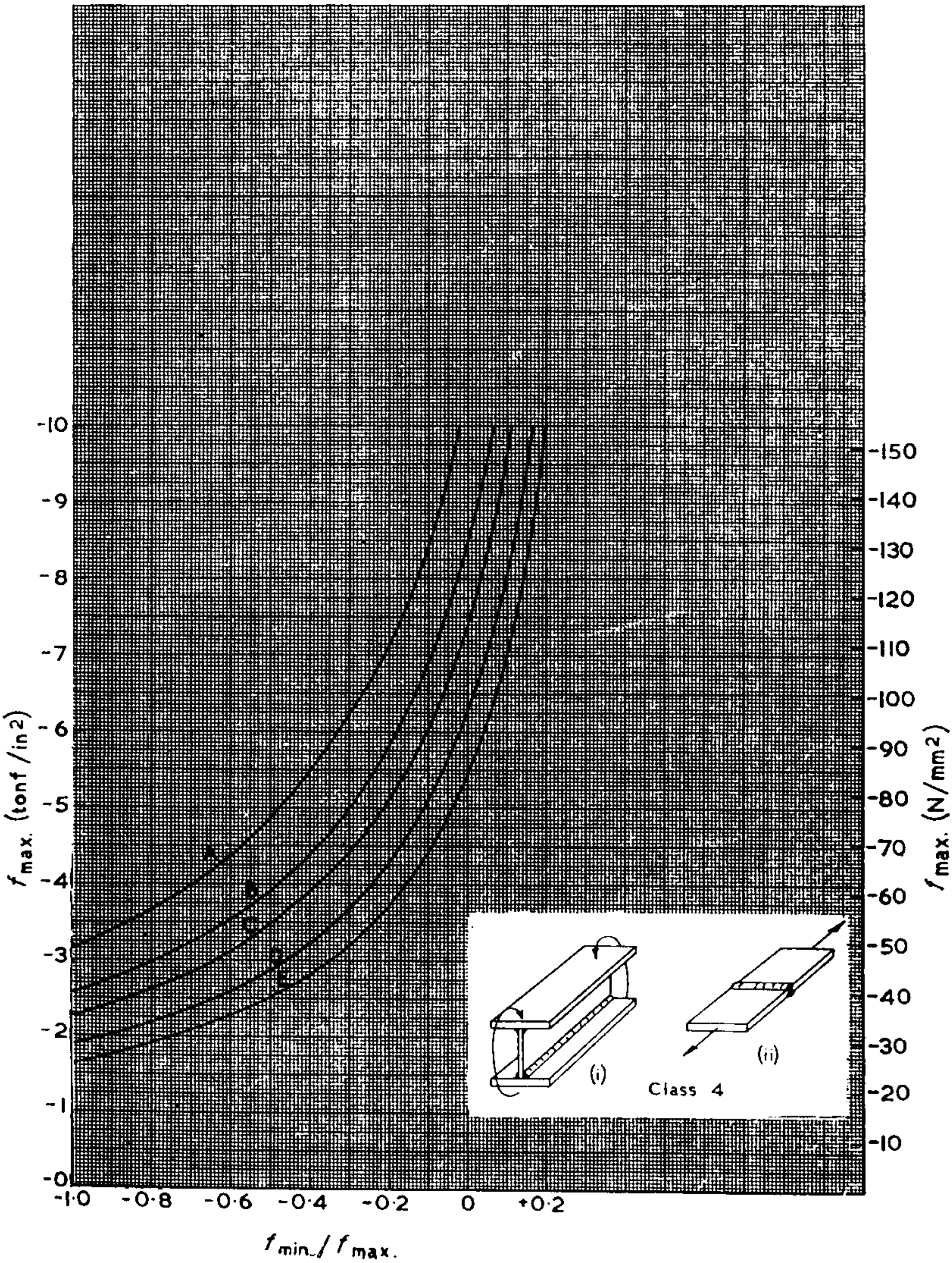
b. Maximum stress compressive

Figure 17 — Curves relating maximum stress, stress ratio and number of cycles for Class 3 members



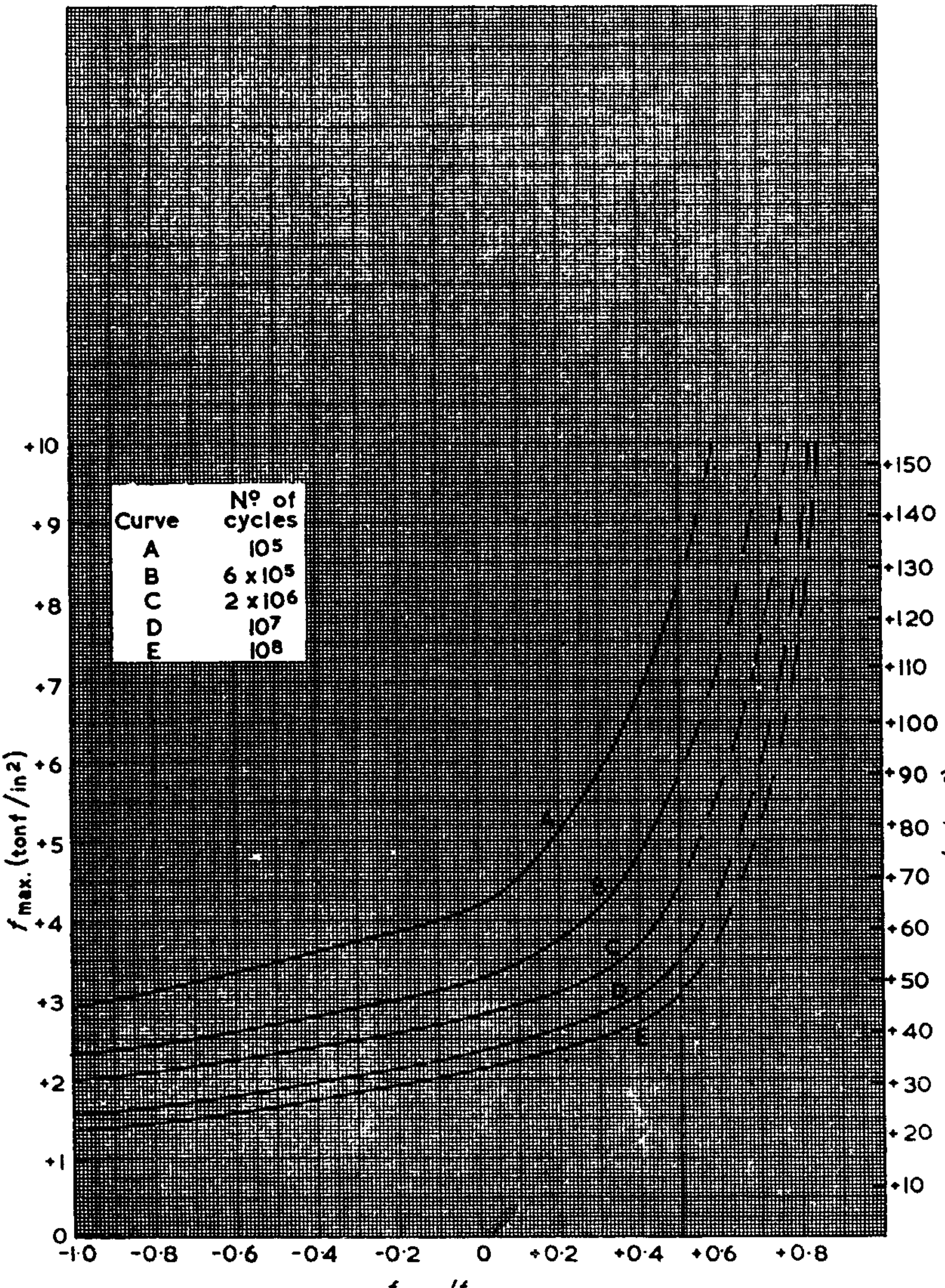
a. Maximum stress tensile

Figure 18 — Curves relating maximum stress, stress ratio and number of cycles for Class 4 members



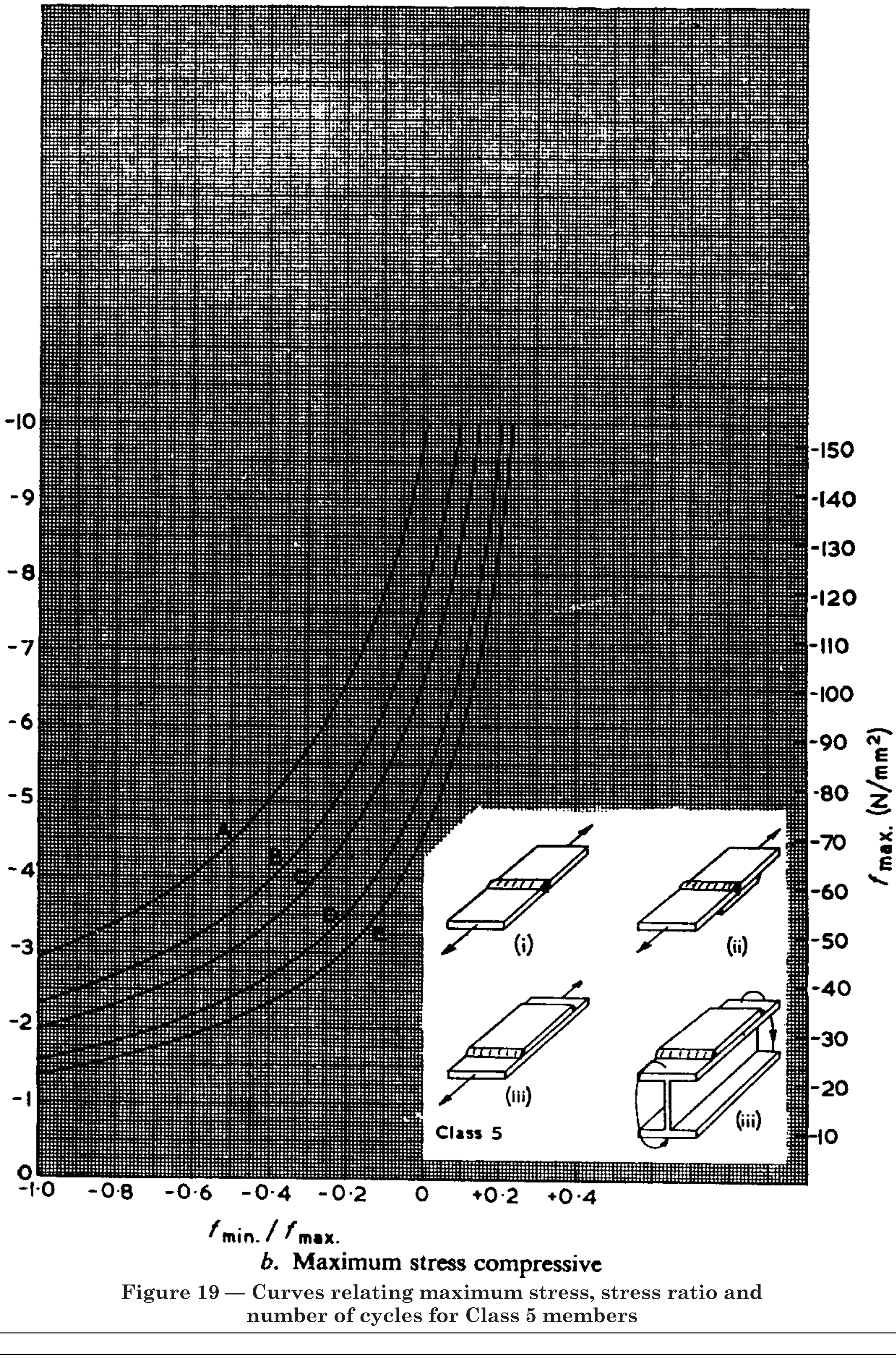
b. Maximum stress compressive

Figure 18 — Curves relating maximum stress, stress ratio and number of cycles for Class 4 members



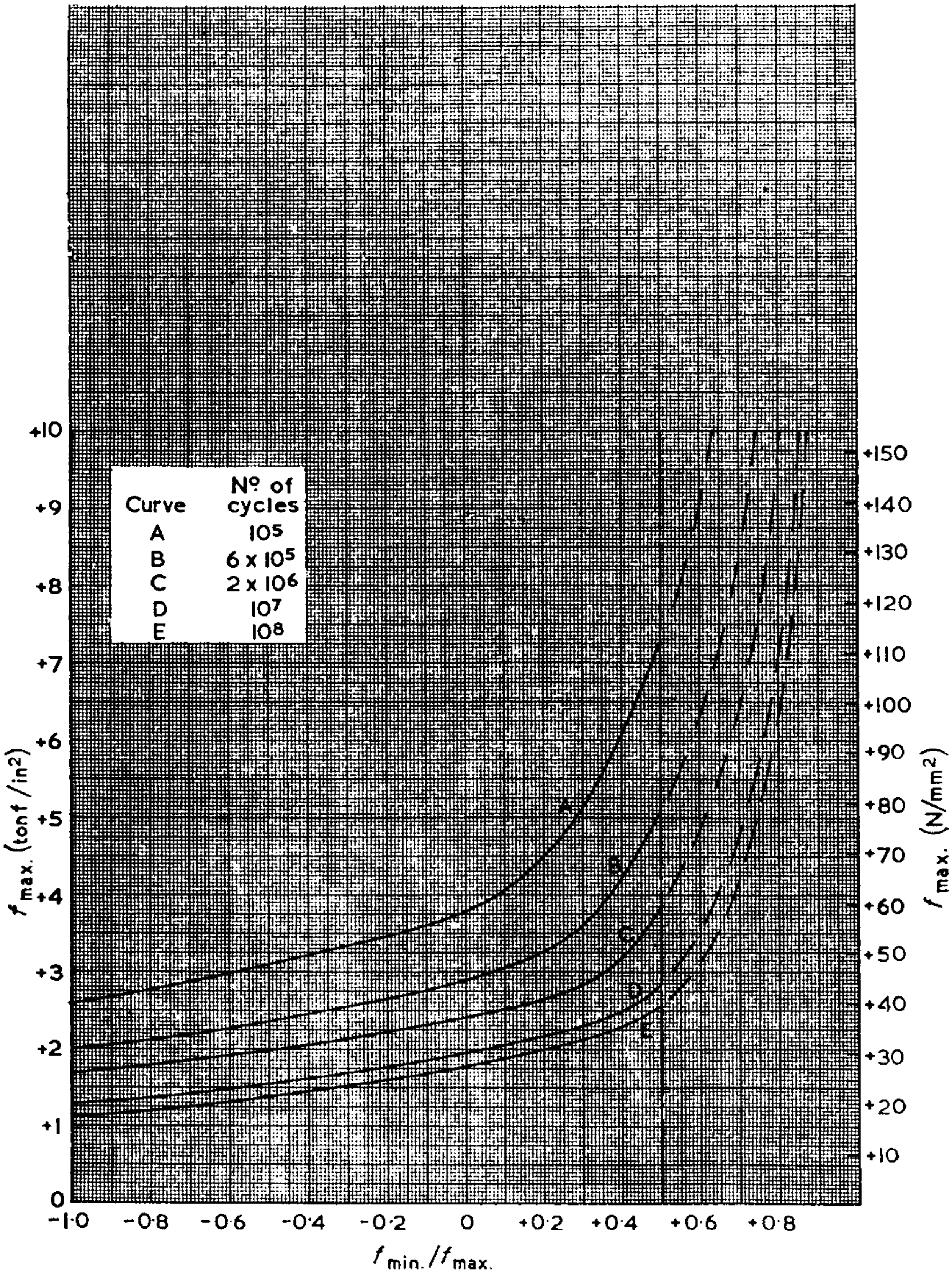
a. Maximum stress tensile

Figure 19 — Curves relating maximum stress, stress ratio and number of cycles for Class 5 members



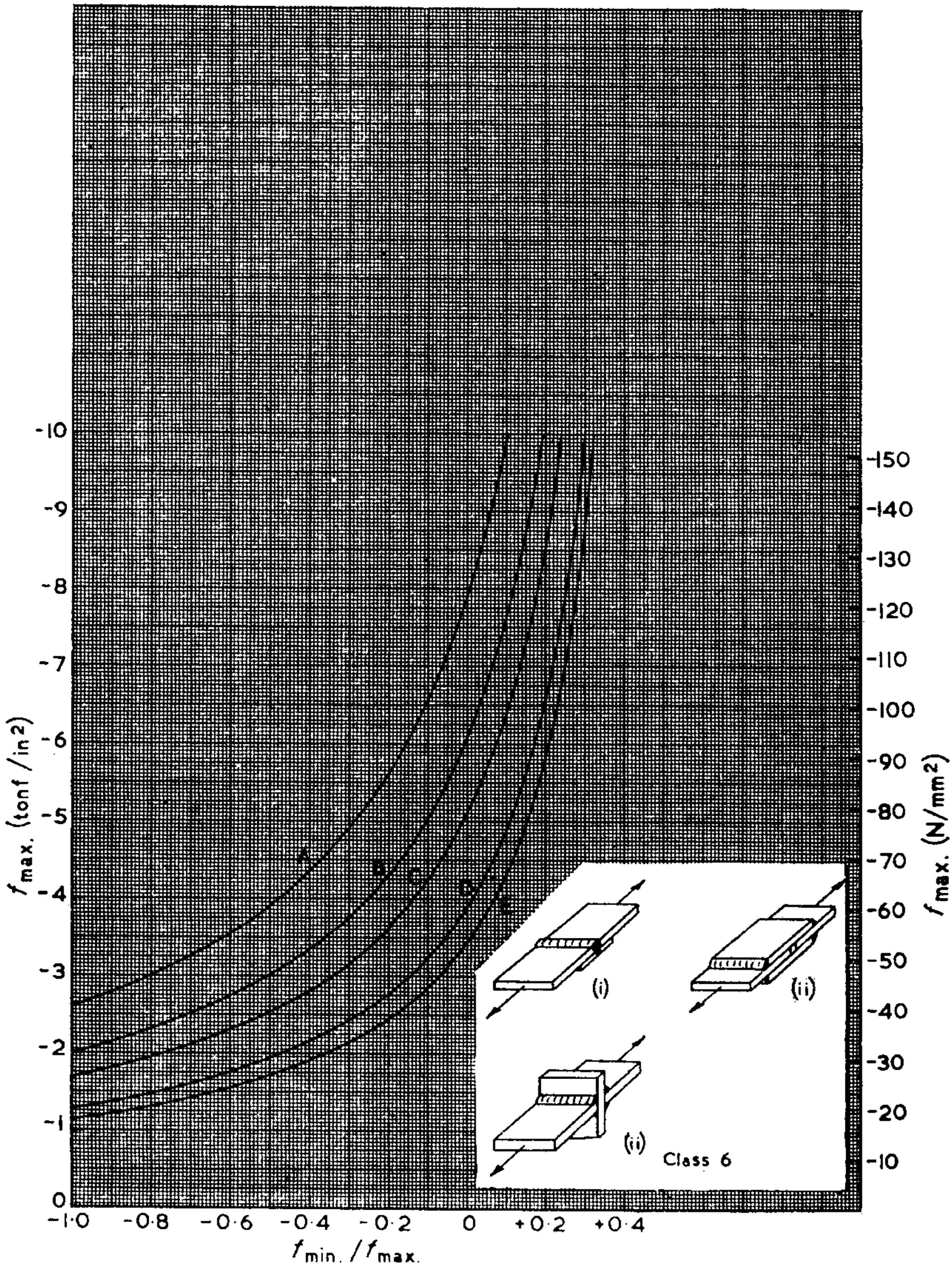
b. Maximum stress compressive

Figure 19 — Curves relating maximum stress, stress ratio and number of cycles for Class 5 members



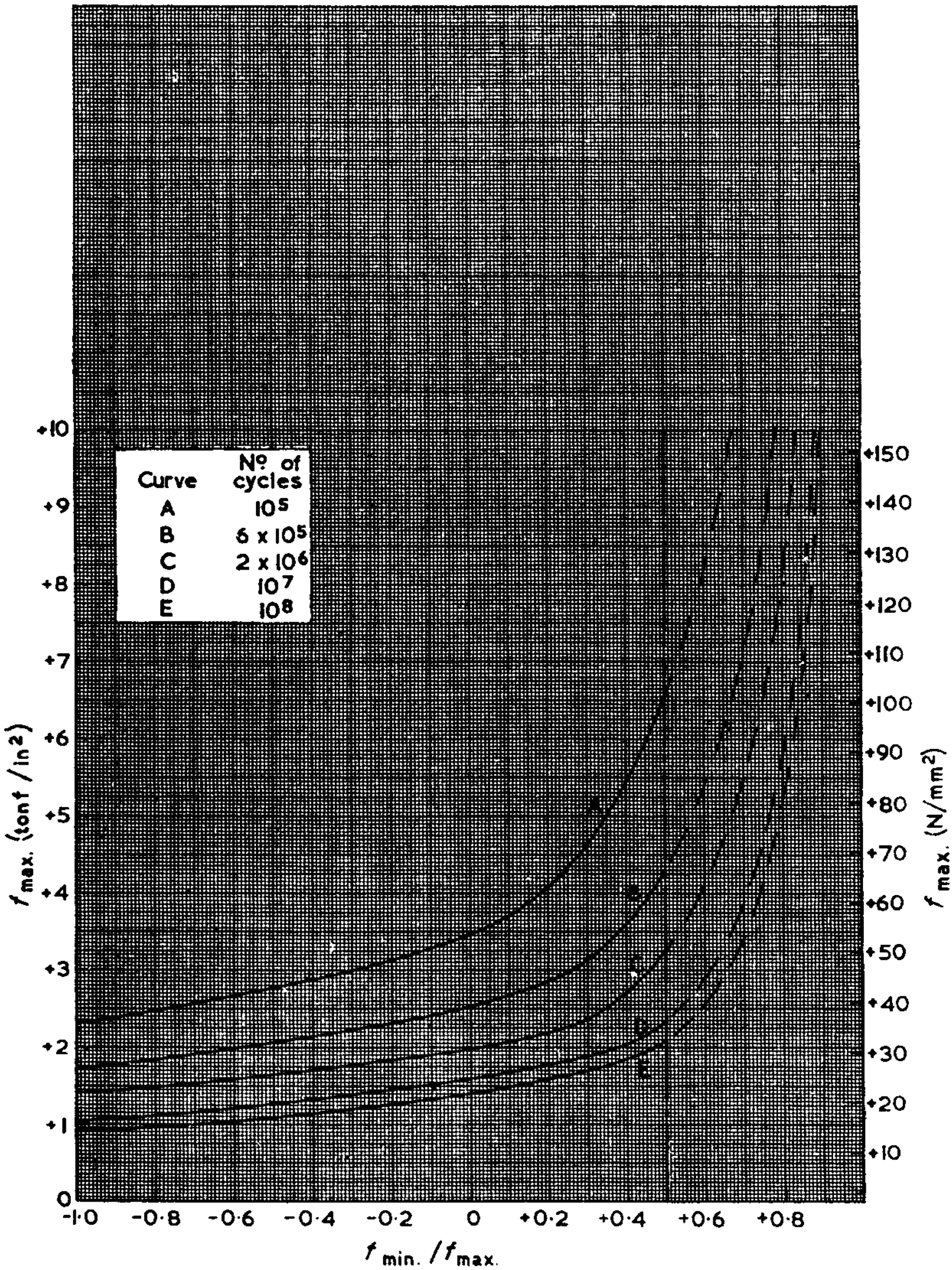
a. Maximum stress tensile

Figure 20 — Curves relating maximum stress, stress ratio and number of cycles for Class 6 members



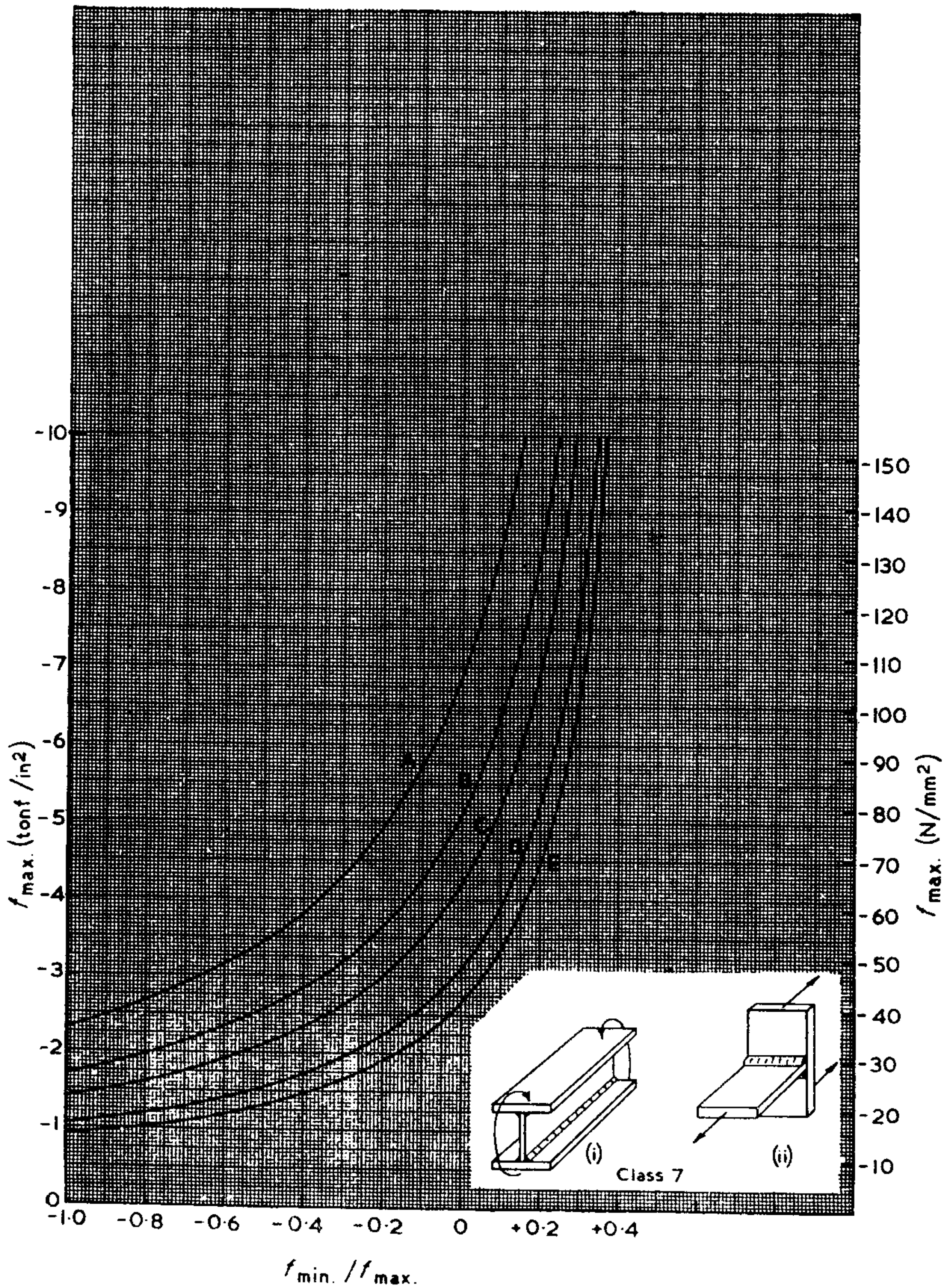
b. Maximum stress compressive

Figure 20 — Curves relating maximum stress, stress ratio and number of cycles for Class 6 members



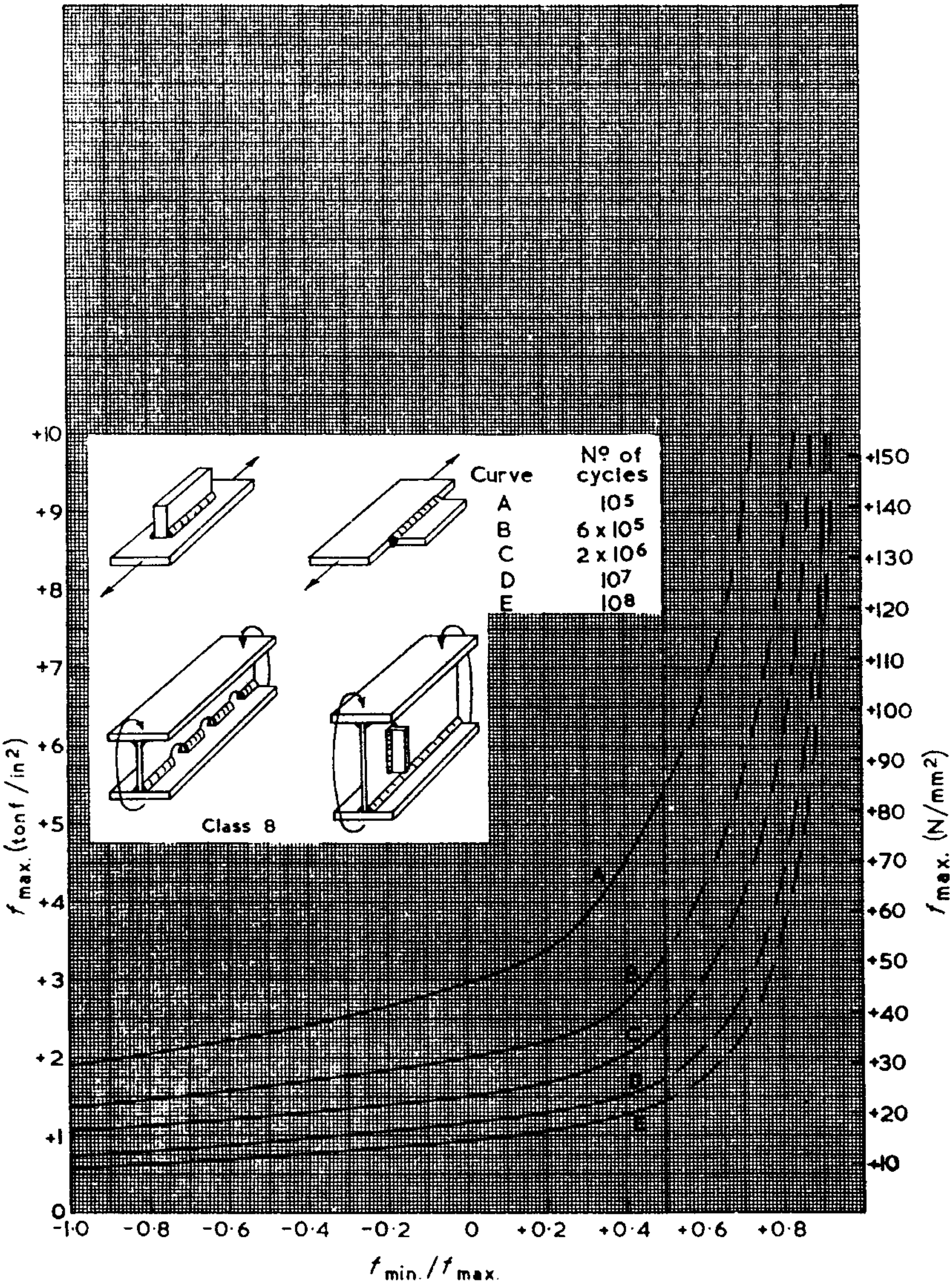
a. Maximum stress tensile

Figure 21 — Curves relating maximum stress, stress ratio and number of cycles for Class 7 members



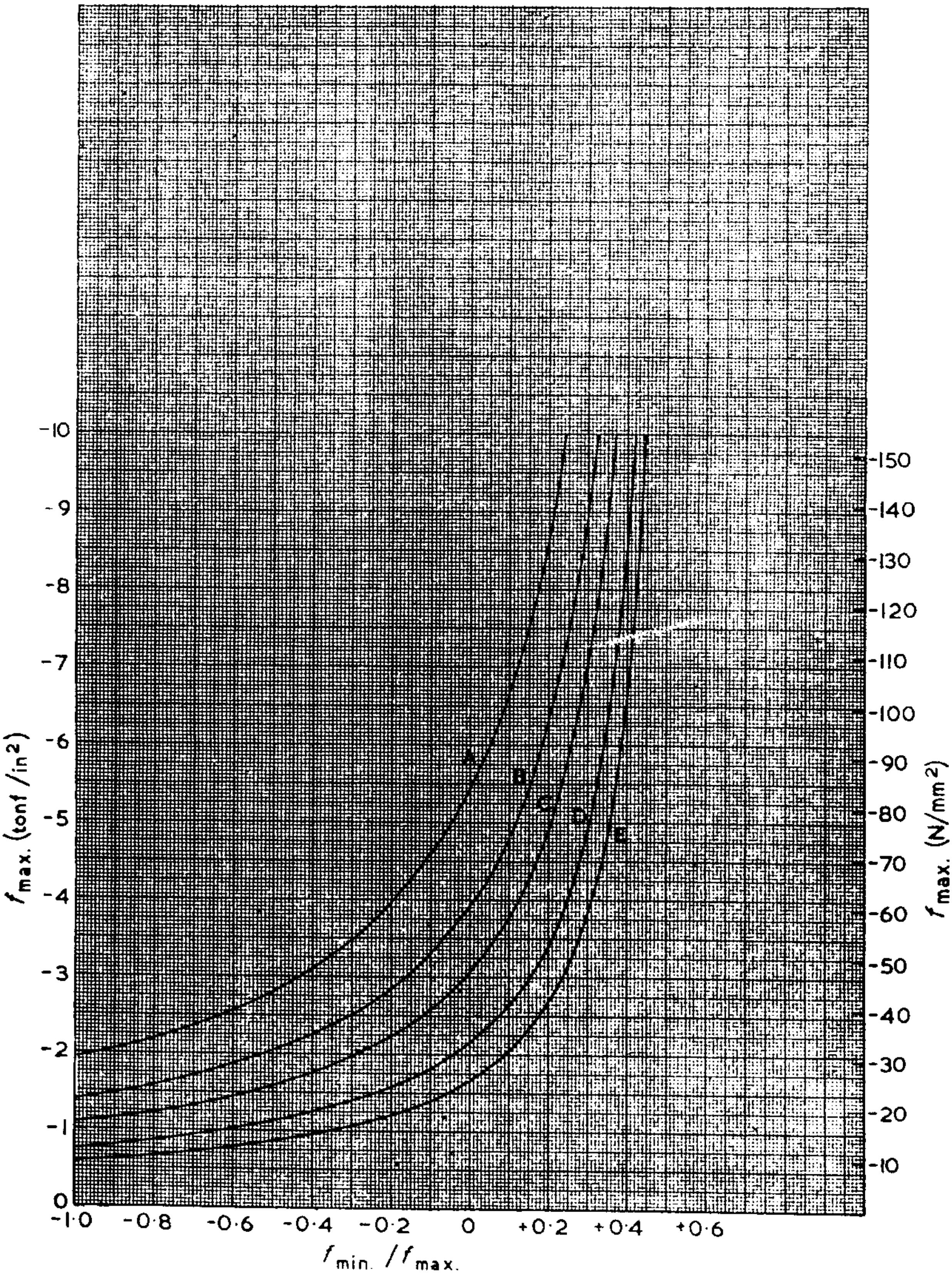
b. Maximum stress compressive

Figure 21 — Curves relating maximum stress, stress ratio and number of cycles for Class 7 members



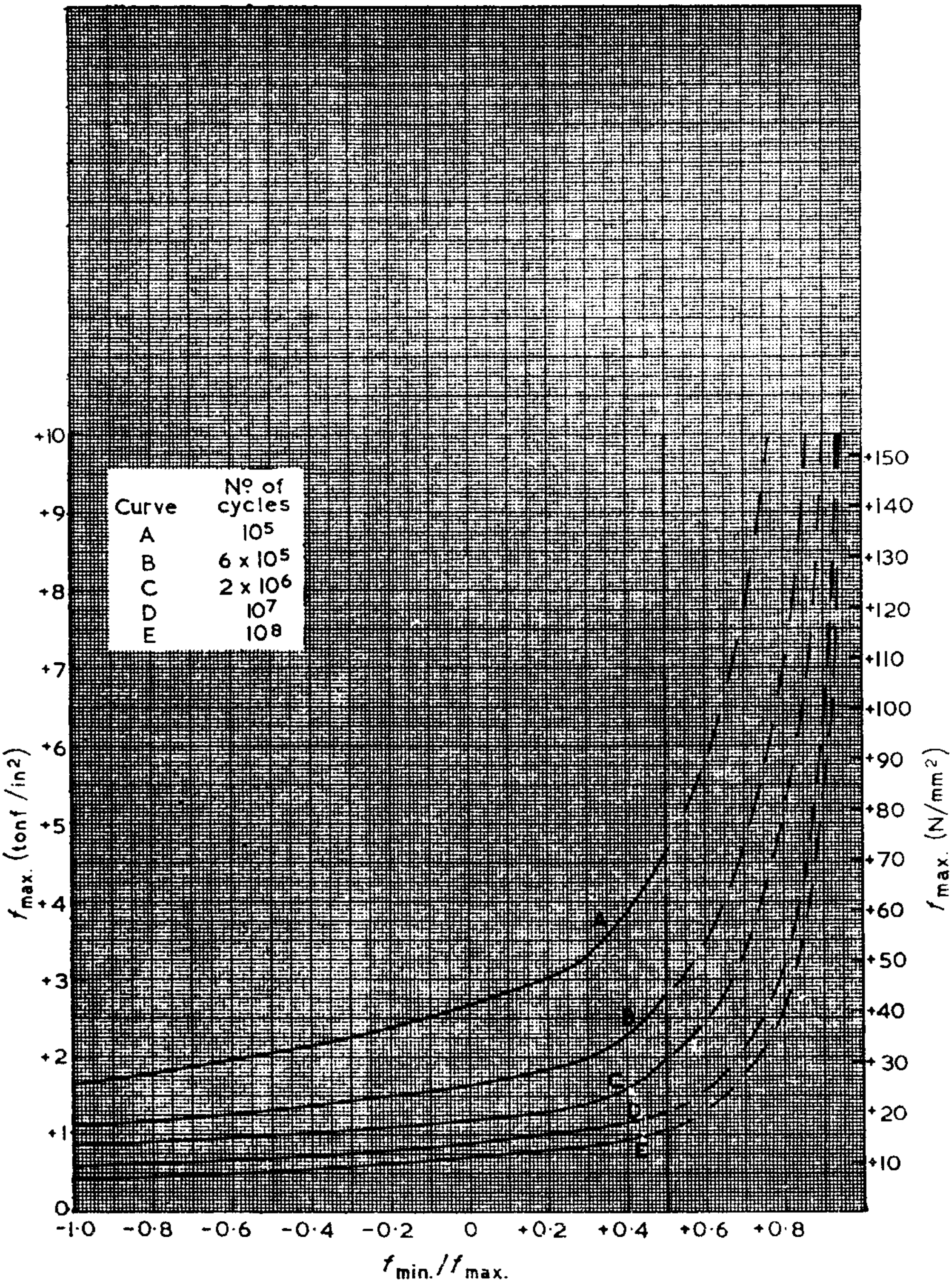
a. Maximum stress tensile

Figure 22 — Curves relating maximum stress, stress ratio and number of cycles for Class 8 members



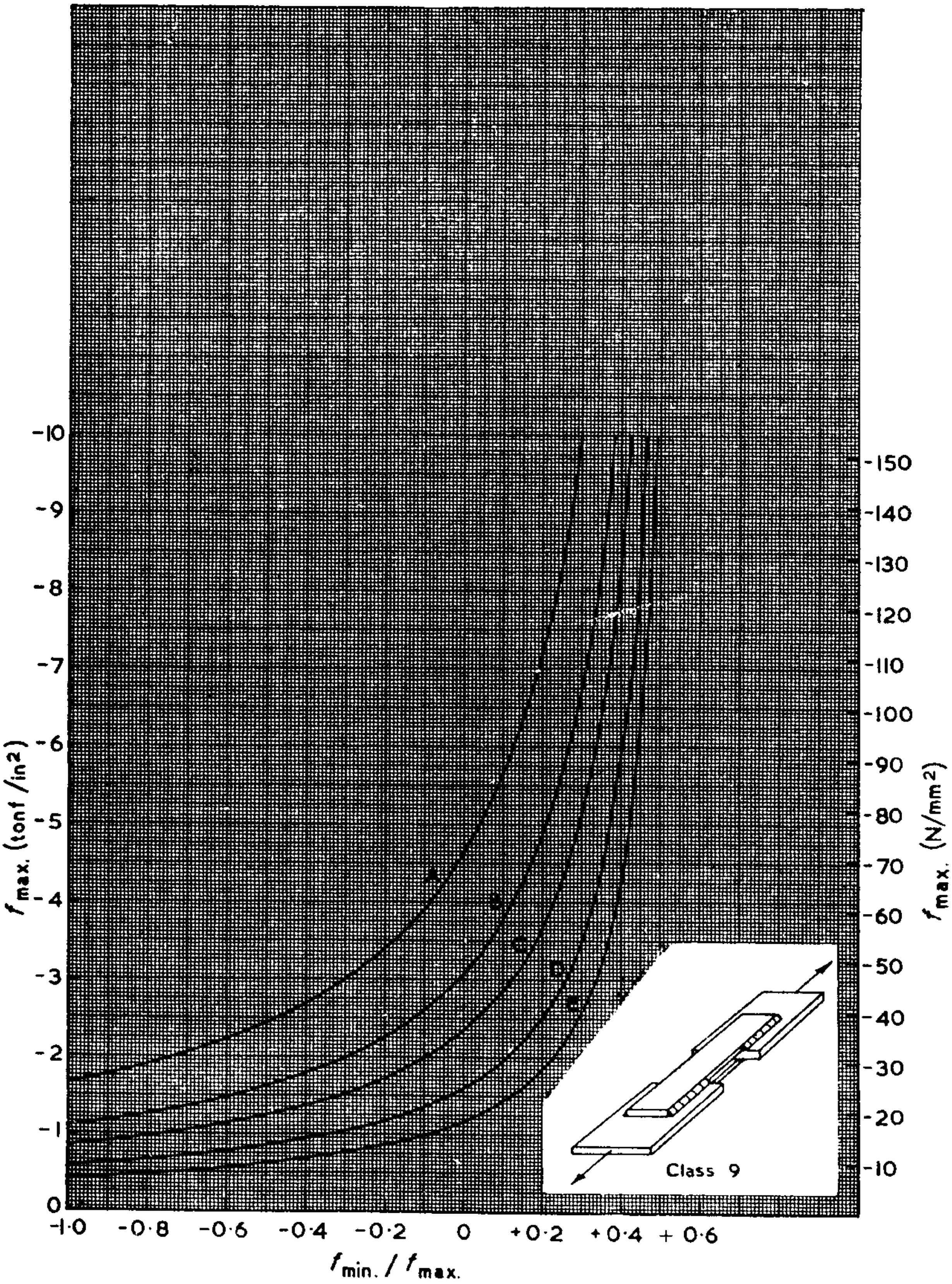
b. Maximum stress compressive

Figure 22 — Curves relating maximum stress, stress ratio and number of cycles for Class 8 members



a. Maximum stress tensile

Figure 23 — Curves relating maximum stress, stress ratio and number of cycles for Class 9 members



b. Maximum stress compressive

Figure 23 — Curves relating maximum stress, stress ratio and number of cycles for Class 9 members

Class 5 (i) Members with transverse butt welds made from one side, with an underbead.

(ii) Members with transverse butt welds made on permanent backing strips attached with full-length fillet welds parallel to the butt welds. To qualify for Class 5, this type of member must comply with **4.7.4.4**.

(iii) Members with transverse non-load-carrying fillet welds.

Class 6 (i) Members with transverse butt welds made on permanent backing strips not attached by full-length fillet welds. To qualify for Class 6, this type of member must comply with **4.7.4.4**.

(ii) Members with transverse load-carrying fillet welds or cruciform welds, either weld being with or without full penetration. To qualify for Class 6, this type of member must comply with **4.7.4.6**.

Class 7 (i) Members with continuous longitudinal fillet welds with interruptions which have not been repaired in accordance with **4.7.4.5**.

(ii) Members with T-joints, the welds being with or without full penetration if made from both sides, but with full penetration if made from one side. To qualify for Class 7, this type of member must comply with **4.7.4.6**.

Class 8 Members with discontinuous longitudinal non-load-carrying fillet or butt welds; this class includes beams with intermittent web-to-flange welds.

Class 9 Members with discontinuous longitudinal load-carrying-fillet or butt welds. To qualify for Class 9, this type of member must comply with **4.7.4.6**.

4.7.4.2 *Dressed butt welds.* Butt welds for members described in Class 2 must be dressed flush by machining finished in the direction of the applied stress; the members must have edges as-extruded or carefully machined or filed in the direction of the stress.

4.7.4.3 *Bolts and rivets.* Bolts or rivets for members described in (i) of Class 3 must be proportioned to develop the full static strength of the member; bolts must be secured against working loose [see **4.6.2.2** 6)].

4.7.4.4 *Butts welds between members of dissimilar thickness or width.* In butt welds for members described in (ii) of Class 3, (ii) of Class 4, (ii) of Class 5, or (i) of Class 6, if the materials on the two sides of the joint differ in thickness by more than ⅛ in (3.2 mm) or one fifth of the thickness of the thinner material, whichever is smaller, the thicker material must be tapered down to the thickness of the thinner with a slope of about 1 in 5 (see Appendix L). Differences in width must be treated similarly. The effect of misalignment on permissible stresses is dealt with in **4.7.2**.

4.7.4.5 *Weld repairs.* In welds of members described in (ii) of Class 3, or (i) of Class 4, if an interruption occurs in welding either the root pass or the final pass, the weld crater must be chipped or machined back in the form of a taper over a length of at least eight times its width, and the weld must then be restarted at the top of the tapered slope; this procedure is intended to prevent lack of fusion and entrapment of oxide. On completion, the surface of the new weld must be machined or filed smooth.

Repairs to members of other classes do not require the above precautions.

4.7.4.6 *Load-carrying fillet welds.* Welds for members described in (ii) of Class 6, (ii) of Class 7, or Class 9, must be designed so that the stress on the total effective throat area does not exceed the appropriate value given for a Class 8 member. Load-carrying fillet-welded joints must be designed so that secondary bending stresses are not introduced (e.g. single-lap joints should not be used except in special circumstances: see Table 29).

5 Testing

5.1 General

A structure designed in accordance with Section 4 is acceptable without testing. A structure or part of a structure not so designed must comply with either the static acceptance test described in **5.2** or the fatigue acceptance test described in **5.3**, except that those tests need not apply where an alternative test is required by an appropriate specification. The choice of test must be agreed with the engineer. An acceptance test is appropriate where:

1) the structure is not amenable to calculation or calculation is deemed impracticable;

2) design methods other than those specifically referred to in Section 4 are used; or

3) there is doubt or disagreement as to whether the structure has been designed in accordance with Section 4, or whether the quality of material or workmanship is of the required standard.

5.2 Static acceptance test[21)]

5.2.1 Application. The static acceptance test applies to structures or parts of structures that are not subject to fluctuating loads likely to cause fatigue failure (see **4.7**). The test is intended to show whether the structure is capable of carrying the design loads without undue distortion and without developing serious defects.

The test may be done on the actual structure under consideration or on one that in all essential respects is its equivalent.

During a static test note must be taken of any readily excited natural vibration and, if the damping characteristics are poor, arrangements must be made to prevent or minimize such vibration in the actual structure.

5.2.2 Loading. If the structure to be tested is complete, its self-weight constitutes the dead load. If the structure is incomplete, the self-weight of each missing part must be carefully estimated and then multipled by 1.1 (or by 0.9 if it acts in opposition to the live load) and applied as a dead load additional to that of the incomplete structure. Any such additional dead load must be positioned so as to represent the missing part as realistically as possible.

All other loads on the structure are considered as live loads; any moving load must be augmented by the appropriate impact effect (see **3.3**).

Prior to the actual test or tests, a preliminary settling-down of the structure must be accomplished by applying to it such a combination of live loads as, together with any additional dead load which may be required as above, produces substantially the severest effect. The live loads must be removed again before the testing begins, but any additional dead load must remain in place except in so far as it may have to be modified according to whether it acts with or in opposition to the live load during the test.

The live loads for the actual test consist of the wind load multiplied by 1.25 and all other live loads multiplied by 1.5. Those combinations of any of them which, together with any additional dead load, produce the severest effects, must in turn be applied to the structure in at least five approximately equal increments. They must in each case be positioned so as to reproduce the actual live loads as realistically as possible.

5.2.3 Duration of loading. The preliminary settling-down live loads must remain in place for at least 15 minutes.

In the actual test, each increment of test live load must remain in place long enough to enable measurements of deflection to be taken at such critical points of the structure as may be determined by the engineer, and to permit examination for damage. The final increment of each combination of loads must remain in place for at least 15 minutes before the measurements and inspection required for acceptance are made.

5.2.4 Acceptance. The criterion for acceptance is that the structure must sustain the test loads without excessive deformation and without the development of deleterious defect. Beam deflections must not exceed the values given in **4.4.1** modified appropriately to allow for the difference between the working load and the test load.

Load-deflection curves must be plotted throughout the incremental loading or loadings, and must be examined for signs of instability. If doubt arises from the examination, the engineer may require that the test be repeated. The engineer must satisfy himself that no undue risk will arise from any local plastic deformation which may be repetitive during the life of the structure.

The recovery of deformation 15 minutes after removal of the test loads must be at least 95 %. Failing this, the structure will be acceptable if, on repetition of the test, recovery is at least 95 % of the deformation occurring during the repetition.

[21)] Attention is drawn to “Report of a committee on the testing of structures” published by the Institution of Structural Engineers in September, 1964.

5.3 Fatigue acceptance test

5.3.1 Application. The fatigue acceptance test applies to structures or parts of structures that are subject to fluctuating loads of such magnitudes and frequencies as to render fatigue failure a reasonable possibility (see **4.7**). The test is intended to show whether the structure is capable of carrying the design loads during its service life.

The test must be done on a specimen which exactly reproduces the structure or part under consideration.

5.3.2 Loading. The structure must be subjected to substantially the same loads or combinations of loads as are expected in service.

Where the service loads vary in a random manner between limits, they must be represented in the test by an estimated equivalent sequence of loads which must be agreed with the engineer. The test programme must be arranged to include at least 30 repetitions of the agreed sequence before failure.

Alternatively, the test load must be the maximum service load, and the number of repetitions must be agreed with the engineer as representing the total number of applications of all service loads that give rise to stresses greater than those permitted for Class 9 assemblies (Figure 23) for the appropriate values of the stress ratio and the number of cycles.

5.3.3 Acceptance. The criterion for acceptance will depend on whether the structure is classified as a safe-life structure (see **5.3.4**) or a fail-safe structure (see **5.3.5**).

5.3.4 Safe-life structures. A safe-life design is one in which the structure is designed to have a fatigue life greater than its estimated service life.

Tests to establish safe-life performance must be done under repeated loadings as defined in **5.3.2** until failure results. The geometric mean life obtained from the effective number of specimens in these tests must be at least equal to the specified service life multiplied by the factor given below.

Effective number of specimens tested	Factor
1	5.0
2	4.2
3	3.9
4	3.75
10	3.5

The effective number of specimens for the purposes of determining the appropriate factor will depend on the design and loading and must be agreed with the engineer. For example, symmetry will normally enable test results to be counted as for two specimens, and a detail which repeats within a length of constant stress may further multiply the effective number.

5.3.5 Fail-safe structures. A fail-safe design is one in which the techniques and frequency of inspection are such that any fatigue crack which would endanger the structure is certain to be discovered before catastrophic failure results.

Acceptance is based on the rate of crack growth, and the test is designed to ensure that the rate is not dangerous in relation to the frequency of inspection.

Tests to establish fail-safe performance must be done under repeated loadings as defined in **5.3.2** and must continue until a fatigue crack is detected by the same technique as will be employed in service. The crack must then be allowed to grow for a testing time equivalent to three times the inspection period, and at the end of that time the static design strength of the structure must not be affected by its presence.

A fail-safe design may, in addition, be required to have a specified minimum life which must be established by tests as for safe life. The tests must show that the geometric mean life obtained from the effective number of specimens is at least half the specified life multiplied by the appropriate factor before significant cracks appear, and is at least equal to the specified life multiplied by the same factor before a prohibitive amount of repair is required.

6 Fabrication and erection

6.1 General

6.1.1 Factors affecting fabrication and erection. Fabrication and erection operations are, in general, the same as for steelwork, but they are considerably affected by the lighter weight of structures and assemblies, by the greater flexibility of members, by the larger dimensional changes due to temperature and by the readier machinability of aluminium. Aluminium lends itself to high standards of workmanship.

During erection the structure must be securely bolted or otherwise fastened, and if necessary temporarily braced, so as to ensure stability under all erection stresses and conditions, including those due to erection equipment and its operation.

6.1.2 Storage and transport. If aluminium is stored in damp conditions, or in conditions where condensation can take place, superficial corrosion may cause unsightly staining or marking; this is particularly the case with sheet and plate.

Where appearance is important, therefore, aluminium must be stored in dry places, clear of the ground; contact with other metals and with materials such as cement and damp timber must be avoided. Care must be taken of material for architectural use, particularly if it is anodized; surfaces should be protected with strippable tapes, waxes or lacquers while danger of damage exists.

For transport, aluminium must be packed so as to avoid mechanical damage, abrasion and, where appearance is important, surface corrosion and staining. For export shipment, aluminium must be packed in moisture-proof parcels, adequately crated to prevent damage to the waterproofing, which may be of heavy bitumen paper. Sheets or other items inside the parcels may be separated by interleaving with paper or cardboard spacers.

6.1.3 Marking out. Marking-out techniques are similar to those for steelwork except that, where subsequent welding is involved, paint, chalk, graphite and other contaminants must not be used. Fine scribing-lines are permissible except on critically stressed areas of thin material.

Due attention must be given to the effects of the relatively high coefficient of expansion of aluminium in measuring, marking out and assembly, particularly when temperature variations are large.

6.1.4 Cutting. Cutting must be by machining, shearing or arc-cutting. Band-saws and circular saws should be of the skip-tooth type. Cut edges must be smooth and free from burrs, distortions and other irregularities. Care must be taken to avoid the use of tools contaminated by other metals, particularly copper or brass.

Shearing should normally be limited to material ¼ in (6.4 turn) thick or less. Arc-cutting must be by a process shown by test, to the satisfaction of the engineer, to have no deleterious effect on the material. Flame-cutting must not be used.

Sheared or arc-cut edges should normally be subsequently machined or filed smooth if used as edge preparations for welds in strength members.

6.1.5 Drilling, punching and reaming. Holes must be made by drilling or reaming or, in sheet, by punching. Undersize punching is permitted provided that all burrs, edge defects and local distortion are removed by subsequent reaming. Holes for bolts and rivets must, unless otherwise specified by the engineer, be of the sizes given in Table 13. Holes for close-fitting bolts must be reamed to exact size after assembly. Holes for bolts and rivets in certain members may need to be drilled with parts assembled and tightly clamped together; if the engineer requires, the parts must be subsequently separated to remove burrs.

6.1.6 Bending and forming. Aluminium alloys are available in a wide range of tempers and formability. Where forming or bending is necessary, the engineer must consult with the manufacturer regarding the alloy and temper appropriate to the operation, and regarding any subsequent heat treatment that may be required. Heat treatment and hot forming or hot bending must be done only under competent metallurgical direction and supervision.

Any piece that cracks or fractures because of forming or bending must be rejected.

6.2 Bolting and riveting

6.2.1 Bolting. The length of the unthreaded part of a bolt must be such that as far as possible no part of the thread is within the thickness of the member. The thread must project beyond the nut for a minimum of one turn.

Washers must be provided under all bolt heads and nuts. Galvanized steel washers must be used with steel bolts. Washers of pure aluminium or of the same material as the bolt or the member must be used with aluminium bolts. Corrosion-resisting-steel washers must be used with corrosion-resisting-steel bolts.

Nuts must be properly, but not excessively, tightened. Locking devices must be used as required (see **4.6.2**).

The threads of aluminium bolts should be lubricated before assembly, particularly if the joint will subsequently be dismantled. Lanolin sealing is recommended for the threads of anodized bolts.

6.2.2 Riveting. Riveted joints must be tightly drawn together before and during riveting. Care must be taken to avoid contaminating rivet holes with paint or other protective material, prior to riveting (see **7.4.1**).

Rivet heads must be in accordance with the standards listed in **2.3.3**.

Rivets must be driven so as to fill the holes, including any countersinkings, completely. Heads must be concentric with their shanks and in close contact with the riveted surfaces.

Overheating of the aluminium parts when a group of steel rivets is hot-driven must be avoided by staggered driving or by temporary cessation of driving.

Tubular and other special rivets must be formed cold, using the tools and procedure recommended by the supplier.

Loose or otherwise defective rivets must be removed, preferably by drilling away the head and punching the shank through, and new ones driven.

6.3 Welding

6.3.1 General. Care must be taken not to strike the arc on parts of the work other than the prepared fusion faces. Run-on and run-off plates must be used where appropriate (see **4.6.3.3**).

Site work should be avoided if possible. It may be done only where there is complete protection which simulates shop conditions.

Care must be taken to ensure that the welding of attachment to strength members does not impair their performance (see Appendix L).

6.3.2 Materials. The choice of structural aluminium alloys for welding is dealt with in **2.2**. Filler rods and wires must be selected in accordance with **2.2.6**. Care must be taken to store filler rods and wires in a dry, clean place so that they remain smooth, bright and free from surface corrosion.

The engineer must satisfy himself that the combination of parent and filler materials is suitable in regard to strength and durability for the service conditions of the structure. Particular attention is drawn to the hot-cracking susceptibility of H30, H9, H20, and N4, which makes it essential to use the filler materials and welding techniques recommended so as to ensure a suitable combination of parent and filler metal in the actual weld.

6.3.3 Processes. Strength members must be welded by either the tungsten-arc (TIG) or the metal-arc including pulsed-arc (MIG) inert-gas process, the welding being done by approved welders using approved procedures (see **6.3.6** and **6.3.5**).

Non-strength members may be welded by inert-gas welding processes or, in suitable cases, by resistance welding, fusion spot-welding or gas welding.

6.3.4 Edge preparation, cleaning and setting up. Suggested edge preparations are given in Appendix M.

Surfaces to be welded must be smooth, and immediately prior to assembly and welding must be cleaned using a clean, dry, power-driven scratch-brush of corrosion-resisting steel. If the area to be cleaned is greasy or otherwise contaminated, such contamination must be removed prior to scratch brushing. The interval between cleaning and welding should be as short as possible and must not exceed six hours. If accidental contamination with dirt or moisture occurs after cleaning and prior to welding, the joint must be recleaned. TIG filler wires must be degreased and cleaned with dry steel wool before use; both TIG and MIG wires must be kept free from contamination before and during use.

Assembly must be by jigging or tack-welding or both. Jigs and fixtures, including backing bars, must be clean and dry and made from materials unlikely to contaminate the weld. Tack welds must be either chipped smooth if necessary to facilitate their incorporation in the weld, or completely removed if their presence is likely to cause defects in the weld.

Flat welding is preferred to positional welding.

6.3.5 Procedure and approval. General recommendations are given in BS 3019-1[22] and BS 3571-1[23].

For strength joints the precise course of action to be followed must be documented as a welding procedure which must contain the information listed in Table 15. The welding procedure must be proved by adequate tests and must receive the approval of the engineer before it is used in actual fabrication. Any significant alteration in a procedure must be similarly approved. Approval tests must be specified by the engineer, bearing in mind the service conditions of the structure, and the specimens must be representative of the size and type of joint to be fabricated. Mechanical tests must be in accordance with BS 3451[24] and in the case of butt welds, the results must meet the requirements of Table 16. For fillet welds, fracture tests must be employed to see that complete root penetration has been achieved. All welds must be defined in accordance with **4.6.3.1** and must meet the requirements of **6.3.7**. Procedures need not be re-approved if the fabricator satisfies the engineer that similar procedures have been approved previously.

Table 15 — Information for welding procedure

	For TIG welding	For MIG welding
1)	Specification of parent metal	
2)	Preparation of edges and set-up of parts	
3)	Method of cleaning	
4)	Size and type of tungsten electrode	Arc voltage
5)	Welding current	Current or wire feed speed
6)	Size and type of filler rod	Size and type of electrode wire
7)	Gas nozzle size and rate of gas flow	
8)	Number and arrangement of weld runs (including back chipping)	
9)	Welding position	
10)	Welding sequence	
11)	Pre-heat or inter-run temperature	
12)	Welding head position and arc travel speed (mechanized welding)	
13)	Shop or site conditions	
14)	Any other relevant information	

[22] BS 3019, "*General recommendations for manual inert-gas tungsten-arc welding*", Part 1, "*Wrought aluminium, aluminium alloys and magnesium alloys*".

[23] BS 3571, "*General recommendations for manual inert-gas metal-arc welding*", Part 1, "*Aluminium, and aluminium alloys*"

[24] BS 3451, "*Testing fusion welds in aluminium and aluminium alloys*".

Table 16 — Mechanical test requirements for butt-weld procedure and welder approval

Alloy	Tensile strength[a] tonf/in^2	(N/mm^2)	Maximum bend radius[b]
H30	12.5	(193)	[c]
N8	17.0	(263)	3*t*
H9	7.5	(116)	[c]
H20	12.5	(193)	[c]
N4	12.0[d]	(185)[d]	2*t*
N5	14.0	(216)	
H17	21.0	(324)	8*t*

[a] Transverse to weld and irrespective of temper before welding.
[b] Controlled side bend test: the specimen thickness *t* is normally ⅜ in (9.5 mm).
[c] Not applicable.
[d] 11.0 (170) for NE 4.0.

6.3.6 Approval of welders. Every welder employed on a structure or assembly must obtain and retain approval by demonstrating at regular intervals, and at any time on the request of and to the satisfaction of the engineer, that he is capable of consistently producing welded joints of the required standard using the approved welding procedure.

Approval tests must be made, separately for each procedure, as specified in **6.3.5**. Approval will be granted if the appearance and mechanical performance of the joints meet the design requirements (see **4.6.3**).

6.3.7 Quality control. The main requirements for control of weld quality are procedure approval (see **6.3.5**) and welder approval (see **6.3.6**).

In addition, welds of strength members must be examined by the engineer. They must be of the correct size, of good appearance and free from cracks. Visual examination is essential. Aids to visual examination such as weld-size gauges, magnifying-glasses and dye-penetrants may be used; dye penetrants, however, must be used with caution so that they do not become sources of contamination in later welding. Special inspection procedures, such as radiographic or other non-destructive tests, must be employed if specified in the design requirements (see **4.6.3.1** and **4.7.4.1** Class 2).

Should the performance of a welder be at any time in question, he may be required to stop work and to re-qualify in accordance with **6.3.6**. Work already done by him must be carefully re-examined.

Welds or parts of welds may be rejected because of cracking, insufficient size, undercut, overlap or otherwise imperfect profile, or because of other imperfections including those revealed by any required special inspection procedure.

6.3.8 Repair or replacement. No repair to or replacement of any weld must be made without the authority of the engineer.

If repair is authorized, the extent of any defective weld area must be determined by the appropriate inspection procedure and clearly marked on the joint.

The material at each defective area must be removed by chipping or machining so as to leave a smooth transition at the ends of the cut-out. The repair must then be made by an approved welder using the approved procedure. Special requirements for certain classes of member are given in **4.7.4.5**.

No weld must be remade, nor any part of a weld replaced, more than twice.

6.4 Glued joints

Glued joints must be made by skilled operators using the precise procedure recommended by the supplier of the adhesive and agreed by the engineer. Glued joints must not be made in the field.

6.5 Inspection and safety

6.5.1 Inspection. The engineer must have access at all reasonable times to all places where fabrication and erection are being done, and the fabricator or contractor must provide the necessary facilities for inspection.

6.5.2 Safety. Attention is drawn to the appropriate statutory requirements which affect operations involved in fabrication and erection.

7 Protection

7.1 Protection from environment

7.1.1 General. Aluminium structures often require no protection. The need for protection depends on the alloy and on the environment; it is not necessarily the same for the inside of a structure and for the outside.

In mild environments an aluminium surface will retain its original appearance for years, and no protection is needed for most structural alloys. In moderate industrial conditions there will be a darkening and roughening of the surface, and protection or maintenance may be necessary. In aggressive atmospheres discolouration and roughening will be worse, and protection is required. In coastal and marine environments the surface will roughen and acquire a grey stone-like appearance, and protection is necessary with some alloys. Where aluminium is immersed in water, special precautions may be necessary. Tropical environments are in general no more harmful to aluminium than temperate ones, although certain alloys (see **4.1.5.2**) are affected by long exposure to high temperature, particularly in a marine environment.

In all environments external surfaces which are sheltered from the weather, but on which atmospheric deposits settle, are affected to a greater extent than those washed by rain.

Where aluminium is in contact with certain other metals or other substances, special protection is necessary, particularly in the presence of sea-spray or of splashing from salt-treated roads. The drainage of water from copper or copper-alloy roofs onto aluminium causes corrosion and must be prevented. Similarly, the presence of copper in paints and in abrasive agents for pre-cleaning must be avoided.

Aluminium surfaces, though not usually in structural work, can be given decorative finishes other than the full protective treatment dealt with in **7.2**. Such treatments, which include anodizing (see BS 1615[25)] and BS 3987[26)]) and certain chemical colouring processes, are not substitutes for painting. Anodized surfaces must be maintained clean (abrasive must not be used) to avoid unsightly pitting in aggressive environments.

7.1.2 Protective treatment. Structures must ordinarily be protected in accordance with Table 17. Environments, whether indoor or outdoor, however, cannot always be categorized precisely, and where there is doubt the engineer should seek expert guidance from the manufacturer. An unprotected structure in a doubtful environment should be examined after, say, twelve months service, and the need for protection re-assessed; this is particularly advisable with material less than ¼ in (6.4 mm) thick.

If an alloy not listed in Table 1 or Table 23 is used, its durability rating must be established by the engineer (see **2.2.4**).

If two or more alloys are used together, protection must be in accordance with the lowest of their durability ratings.

7.2 Painting

7.2.1 General. Painting must be preceded by appropriate pre-treatment, the several operations referred to in **7.2.2** to **7.2.5** being done in sequence without any delay between them. Surfaces must be thoroughly dry, and preferably at a temperature above 40 °F (4 °C). Contact surfaces must be painted where specified (see **7.4**).

[25)] BS 1615, "*Anodic oxidation coatings on aluminium*".
[26)] BS 3987, "*Anodized wrought aluminium for external architectural applications*".

Table 17 — General protection of aluminium structures

Durability rating[a]	Requirements according to environment					
	Dry unpolluted	Mild	Industrial and industrial-marine		Marine (non-industrial)	Sea-water immersion
			Moderate	Severe		
A	None	None	None	P	None	None
B	None	None	P[b]	P	P[b]	N
C	None	P	P	N	N	N

P = protection. N = not recommended.

[a] See **2.1.2**.

[b] Material over ⅛ in (3.2 mm) thick normally does not need protection.

Attention is drawn to CP 231[27)].

7.2.2 Cleaning. The surfaces must be cleaned, dried and thoroughly degreased by an appropriate solvent such as one consisting of equal parts of white spirit and light solvent naphtha. Flame cleaning is not suitable for aluminium.

7.2.3 Pre-treatment. The clean degreased surfaces must be treated to ensure paint adhesion. This may be done by mechanical roughening with abrasive paper or abrasive-impregnated nylon pads or by abrasive-blasting, provided in each case that the abrasive is either alumina or other non-metallic and copper-free grit. Mechanical roughening may-also be done with corrosion-resisting-steel, but not copper-plated-steel, wool or wire brushes.

Alternatively, paint adhesion may be obtained by the use of a chromate conversion coating or an etch-primer or wash-primer, provided the process and its method of application are approved by the engineer.

7.2.4 Priming coat. The pre-treated (see **7.2.3**) or metal-sprayed (see **7.3**) surfaces must receive a priming coat with an inhibiting pigment containing not less than 20 % by weight of zinc chromate or other approved chromate in a suitable water-resisting vehicle.

The priming coat must not contain any copper or mercury compounds, graphite or carbonaceous materials and preferably should not contain lead.

A suitable priming coat consists of a tung-oil phenolic-resin vehicle pigmented with equal parts of zinc tetroxy-chromate and red iron oxide.

7.2.5 Subsequent coat or coats

7.2.5.1 *Conventional paints.* The primed surfaces must be painted with one or more coats of paint of a type compatible with the priming coat and any subsequent coats, and chosen to suit the conditions of exposure.

Such subsequent coats must not contain any copper or mercury compounds, graphite or carbonaceous materials and preferably should not contain lead.

An aluminium paint system should consist of a non-leafing under-coat and a leafing finishing coat.

7.2.5.2 *Bituminous paints.* Bituminous paints or hot bitumen are commonly specified for protection where aluminium is in contact with building materials (see **7.7**). Bituminous paint to BS 3416[28)] is recommended for normal use, with dip-applied hot bitumen as an alternative. For severe exposures, or in warm climates, or under conditions of immersion where abrasion is likely from solids in the water (e.g. in sewage), however, it may be desirable to use a plasticized coal-tar pitch, preferably with an epoxy-resin additive, obtained from a reputable maker. The above materials must be applied direct to surfaces cleaned in accordance with **7.2.2** and roughened if necessary by mechanical means (see **7.2.3**); they must not be applied over painted surfaces.

7.2.6. Pre-coated material. Aluminium sheet and sections may be obtained with a fully protective coating already applied. Such a coating is acceptable provided that the engineer is satisfied by the results of tests that it affords protection appropriate to the alloy, the assembly and the environment.

[27)] CP 231, "*Painting of buildings*".

[28)] BS 3416, "*Black bitumen coating solutions for cold application*".

7.3 Metal spraying

7.3.1 Preparation. Surfaces to be metal-sprayed must be thoroughly cleaned (see **7.2.2**) and then roughened, to provide an adequate key, by blasting with alumina or other non-metallic and copper-free grit; a coarser grit usually gives a better key than a finer one. Surfaces must be free from grease, moisture and other foreign matter immediately before spraying.

7.3.2 Spray metal. The metal for spraying must be aluminium of commercial purity (normally 1B of BS 1475[29]) except with certain non-standard alloys, in which cases the advice of the manufacturer must be sought.

7.3.3 Application. Metal spraying may, at the discretion of the engineer, be used either instead of or in conjunction with painting.

The spray metal must be applied by a process approved by the engineer. The thickness of the sprayed coating must be not less than 0.004 in (0.1 mm) or, where protective painting is to be applied over it, not less than 0.002 in (0.05 mm); the coating in either case must be complete and undamaged.

Attention is drawn to BS 2569-1[30].

7.4 Metal-to-metal contact surfaces, and bolted and riveted joints

7.4.1 General. To provide protection, one of the five procedures given below must be followed for contact surfaces and bolted and riveted joints, in accordance with **7.4.2** to **7.4.6**.

Procedure 1. The heads of steel bolts and rivets may for appearance be over-painted with a priming coat (see **7.2.4**) followed by a coat of aluminium paint; protection otherwise is not required.

Procedure 2. Both contact surfaces, including bolt and rivet holes (but not holes for close-fitting bolts), must, before assembly, be cleaned, pre-treated and receive one priming coat (see **7.2.4**) extending beyond the contact area. The surfaces must be brought together while the paint is wet.

The heads of steel bolts and rivets and their surrounding areas, and any steel, cast iron or lead edges of the joint, must after assembly be overpainted with at least one priming coat, care being taken to seal all crevices.

When hot-driven rivets are used, any protective paints or compounds must be kept clear of the actual rivet holes so as to avoid carbonization due to the heat of the rivets.

Procedure 3. As Procedure 2 above, but additional protection must be afforded by an elastomeric jointing compound (preferably of the polysulphide type) applied onto and extending beyond the contact surfaces, before assembly but after the priming coat on them is dry. A neoprene gasket may be used instead of a jointing compound.

Bolts or rivets must be closely spaced and have minimum edge-distances.

Procedure 4. As Procedure 3 above, but the heads of steel bolts and rivets and surrounding areas, and any steel or cast iron edges of the joints, must, unless they are already metal-sprayed or galvanized, be metal-sprayed preferably with aluminium (see **7.3**) either before or after assembly, and then overpainted with at least one priming coat.

The engineer may authorize a lesser degree of protection, such as a neoprene, chlorinated-rubber or zinc-rich paint system instead of metal spraying. Such a system must in any case be used on surfaces or edges of lead.

Procedure 5. As Procedure 4 above, but in addition full electrical insulation between the two metals must (unless metal-to-metal contact is specified, as in the attachment of sacrificial anodes) be ensured by the insertion of a non-absorbent non-conducting (preferably neoprene) gasket between and extending beyond the separated areas, and of sleeves and washers of the same material to prevent metallic contact of bolts. Rivets should not be used.

[29] BS 1475, "*Wrought aluminium and aluminium alloys for general engineering purposes. Wire*".

[30] BS 2569, "*Sprayed metal coatings*", Part 1, "*Protection of iron and steel by aluminium and zinc against atmospheric corrosion*".

7.4.2 Aluminium to aluminium. Contact surfaces and joints of aluminium to aluminium must be protected in accordance with Table 18, in which the numbers refer to the procedures of **7.4.1**. The numbers that are not in brackets refer to structures with aluminium bolts or rivets; those in brackets apply where steel bolts or rivets, or bolts of galvanized steel or corrosion-resisting steel, are used.

Corrosion-resisting-steel bolts must not be used for joints subject to sea-water immersion.

Table 18 — Protection at joints of aluminium to aluminium

Durability rating	Procedures according to environment					
	Dry unpolluted	Mild	Industrial and industrial-marine		Marine (non-industrial)	Sea-water immersion
			Moderate	Severe		
A	1 (1)	1 (1)	1 (2)	2 (4)[a]	2 (3)	3 (5)
B	1 (1)	1 (1)	1 (2)	2 (4)[a]	2 (4)[a]	N (N)
C	1 (1)	2 (2)	1 (2)	N (N)	N (N)	N (N)

[a] (3) for bolts of corrosion-resisting steel.
N = not recommended.
Bracketed references apply with ferrous bolts or rivets.

7.4.3 Aluminium to zinc or galvanized steel. Contact surfaces and joints of aluminium to zinc or galvanized steel must be protected in accordance with Table 19, in which the numbers refer to the procedures in **7.4.1**.

Joints must be made with galvanized steel bolts.

Table 19 — Protection at joints of aluminium to zinc or galvanized steel

Durability rating	Procedures according to environment					
	Dry unpolluted	Mild	Industrial and industrial-marine		Marine (non-industrial)	Sea-water immersion
			Moderate	Severe		
A	1	1	2	4	3	3
B	1	1	2	4	4	N
C	1	2	2	N	N	N

N = not recommended.

7.4.4 Aluminium to steel, cast iron or lead. Where aluminium roofing or cladding is supported on steel members, the protection must be in accordance with CP 143-7[31].

Other contact surfaces and joints of aluminium to steel, cast iron or lead must be protected in accordance with Table 20, in which the numbers refer to the procedures in **7.4.1**.

Corrosion-resisting-steel bolts must not be used for joints subject to sea-water immersion or for joints of aluminium to lead. Otherwise, steel bolts or rivets, or bolts of galvanized steel or corrosion-resisting steel, must be used.

Table 20 — Protection at joints of aluminium to steel, cast iron or lead

Durability rating	Procedures according to environment					
	Dry unpolluted	Mild	Industrial and industrial-marine		Marine (non-industrial)	Sea-water immersion
			Moderate	Severe		
A	1	2	2	4	4	5
B	1	2	2	4	4	N
C	1	2	3	N	N	N

N = not recommended.

[31] CP 143, "*Sheet roof and wall coverings*", Part 7, "*Aluminium*".

7.4.5 Aluminium to corrosion-resisting steel. Contact surfaces and joints of aluminium to corrosion-resisting steel must be protected in accordance with Table 21, in which the numbers refer to the procedures in **7.4.1**.

Corrosion-resisting-steel bolts must be used.

Table 21 — Protection at joints of aluminium to corrosion-resisting steel

Durability rating	Procedures according to environment					
	Dry unpolluted	Mild	Industrial and industrial-marine		Marine (non-industrial)	Sea-water immersion
			Moderate	Severe		
A	1	1	2	3	3	5
B	1	1	2	3	3	N
C	1	2	3	N	N	N

N = not recommended.

7.4.6 Aluminium to copper or copper alloys. Contact surfaces and joints of aluminium to copper or copper alloys should be avoided. If they are used, the aluminium must be of durability rating A or B, and the bolts or rivets must be of copper or copper alloy. In mild environments protection must be by Procedure 3 of **7.4.1**, and in all other environments by Procedure 5.

7.5 Welded joints

Welded joints of durability rating A in abnormally corrosive environments, of durability rating B in all but dry unpolluted environments, and of durability rating C in all environments, must, prior to painting, be sealed against ingress of moisture. This may be done by a suitable mastic, or by welding provided that the welding does not reduce the design strength.

7.6 Glued joints

The advice of the manufacturer of the adhesive used in a glued joint must, provided it is approved by the engineer, be followed in regard to any special protection necessary to prevent deterioration due to contact of the glue with moisture or with other protective treatments.

Further protective treatment must be in accordance with **7.1** and **7.2**.

7.7 Contact between aluminium and non-metallic materials

7.7.1 Contact with concrete, masonry or plaster. Aluminium in contact with concrete, masonry, mortar or plaster in a dry unpolluted environment needs no protection. In any other environment the aluminium must be of durability rating A or B. In a mild environment the surfaces must be protected with at least two coats of bituminous paint or hot bitumen (see **7.2.5.2**). In an industrial or marine environment they must be painted with at least three coats; the surface of the contacting material should preferably be similarly painted. Submerged contact is not recommended.

7.7.2 Embedment in concrete. Aluminium set in concrete must be of durability rating A or B. In a mild environment the surfaces before embedment must be protected with at least two coats of bituminous paint or hot bitumen (see **7.2.5.2**), the coats to extend at least 3 in (76 mm) above the concrete surface after embedment.

In an industrial or marine environment, or where the concrete contains chlorides, (e.g. as additives or due to the use of sea-dredged aggregate), at least two coats of a plasticized coal-tar pitch must be applied (see **7.2.5.2**) and the finished assembly must be overpainted locally with the same material, after the concrete is fully set, to seal the joint at the surface. Care must be taken to avoid metallic contact between the embedded aluminium parts and any steel reinforcement.

7.7.3 Contact with time. Aluminium surfaces in contact with timber, unless the timber is fully seasoned and the environment dry and unpolluted, must in a mild environment be painted with at least one coat of paint in accordance with **7.2**. In an industrial, damp or marine environment the aluminium must be of durability rating A or B and must be painted with two coats of bituminous paint or hot bitumen (see **7.2.5.2**); the timber also should, where practicable, be primed and painted in accordance with good practice.

Timber in contact with aluminium must not be treated with preservatives containing copper sulphate, zinc chloride or mercuric salts. Other preservatives may be used provided the engineer is satisfied that timber treated with them is not harmful to aluminium. Reference may be made to CP 143-7[32].

Oak, chestnut and western red cedar, unless well seasoned, are likely to be harmful to aluminium, particularly where there are through fastenings.

7.7.4 Contact with soils. The use of aluminium in contact with soils is not recommended. Where such contact is unavoidable, the surface of the metal must be protected with at least two coats of bituminous paint, hot bitumen, or a plasticized coal-tar pitch (see **7.2.5.2**). Additional wrapping-tapes may be used to prevent mechanical damage to the coating.

7.7.5 Immersion in water. Where aluminium parts are immersed in water (other than sea water) either fresh or contaminated, the aluminium should preferably be of durability rating A, with fastenings of aluminium or corrosion-resisting steel or made by welding. The engineer must obtain competent advice on the degree of corrosion to be expected: oxygen content, pH number, chemical or metallic (particularly copper) content and the amount of movement of the water are important factors. He should also seek advice on appropriate protection, which may consist either of a conventional paint-treatment (see **7.2.5.1**) or of an appropriate number of coats of bituminous paint or hot bitumen (see **7.2.5.2**). Where abrasion from suspended solids is likely, a plasticized coal-tar pitch (see **7.2.5.2**) is recommended. Joints and contact surfaces must be completely sealed.

Sea-water immersion is dealt with in **7.4.2** to **7.4.5**.

7.8 Protection against fire

7.8.1 General. Aluminium is non-combustible; it neither contributes fuel to nor assists in the spread of fire. Its load-carrying capacity, however, is seriously reduced at temperatures above about 480 °F (250 °C) and it melts at about 1 200 °F (650 °C). Aluminium has a higher thermal conductivity than steel, but this property does not significantly influence the temperature rise of parts of a structure in a fire.

Aluminium may need fire protection to minimize loss of strength due to overheating, or to reduce risk of damage due to thermal expansion. The possibility of fire either inside or outside a structure must be considered.

7.8.2 Structural members. Aluminium beams, columns and other members may be insulated by individual encasement or by continuous membranes such as ceiling or wall linings.

In buildings, all joints in a protective system such as occur for example at each floor level of a long stanchion must be sealed adequately. Specific periods of fire resistance for various applications, and information on certain kinds of encasement, are given in the Building Regulations 1965 and in the Building Standards (Scotland) Regulations.

7.8.3 Wall cladding. Where a period of fire resistance is specified a lining is needed which provides independently the degree of fire resistance necessary. The method and type of fixing must match the resistance of the construction.

Aluminium foil used in conjunction with a lining is known to reduce heat transmission but, in the absence of quantitative data, tests are necessary to establish the fire resistance.

Where insulation is provided by means of an infilling of mineral wool the lining itself need only retain the mineral wool in position for the specified period.

Where the cladding forms a part of the structural system the effects of external fire must be considered.

7.8.4 Roof covering. Where a fire occurs in a single-storey building it is preferable for smoke and fumes to be exhausted, and fire-spread to be checked, by the early operation of a special roof-venting system. Where such venting is absent or inadequate and a fire develops a high temperature, failure of the roof deck can assist in checking fire spread at roof level. The softening and melting temperatures of aluminium, although too high for immediate failure, are low enough to permit useful venting over the seat of a fire, provided the roof is unlined or equipped with a lining which can fall away if the temperature rises dangerously.

[32] CP 143, "*Sheet roof and wall coverings*", Part 7, "*Aluminium*".

Appendix A Nomenclature of aluminium products

A.1 Introduction

Complete information on the nomenclature of structural aluminium products is to be found in the standards for aluminium alloys for general engineering purposes (see **2.3**).

The following notes, however, serve as a general guide.

A.2 The nomenclature system

The complete nomenclature for an aluminium product consists of a series of symbols:

1) A first prefix letter, H or N, to denote whether a wrought alloy is heat-treatable or non-heat-treatable; casting alloys, however, are all identified by the prefix letters LM;

2) A second prefix letter to denote the form of the product (see **A.3**); in referring to an alloy generally, without reference to a particular form, this second letter is omitted;

3) A number chosen arbitrarily to identify the alloy (see **A.4**);

4) A symbol, preceded by a hyphen, to denote the temper or condition (see **A.5**); in referring to an alloy generally, without reference to a particular temper or condition, this symbol is omitted.

Examples of nomenclature are given in **A.6**.

A.3 Form of product

Wrought alloys are available in a variety of forms, as follows:

Second prefix letter	Form of product	Relevant specification
E	Bars, extruded round tube and sections	BS 1474[a]
T	Drawn tube	BS 1471
S	Sheet and plate	BS 1470[b]
C	Clad sheet and plate	BS 1470
B	Bolt and screw stock	BS 1473
R	Rivet stock	BS 1473
G	Wire (including welding filler)	BS 1475
F	Forgings and forging stock	BS 1472

[a] For alloy H17 see BS 4300-15.
[b] For alloy H17 see BS 4300-14.

A.4 Alloy

The numbers denoting the alloys have been chosen arbitrarily. The alloys denoted by the numbers 3 to 8 inclusive are the non-heat-treatable ones, and those denoted by the numbers 9 onwards are heat-treatable.

A.5 Temper or condition

The non-heat-treatable alloys (e.g. N8) are those of which the strength can be increased only by strain-hardening. This strain-hardening may be deliberate (as in the rolling of sheet to a specific hardness or temper), incidental to manufacture (as in the stretch-straightening of an extrusion) or due to forming or other cold-working of a finished product. The tempers of non-heat-treatable products are identified by the following suffix letters and symbols:

Letter or symbol	Temper
O	softest (i.e. annealed)
H2 to H8	progressive degrees of hardness
M	as manufactured (i.e. partly hardened in the ordinary course of manufacture)
O	annealed
M	as manufactured, with no formal heat treatment
TB	solution-heat-treated
TF	fully (i.e. two-stage) heat-treated
TE	artificially aged without prior solution-heat-treatment

The effect of heating these materials is to reduce their strength, which can then be recovered only by strain-hardening.

The heat-treatable alloys (e.g. H30) derive enhanced strength from either one or two stages of heat treatment. The first stage (solution-heat-treatment) consists of heating the material thoroughly to a prescribed high temperature and then quenching it in cold water; the quench increases the strength considerably from that of the hot (annealed) condition. The second stage (precipitation-heat-treatment, or ageing), when the material is kept for a prescribed time at a prescribed moderate temperature, produces a further increase of strength. With some alloys ageing occurs naturally after some days or weeks at room temperature, so that the second formal heat treatment may be dispensed with. The condition of a heat-treatable product is identified by one or two suffix letters as follows:

Letter or symbol	Condition
O	annealed
M	as manufactured, with no formal heat treatment
W	solution-heat-treated
WP	fully (i.e. 2-stage) heat-treated
P	artificially aged without prior solution-heat-treatment

A.6 Examples of nomenclature

NS5-H2	Indicates the non-heat-treatable magnesium-bearing wrought alloy N5 in the form of sheet or plate in the H2 temper.
HE30-TF	Indicates the heat-treatable magnesium-silicon wrought alloy H30 in the form of extrusion which has received full heat-treatment.
HC15-TB	Indicates the heat-treatable copper-bearing wrought alloy H15 in the form of pure-aluminium-clad sheet or plate in the solution-heat-treated condition.
LM25-TE	Indicates the heat-treatable magnesium-silicon casting alloy LM25 with precipitation-heat-treatment only.

Appendix B

Table 22 — Foreign equivalents of U.K aluminium alloys

This Appendix lists some foreign equivalents of the British Standard alloys referred to in this Code. They are not necessarily exact equivalents, and for detailed information on their compositions and properties reference must be made to the relevant national standards.

U.K. (BSI)	ISO Designation	AUSTRIA (ÖNA)	BELGIUM (IBN)	CANADA (CSA)	FRANCE (AFNOR)
H30	Al-Si1Mg ISO R 209	AlMgSi1 ÖNORM M 3430	AlMg1Si1 NBN 437	GS 11R HA series	A-SGM NF A 57-350 NF A 57-650
N8	Al-Mg4.5Mn ISO R 209	—	AlMg4 NBN 437	GM 41 HA series	A-G4 NF A 57-350 NF A 57-650
H9	Al-MgSi ISO R 209	AlMgSi 0.5 ÖNORM M 3430	AlMgSi NBN 437	GS 10 HA series	A-GS NF A 57-350 NF A 57-650
H20	Al-Mg1SiCu	—	—	GS 11N HA series	—
H15	Al-Cu4SiMg ISO R 209	—	AlCu4MgSi NBN 437	CS 41N HA series	A-U4SG NF A 57-350 NF A 57-650
N3	Al-Mn1 ISO R 209	AlMn ÖNORM M 3430	AlMn NBN 437	M1 HA series	A-M1 NF A 57-350 NF A 57-650
N4	Al-Mg2.5 ISO R 209	AlMg2 ÖNORM M 3430	—	GR 20 HA series	A-G2 NF A 57-350 NF A 57-650
N5	Al-Mg3.5 ISO R 209	AlMg3 ÖNORM M 3430	AlMg3 NBN 437	GR 40 HA series	A-G3 NF A 57-350 NF A 57-650
H17	Al-Mg5 ISO R 209	—	—	—	—

Table 22 — Foreign equivalents of U.K aluminium alloys

GERMANY (DNA)	ITALY (UNI)	NEDERLANDS (NNI)	SWEDEN (SIS)	SWITZERLAND (SNV)	U.S.A. (ASA)
AlMgSi1 DIN 1725 Bl.1	P-AlSi1 MgMn UNI 3571	K AlMgSi	SIS 14-4212	Al-Si-Mg VSM 10850	AA6351
	—	K Al Mg4	—	—	AA5083
AlMgSi0.5 DIN 1725 Bl.1	P-AlMgSi UNI 3569	K AlMgSi ½	SIS 14-4104	—	AA6063
—	—	—	—	—	AA6061
AlCuSiMn DIN 1725 Bl.1	P-AlCu4.4Si MnMg UNI 3581	K AlCu4Mg	SIS 14-4338	Al-4Cu-0.5Mg VSM 10852	AA2014
AlMn DIN 1725 Bl.1	P-AlMn1.2 UNI 3568	—	SIS 14-4054	Al-Mn VSM 10848	AA3003
AlMg2 DIN 1725 Bl.1	P-AlMg2.5 UNI 3574	K AlMg2	SIS 14-4120	Al-2Mg VSM 10849	AA5052
AlMg3 DIN 1725 Bl.1	P-AlMg3.5 UNI 3575	K AlMg3	—	Al-3Mg VSM 10849	AA5154
AlZnMG1 DIN 1725 Bl.1	—	—	—	—	—

Appendix C Supplementary alloys

C.1 Selection of material

Six further alloys often used in general and structural engineering are listed, with their properties, in Table 23.

H20 is similar in structural behaviour to H30.

The use of H15 is commonly confined to special applications (e.g. aircraft) where its higher strength is essential. Its durability, except in the form of pure-aluminium-clad plate and sheet, is such as normally to require protection. In the TF condition this material has less resistance to crack-propagation than the other alloys in the British Standard general engineering series. It is not normally weldable.

N3 is mainly used as NS3-H8 for corrugated and troughed sheet for roof and wall cladding; it has high durability. N4 and N5, generally used in sheet form, combine high durability with a wide range of mechanical properties. These materials all have good weldability.

H17, available as plate and extrusions, combines strength and weldability. Moreover its property of naturally ageing confers the advantage of recovery of strength after welding. The material is however sensitive to environment, and its satisfactory performance is as dependent on correct methods of manufacture and fabrication as on control of composition and tensile properties. It is essential therefore that there be direct collaboration between the engineer and the manufacturer concerning the intended use and the likely service conditions.

C.2 Permissible stresses

The permissible stresses in tension and bearing, and in compression, bending and shear where buckling is not a factor, are given in Table 24; the values have been obtained by the procedures given in Appendix D, the further requirements of which must be followed to obtain other permissible stresses.

Table 23 — Properties of supplementary alloys

Small figures in parentheses refer to the Notes.

Alloy	(1) Condition	(1) Form	(1) (2) Thickness mm from	to	(3) 0.2 % tensile proof stress N/mm^2	(3) Tensile strength N/mm^2	(3) (4) Elongation % on $5.65\sqrt{S_0}$	50 mm	(5) 0.2 % compressive proof stress N/mm^2	(5) Bearing strength N/mm^2	(6) Modulus of elasticity N/mm^2	(7) Coefficient of linear expansion per °C	Density kg/m^3	(8) Durability rating
H20	TF	Extrusions	—	150 (9)	240	280	8	7	Same as tensile	556	68 900	24×10^{-6}	2 710	B
H15	TB	Extrusions	—	20	230	370	11	10	206	664	72 400	22×10^{-6}	2 800	C
	TF	Extrusions	—	20	370	435	7	6	Same as tensile	772				
		Clad sheet and plate	3.0	12.5	365	425	—	8		726	68 900			A(10)
			12.5	25	380	440	6	—						
N3	H8	Sheet	0.2	3.0	—	175	—	2–4	—	355		23×10^{-6}	2 740	A
N4	H3		0.2	6.0	130	200	—	4–8	115	463		24×10^{-6}	2 690	
N5	H2		0.2	6.0	165	245	—	5–8	150	494		23×10^{-6}	2 670	
H17 (11)	TB	Extrusions	—	25	190	300	12	10	Same as tensile	600	71 700	23×10^{-6}	2 800	B
		Sheet, plate	0.2	25	170	280				560				
	TF	Extrusions	—	25	280	340	10	8		660				
		Sheet, plate	0.2	25	270	320				630				

NOTE 1 For other conditions, forms and thicknesses see BS 1470 to BS 1475.
NOTE 2 Each thickness range includes its upper limit.
NOTE 3 Minimum value specified in BS 1470, BS 1471, BS 1474 or BS 4300.
NOTE 4 For specific elongations see BS 1470, BS 1471, BS 1474 and BS 4300.
NOTE 5 Minimum expected value (see Appendix D).
NOTE 6 For modulus of rigidity multiply by 0.38.
NOTE 7 Applies to range 20 °C to 100 °C.
NOTE 8 See **2.1.2**.
NOTE 9 For round tube and hollow sections these properties do not apply above 75 mm.
NOTE 10 C for immersion in fresh or sea water.
NOTE 11 See **C.1** of this appendix.

Table 24 — Permissible stresses for supplementary alloys
N/mm^2

Small figures in parentheses refer to the Notes.

Alloy	Condition (1)	Form (1)	Thickness mm from (1)	Thickness mm to (2)	Axial (3) p_t	Axial (3) p_c	Bending (3) p_{bt}	Bending (3) p_{bc}	Shear (3) p_q	Bearing (4) p_b	λ_s (5)
H20	TF	Extrusions	—	(6) 150	131		145		78	201	63
H15	TB	Extrusions	—	20	135	124	153	142	81	239	71
	TF	Extrusions	—	20	(7) 154	202	(7) 154	224	(7) 108	278	49
		Clad sheet and plate	3.0	12.5	(7) 147	199	(7) 147	220	(7) 100	261	50
			12.5	25	(7) 147	207	(7) 147	229			49
N3	H8	Sheet	0.2	3.0	(8)		(8)		(8)	128	(8)
N4	H3		0.2	6.0	75	69	85	79	45	167	104
N5	H2		0.2	6.0	95	88	107	100	57	178	86
(9) H17	TB	Extrusions	—	25	111		126		67	216	74
		Sheet, plate	0.2	25	100		114		60	202	79
	TF	Extrusions	—	25	154		171		92	238	58
		Sheet, plate	0.2	25	148		164		89	227	59

NOTE 1 For other conditions, forms and thicknesses use procedure of Appendix D: for bolts and rivets see Table 12.
NOTE 2 Each thickness range includes its upper limit: minimum recommended thicknesses are given in **4.1.6**.
NOTE 3 Applies only when buckling is not the criterion: see **4.3**, **4.4** and **4.5**.
NOTE 4 Joints in single shear: see **4.6.2.1**.
NOTE 5 See Appendix D.
NOTE 6 For round tube and hollow section the permissible stresses do not apply above 75 mm.
NOTE 7 Arbitrarily reduced values to allow for inferior crack-propagation resistance.
NOTE 8 Values obtainable (Appendix D) from proof stress of suitable sample
NOTE 9 See **C.1** of this appendix.

Appendix D Derivation of permissible stresses

D.1 General

The procedures given in this Appendix may be used to obtain permissible stresses for any of the principal or supplementary alloys which have guaranteed non-standard properties (see **4.1.3.3**), and also as a guide to permissible stresses for other alloys (see **4.1.3.4**).

D.2 Permissible stresses

D.2.1 *Axial tension and compression.* The permissible stresses in axial tension p_t, and in axial compression p_c where buckling is not a factor, are given by:

$$p_t = 0.44\, f_{2t} + 0.09\, f_u, \text{ and}$$

$$p_c = 0.44\, f_{2c} + 0.09\, f_u,$$

where f_{2t} is the guaranteed or the minimum expected 0.2 % proof stress in tension

f_{2c} is the guaranteed or the minimum expected 0.2 % proof stress in compression, and

f_u is the guaranteed or the minimum expected tensile strength.

The minimum expected values of f_{st}, f_{sc} and f_u may be determined from a sufficient number of tests made, under competent supervision and to the satisfaction of the engineer, on production samples of the material.

The permissible stress in axial tension p_t will need to be reduced if the resistance of the material to crack propagation. (e.g. H15-WP in Table 24) is in doubt.

For permissible stresses in axial compression where buckling is a factor, a diagram with a horizontal cut-off at p_c is drawn relating those stresses to λ. The form of the diagram is shown in Figure 24, in which λ_s is given by

$$\lambda_s = \sqrt{22\,000/p_s} \text{ (imperial units), or } \sqrt{3{\cdot}4 \times 10^5/p_s} \text{ (SI units)}$$

where $p_s = (0.44\, f_{2c} - 0.02\, f_u - 1)$ tonf/in², or

$(0.44\, f_{2c} - 0.02\, f_u - 15)$ N/mm², respectively.

The values of λ for entering the diagram are given in **4.3.1** and **4.3.3**.

D.2.2 *Bending*. The permissible stresses in bending tension p_{bt}, and in bending compression p_{bc} where buckling is not a factor, are given by:

$p_{bt} = 0.44\, f_{2t} + 0.14\, f_u$, and

$p_{bc} = 0.44\, f_{2c} + 0.14\, f_u$ respectively.

The permissible stress in bending tension p_{bt} will need to be reduced if the resistance to crack propagation of the material is in doubt.

The permissible stresses in bending compression where buckling is a factor are determined from a diagram as in **D.2.1**; the form of the diagram, with a horizontal cut-off at p_{bc}, is shown in Figure 24. The values of λ for entering the diagram are given in **4.4.4**, **4.5.1** and Appendix H and Appendix K.

D.2.3 *Shear*. The permissible shear stress p_q, where buckling is not a factor, is 0.6 p_t. To determine the permissible average shear stresses in thin plates and unstiffened or stiffened webs, the curves in Figure 6 and Figure 13 are used with horizontal cut-offs at 0.85 p_q (see **4.4** and **4.5.2**).

D.2.4 *Bearing*. The permissible bearing stress for members in double shear is the minimum expected bearing strength divided by 2.5; where this is not available the tensile strength divided by 1.4 may be used. The minimum expected bearing strength may be determined by a sufficient number of tests made, under competent supervision and to the satisfaction of the engineer, on actual double shear joints made with close-fitting steel pins or bolts with an edge distance of at least twice the hole diameter (see **4.6.2.2**), the bearing strength being the ultimate load divided by the product of the pin diameter and the specimen thickness.

The permissible bearing stress for members in single shear and for the outer plies of multiple-shear joints is 0.9 times that in double shear.

D.2.5 *Bolts and rivets*. The permissible tensile stress in a bolt or solid rivet is the minimum expected proof stress of the bolt or rivet material divided by 4. The minimum expected proof stress may be determined from a sufficient number of tests made, under competent supervision and to the satisfaction of the engineer, on bolt or rivet stock of the material, condition and diameter to be used in the actual structure.

The permissible shear stress in a close-fitting bolt (see **4.6.2.2**) or solid rivet is the minimum expected shear strength divided by 3. The minimum expected shear strength may be determined from a sufficient number of tests made, under competent supervision and to the satisfaction of the engineer, on joints made with close-fitting bolts or driven rivets of the material, condition and size used in the actual structure. The permissible shear stress in a bolt in a clearance hole is 0.9 times the value obtained as above.

D.2.6 *Welded joints*. If the resistance to crack propagation of parent metal, heat-affected parent metal or weld metal is in doubt, welding is not permitted. Otherwise the permissible stress for a welded joint made with a combination of parent and filler material other than those given in Table 3 is, for a fillet-welded joint, the minimum expected shear strength divided by 3; and for a butt-welded joint, the minimum expected 0.2 % proof stress divided by 1.5, the proof stress being measured on a gauge length of 2 in (51 mm) normal to the weld and disposed symmetrically about its centre line.

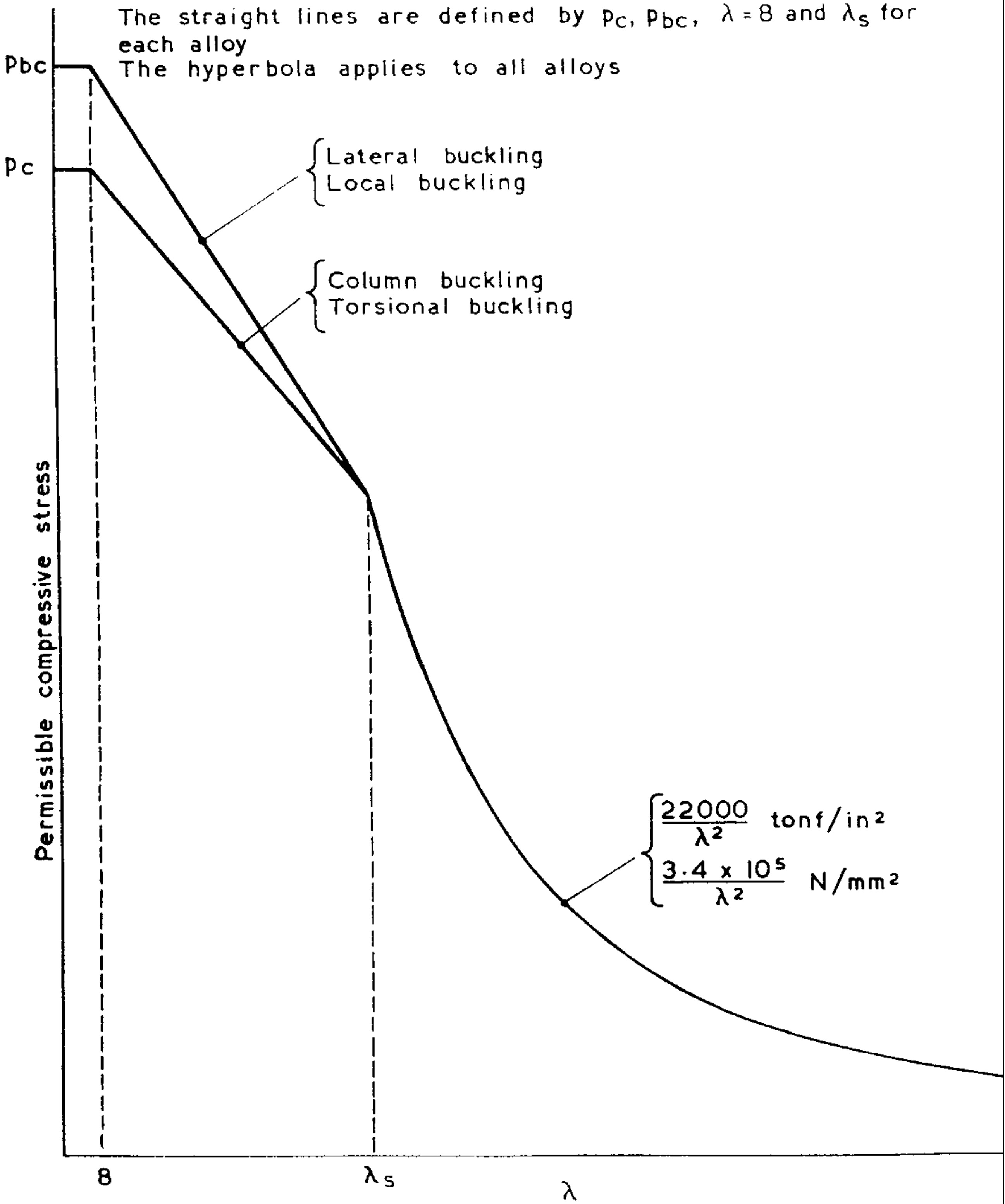


Figure 24 — Form of compression buckling diagrams

The minimum expected strength or proof stress may be determined from a sufficient number of tests made, by an approved procedure and to the satisfaction of the engineer, on joints of size, geometry and direction of loading similar to those of the actual structure. Due allowance must be made for the effect of weld repairs.

D.2.7 *Fatigue.* The permissible stresses in fatigue for members in a non-standard ahoy may be established from a sufficient number of tests made, under competent supervision and to the satisfaction of the engineer, on members representative of those in the actual structure.

Appendix E Deduction for holes in members

E.1 The following example illustrates the rule given in **4.2.1** 1) using imperial units.

Consider a plate 18 in wide and 1 in thick, with 25/32 (0.78) in diameter holes as shown in Figure 25, where $s = 2$ in, $g_1 = 4$ in and $g_2 = 6$ in.

The area to be deducted is the largest of the following:

1) For holes in straight line A-A,
   area $= 2 \times 0.78 \times 1$
   $= 1.56 \text{ in}^2$
2) For holes in zig-zag line B-B,
   area $= (3 \times 0.78 \times 1) - (1 \times s^2t/4\, g_1) - (1 \times s^2t/4\, g_2)$
   $= (3 \times 0.78 \times 1) - (1 \times 2^2 \times {}^1/_{16}) - (1 \times 2^2 \times {}^1/_{24})$
   $= 2.34 - 0.25 - 0.17$
   $= 1.92 \text{ in}^2$
3) For holes in zig-zag line C-C,
   area $= (4 \times 0.78 \times 1) - (2 \times s^2t/4\, g_1) - (1 \times s^2t/4\, g_2)$
   $=(4 \times 0.78 \times 1) - (2 \times 2^2 \times {}^1/_{16}) - (1 \times 2^2 \times {}^1/_{24})$
   $= 3.12 - 0.50 - 0.17$
   $= 2.45 \text{ in}^2$

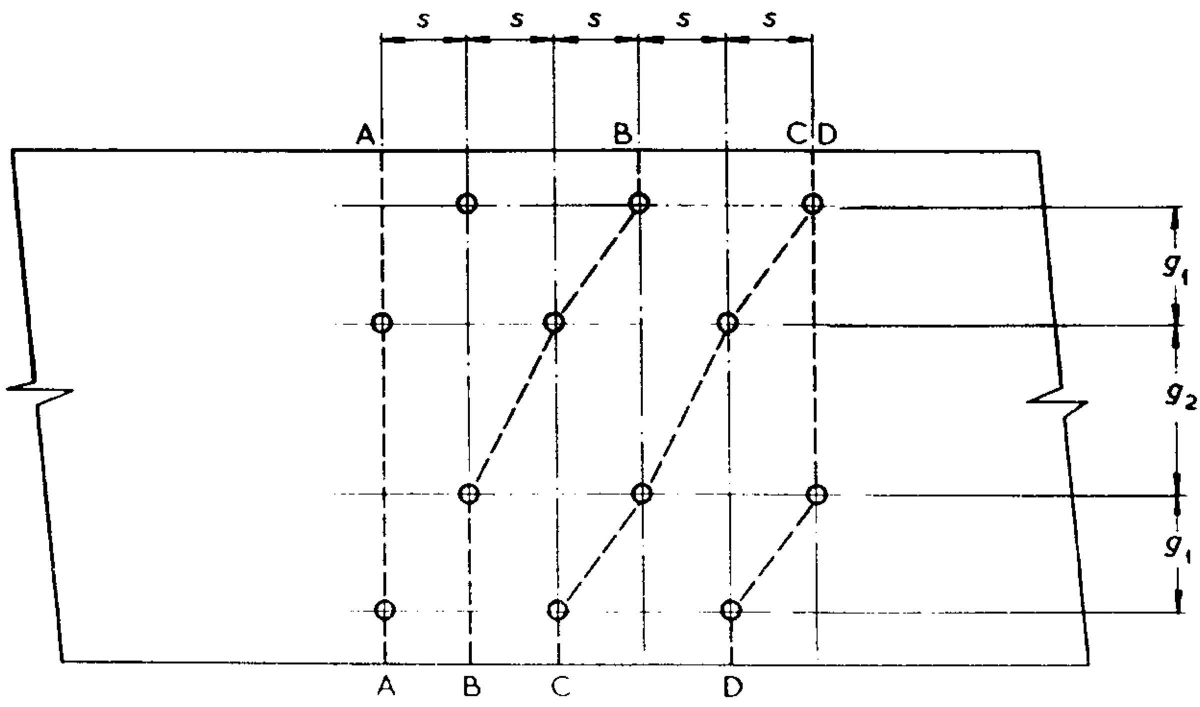


Figure 25 — Choice of lines for deduction of holes

4) For holes in zig-zag line D-D,

area $= (3 \times 0.78 \times 1) - (1 \times s^2t/4\ g_1)$

$= (3 \times 0.78 \times 1) - (1 \times 2^2 \times {}^1/_{16})$

$= 2.34 - 0.25$

$= 2.09\ \text{in}^2$

The area to be deducted from the gross area (18 in^2) is therefore 2.45 in^2.

E.2 The following example illustrates the rule given in **4.2.1** 1) using metric units.

Consider a plate 460 mm wide and 25 mm thick, with 20.8 mm diameter holes as shown in Figure 25, where s = 50 mm, g_1 = 100 mm and g_2 = 150 mm.

The area to be deducted is the largest of the following:

1) For holes in straight line A-A,

area $= 2 \times 20.8 \times 25$

$= 1040\ \text{mm}^2$

2) For holes in zig-zag line B-B,

area $= (3 \times 20.8 \times 25) - (1 \times s^2t/4\ g_1) - (1 \times s^2t/4\ g_2)$

$= (3 \times 20.8 \times 25) - (1 \times 50^2 \times {}^{25}/_{400}) - (1 \times 50^2 \times {}^{25}/_{600})$

$= 1\,560 - 156.3 - 104.2$

$= 1299.5\ \text{mm}^2$

3) For holes in zig-zag line C-C,

area $= (4 \times 20.8 \times 25) - (2 \times s^2t/4\ g_1) - (1 \times s^2t/4\ g_2)$

$= (4 \times 20.8 \times 25) - (2 \times 50^2 \times {}^{25}/_{400}) - (1 \times 50^2 \times {}^{25}/_{600})$

$= 2\,080 - 312.5 - 104.2$

$= 1663.3\ \text{mm}^2$

4) For holes in zig-zag line D-D,

area $= (3 \times 20.8 \times 25) - (1 \times s^2t/4\ g_1)$

$= (3 \times 20.8 \times 25) - (1 \times 50^2 \times {}^{25}/_{400})$

$= 1\,560 - 156.3$

$= 1403.7\ \text{mm}^2$

The area to be deducted from the gross area (11 500 mm^2) is therefore 1663.3 mm^2.

Appendix F Torsional properties of thin-walled open sections

F.1 Introduction

Struts of thin-walled open cross-section are frequently prone to failure by torsional buckling rather than by ordinary column-buckling, and beams of similar cross-section by lateral buckling rather than by bending. Such struts and beams differ greatly from members of closed cross-section, a thin-walled tube for instance being several hundred times stiffer in torsion than the same tube split longitudinally.

Calculations for torsional instability (see **4.3.3** and Appendix G) involve the use of the torsion factor, the polar second moment of area of the cross-section about its shear centre and the warping factor as defined below.

F.2 Torsion factor

The torsional stiffness of a member when free of any restraint against out-of-plane warping of its end cross-sections is determined by the product GJ, where G is the modulus of rigidity of the material and J is the torsion factor. The rate of twist along the member is related to the torque T (Reference 1) by:

$$T = GJ\,\frac{d\theta}{dz}$$

For a closed circular cross-section, as for example a solid or hollow shaft, J is equal to the polar second moment of area I_p; but for all other sections J is less, and for thin-walled open sections very much less, than I_p. The shear-stress distribution over the cross-section of such members is complex (Reference 2); and it should be noted that the torsion factor J is not applicable in the common shear-stress equation $f_q = Tr/J$ for shafts, where r is the distance of a fibre from the centroid and J is identical with I_p.

The value of J for a thin-walled open section without pronounced variations of thickness such as fillets or bulbs is given (Reference 1) by:

$$J = \int_0^s \frac{t^3 ds}{3},$$

where t is the thickness of the section and s is measured along the middle line of the profile, the integration being performed along the whole developed length of the cross-section. From this it is apparent that the position of the metal in the cross section is unimportant in regard to torsional stiffness. A strip of given width and small thickness will have the same J whether it be used as a flat bar or is formed to an angle, channel, circular arc, or any other open shape.

Thus, for a section consisting of a series of thin flanges, webs, or other parts, whether straight or curved, each of uniform thickness but not necessarily all of the same thickness:

$$J = \sum \frac{bt^3}{3},$$

where b and t are the width and thickness of each part respectively. Pails with non-uniform thickness can be dealt with individually by integration or by summation.

The torsional stiffness of a thin-walled open section can be much improved by the addition of fillets or bulbs, the contribution to J of such local thickenings commonly exceeding that of the basic thin rectangles. Owing however to the difficulty of locating the middle line accurately in regions of rapidly-changing thickness, the above equation is not applicable to fillets and bulbs. The J-contribution of such elements is given (Reference 3) by:

$$J = [(p + q^N)t]^4,$$

where t is the general thickness of the parts, N is the fillet or bulb dimension and p and q are empirical constants (see Figure 26).

The factor J for a complete cross-section is obtained by adding the fillet and bulb contributions to those of the remaining thin-walled parts, the extent of the fillet or bulb regions being as shaded in the figure.

Values of J for British Standard sections are given in BS 1161[33], Graphs for the determination of J for a single-bulb angle are given in Structural Data Sheet 00.07.01[34].

F.3 Shear centre

The shear centre S is the point on the cross-section through which a transverse load must act in order to cause bending without twisting. Its position must be known in order to obtain the polar second moment of area I_p and also the warping factor H that is dealt with in **F.4**. The value of I_p may be obtained from:

$$I_p = I_x + I_y + Ag^2,$$

where I_x and I_y are the second moments of area about the centroidal axes, A is the section area, and g is the distance of the shear centre from the centroid.

[33] BS 1161, "*Aluminium and aluminium alloy sections*".
[34] Engineering Sciences Data Unit.

For sections having two axes of symmetry (such as I-beams) or point-symmetry (such as zeds), the shear centre coincides with the centroid. Where there is only one axis of symmetry it lies on that axis, but not usually at the centroid. In the special case of a section (such as an angle or a tee) consisting of flat elements whose middle lines intersect at a single point the shear centre is at that point (see Figure 28). For other singly-symmetrical sections the shear-centre position may be determined by the equation given below. Where a section has no symmetry, the shear centre must be located with respect to two axes, and reference should be made to the relevant literature (References 4, 5, 6, 7 and 8).

To locate the shear centre in a singly-symmetrical section the following procedure, using the notation of Figure 27, is convenient. The cross-section is broken down into 2 V flat elements, numbered from I to V on each side of the axis of symmetry AA, counting outwards from the point B where the middle line of the cross-section intersects AA. The width and thickness of the Rth element are *b* and *t* respectively, and *a* is the distance of its centroid from AA: the quantity *a* is always positive. The projected length *c* of the middle line of the element on an axis perpendicular to AA is positive if that middle line in the sense towards B is convergent with AA, and negative if it is divergent. The distance *d* from B to the middle line of the element is positive if that middle line produced in the sense towards B has B on its left, and negative if B is on its right.

Then the distance *e* by which the shear centre lies to the left of B is given by:

$$e = \frac{1}{I_A}\sum_2^V bt\left(2\,aP - bd\left(a - \frac{c}{6}\right)\right),$$

where $P = \sum_2^R bd$, and I_A is the second moment of area of the whole section about AA.

The summation (unlike I_A) applies to only the half of the section above the axis in Figure 27; it begins with the 2nd element since there is no contribution (*d* being zero) from the 1st element.

A specimen shear-centre calculation for a thin-walled section with one axis of symmetry is shown in Table 25. Expressions for the shear-centre position in some commonly used sections are given in Figure 28.

The influence of bulbs on the shear-centre position is not yet fully understood. They can be approximately allowed for by replacing them by equivalent rectangles.

F.4 Warping factor

Where the ends of a member are not free to warp, the torque needed to produce a given twist is increased.This occurs if the member is built-in so that the end cross-sections are restrained to stay in their original planes. Warping restraint can also be important in torsional buckling even when the ends of a strut are free, because the induced torque after buckling varies along the member; and the inability of each cross-section to freely warp tends to increase the torsional stiffness and hence the strength of the strut. The warping factor *H* is a measure of this increase in stiffness.

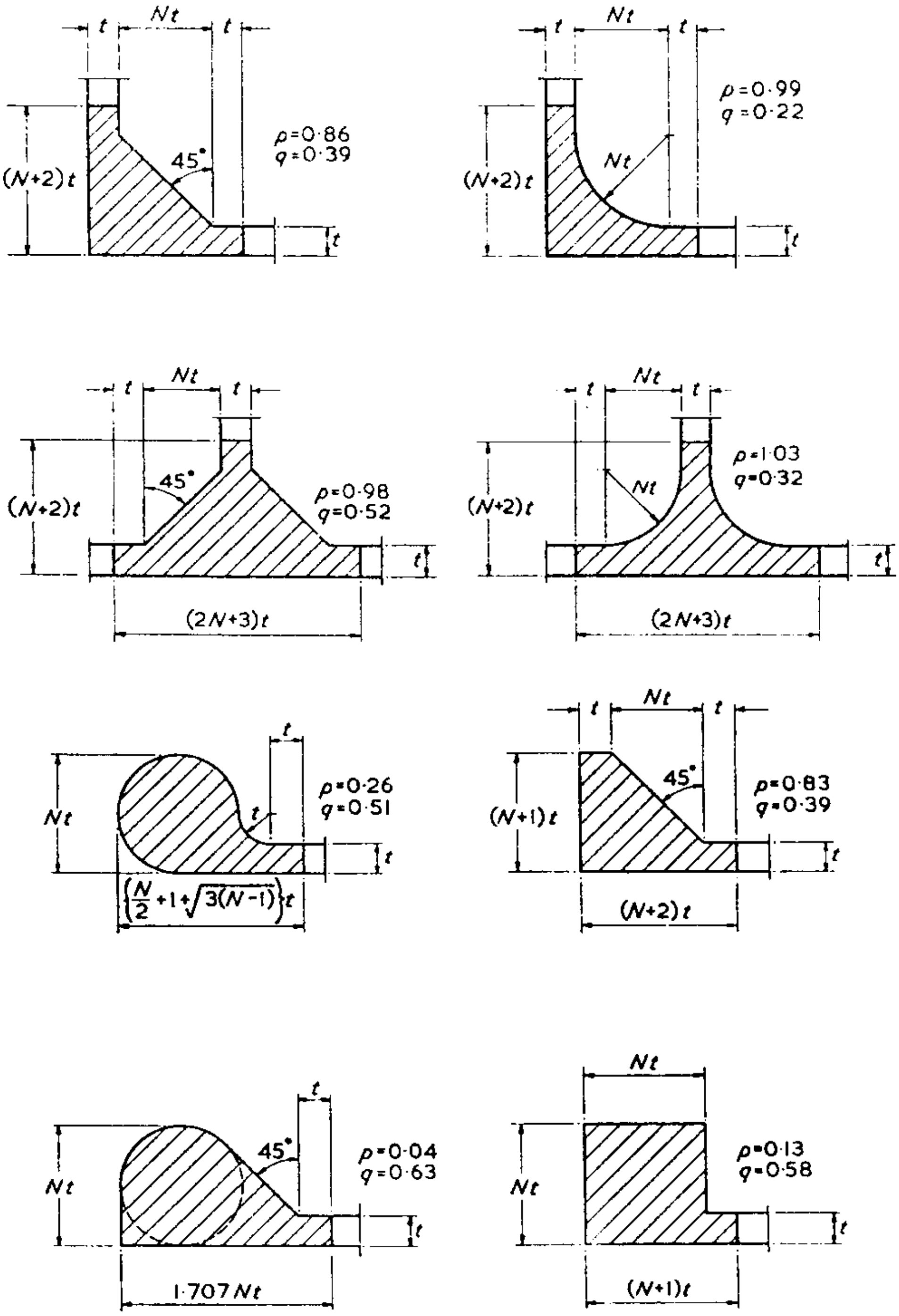


Figure 26 — Constants for torsion factor for certain fillets and bulbs

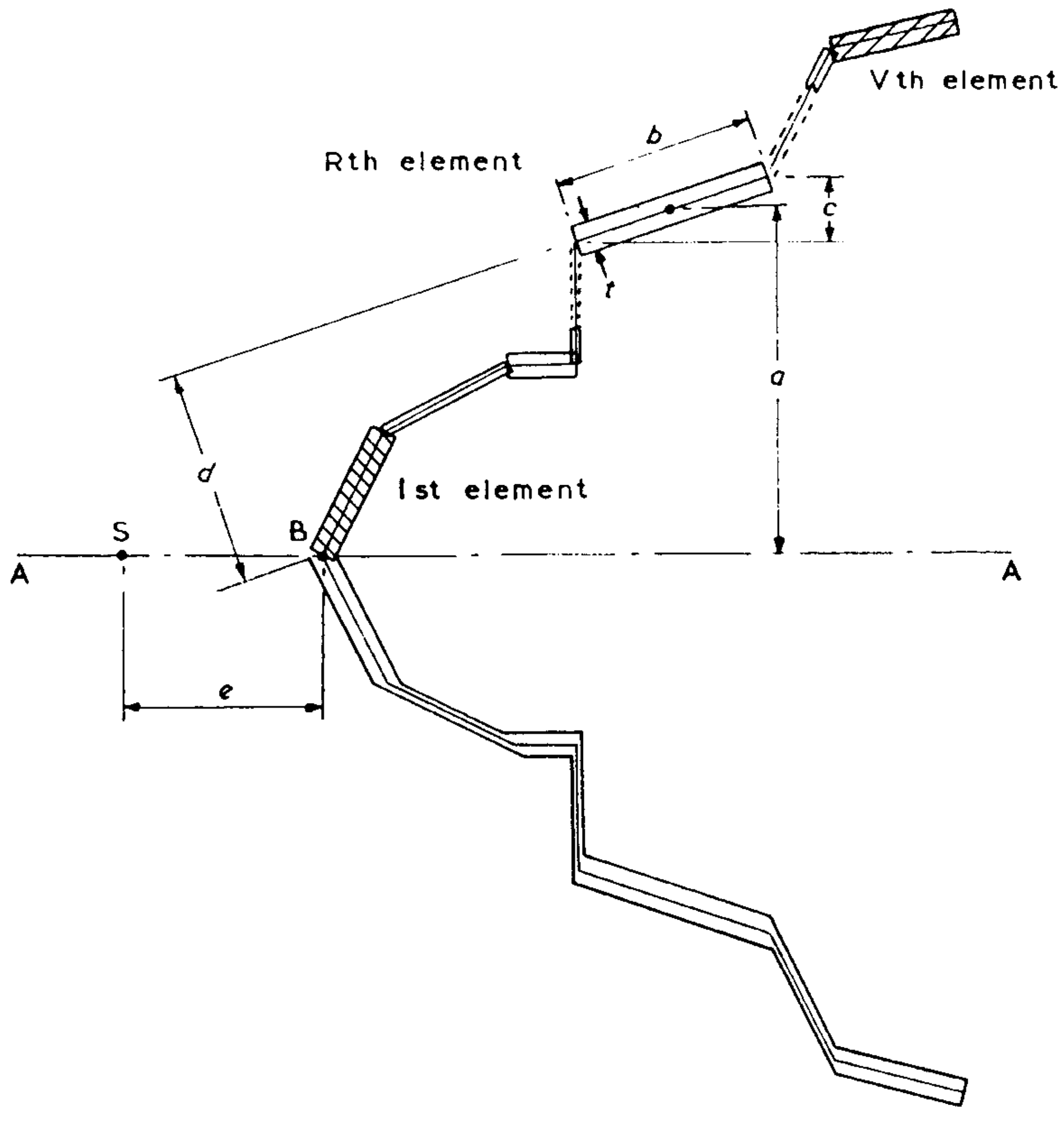


Figure 27 — Notation for calculating shear-centre position and warping factor

The relation between torque and twist where there is warping restraint is given (Reference 5) by:

$$T = GJ\frac{d\theta}{dz} - EH\frac{d^3\theta}{dz^3},$$

where E is the modulus of elasticity.

For thin-walled sections having one axis of symmetry and composed entirely of flat elements, the warping factor is given by the expression:

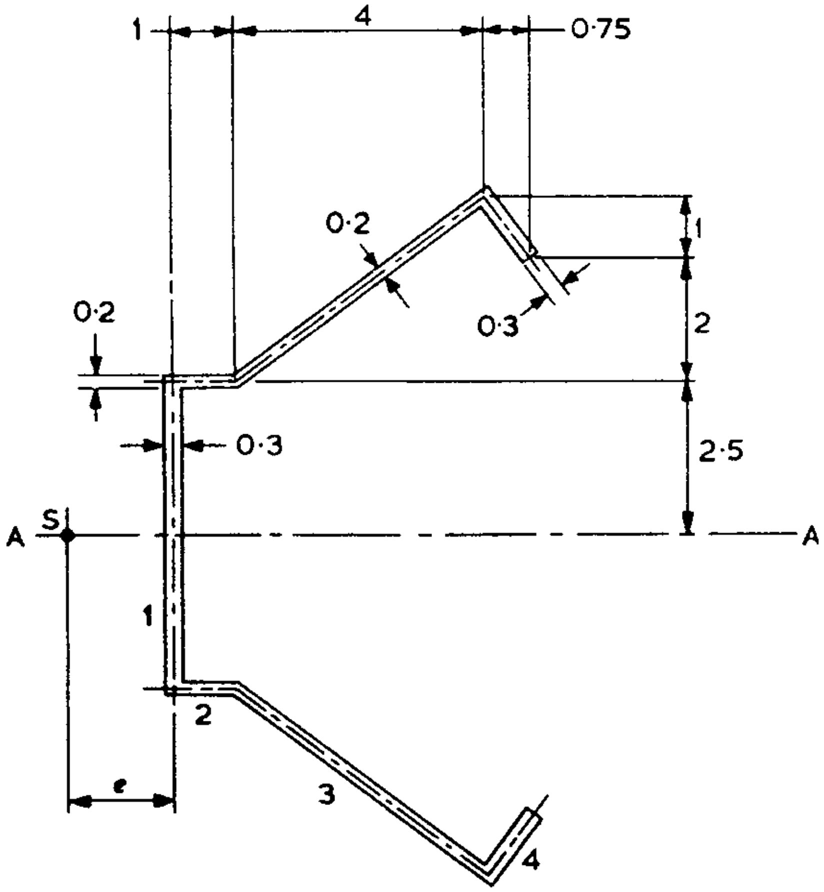
$$H = 2\sum_{2}^{v}\left[bt\left(P^2 - bdP + \frac{b^2d^2}{3}\right)\right] - e^2 I_A,$$

where the notation is that previously used in the equation for locating the shear centre.

A specimen calculation of H for the singly-symmetrical section previously considered is also shown in Table 25. A completely general treatment of this nature cannot be conveniently given for either doubly-symmetrical or unsymmetrical sections, or indeed for any section consisting of other than a simple and symmetrical series of flat elements as in Figure 27.

Sections consisting of a number of flat elements meeting at a common intersection (such as angles, tees and cruciform sections) have warping factors which are of negligible magnitude. But with all other sections warping has a significant effect on torsional stiffness and must be taken into account. Expressions for H for some commonly used sections are given in Figure 28. Graphs for determining H for a few simple sections may be found in Structural Data Sheets 00.07.02 to 00.07.06.[35)]

As in shear-centre determinations, bulbs are difficult to deal with precisely. They can be approximately allowed for in the several expressions by replacing them by equivalent rectangles.



[35)] Engineering Sciences Data Unit.

Table 25A — Specimen calculation of shear-centre position and warping factor

(Dimensions in inches)

Quantity	2nd Element	3rd Element	4th Element
b	1	5	1.25
t	0.2	0.2	0.3
a	2.5	4	5
c	0	3	– 1
d	2.5	1.4	7.3
bd	2.5	7.0	9.1
P	2.5	9.5	18.6
$2aP$	12.5	76	186
$bd\ (a - c/6)$	6.2	24.5	47
$2aP - bd\ (a - c/6)$	6.3	51.5	139
$bt\ [2aP - bd\ (a - c/6)]$	1.3	51.5	52.1
Summation of last line		$= 104.9\ \text{in}^5$	
I_A (obtained by calculation not shown)		$= 57.9\ \text{in}^4$	
Shear-centre position $e = \frac{104.9}{57.9}$		$= 1.8$ in	
P^2	6.2	90	346
bdP	6.2	66.5	169
$b^2d^2/3$	2.1	16.3	27.6
$P^2 - bdP + b^2d^2/3$	2.1	39.8	205
$bt\ (P^2 - bdP + b^2d^2/3)$	0.4	39.8	77
Summation of last line		$= 117.2\ \text{in}^6$	
Warping factor H		$= (2 \times 117.2) - (1.8 \times 104.9)$ $= 45\ \text{in}^6$	

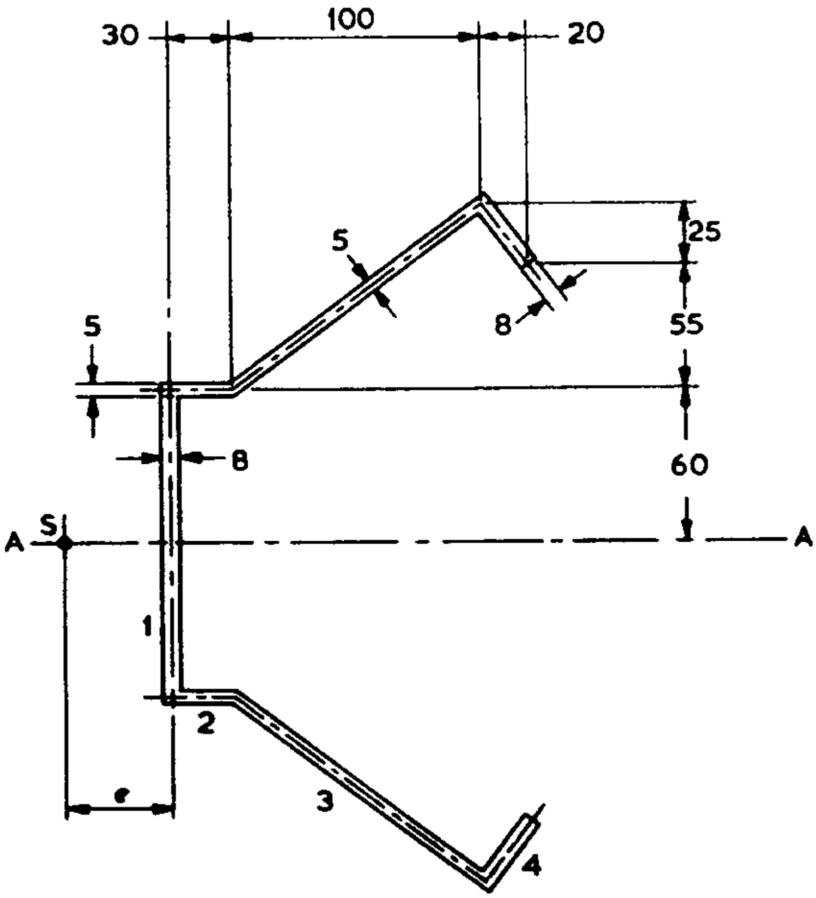

30
100
20
25
5
8
55
5
8
60
A
S
A
1
2
e
3
4

Table 25B — Specimen calculation of shear-centre position and warping factor

(Dimensions in mm)

Quantity	2nd Element	3rd Element	4th Element
b	30	128	32
t	5	5	8
a	60	100	127
c	0	80	– 25
d	60	28	189
bd	1.80×10^3	3.58×10^3	6.05×10^3
P	1.80×10^3	5.40×10^3	1.14×10^4
$2aP$	2.16×10^5	1.08×10^6	2.90×10^6
$bd\ (a - c/6)$	1.08×10^5	3.10×10^5	7.94×10^5
$2aP - bd\ (a - c/6)$	1.08×10^5	7.70×10^5	2.11×10^6
$bt\ [2aP - bd\ (a - c/6)]$	1.62×10^7	4.93×10^8	5.40×10^8
Summation of last line		$= 1.05 \times 10^9$ mm^5	
I_A (obtained by calculation not shown)		$= 2.35 \times 10^7$ mm^4	
Shear-centre position $e = \dfrac{1.05 \times 10^9}{2.35 \times 10^7}$		= 45 mm	
P^2	3.24×10^6	2.92×10^7	1.30×10^8
bdP	3.24×10^6	1.93×10^7	6.90×10^7
$b^2d^2/3$	1.08×10^6	4.28×10^6	1.22×10^7
$P^2 - bdP + b^2d^2/3$	1.08×10^6	1.42×10^7	7.32×10^7
$bt\ (P^2 - bdP + b^2d^2/3)$	1.62×10^8	9.09×10^9	1.87×10^{10}
Summation of last line		$= 2.80 \times 10^{10}$ mm^6	
Warping factor H		$= (2 \times 2.80 \times 10^{10}) - (45 \times 1.05 \times 10^9)$	
		$= 8.7 \times 10^9$ mm^6	

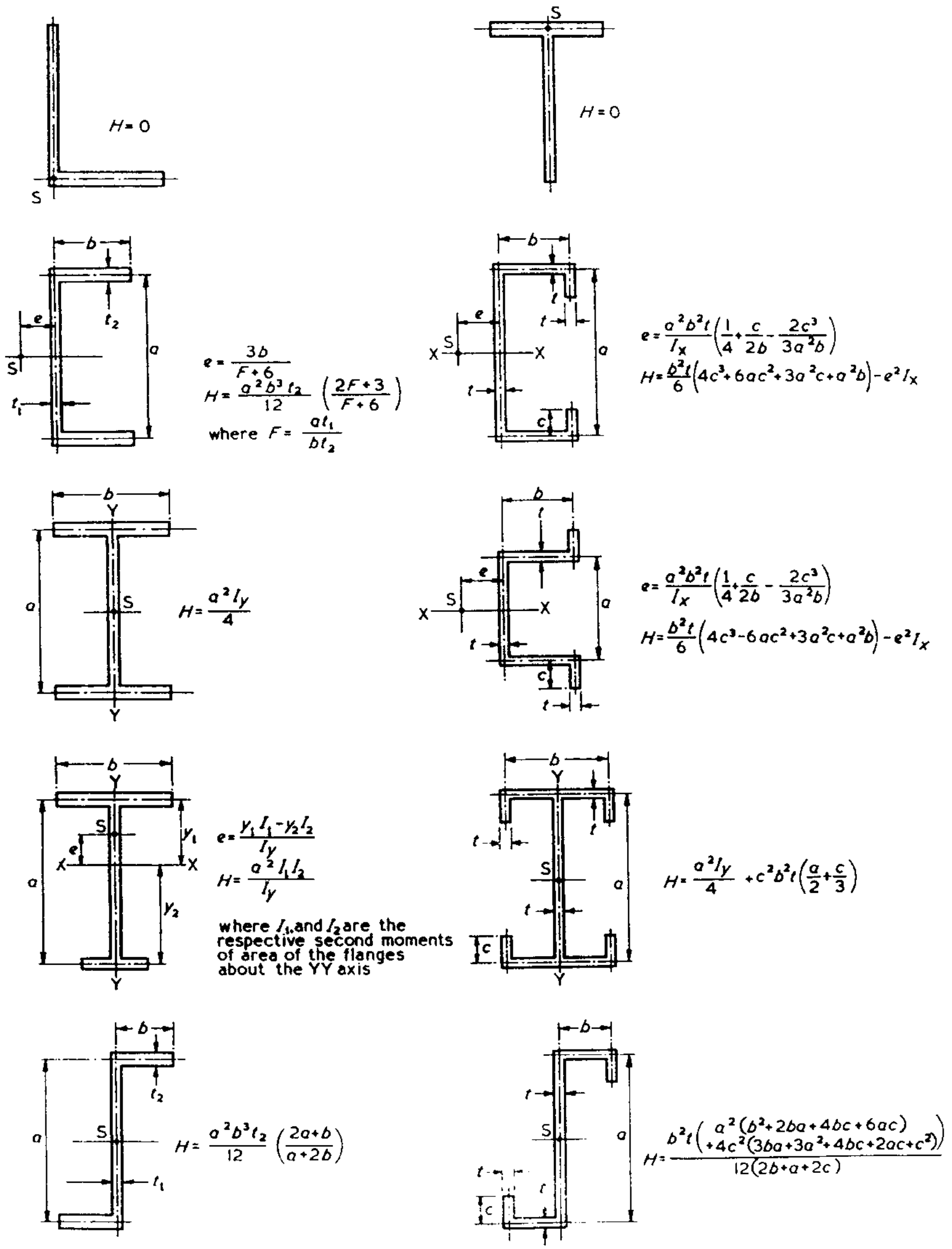


Figure 28 — Shear-centre position and warping factor for certain thin-walled sections

References for Appendix F

1. M. S. G. Cullimore and A.G. Pugsley. "The torsion of aluminium alloy structural members", *Aluminium Development Association Research Report No.* 9, 1952.

2. S. P. Timoshenko. "Theory of elasticity", McGraw-Hill, 1934.

3. P.J. Palmer, "The determination of torsion constants for bulbs and fillets by means of an electrical potential analyser", *Aluminium Development Association Research Report No.* 22, 1953.

4. F. Bleich. "Buckling strength of metal structures", McGraw-Hill, 1952.

5. S. P. Timoshenko. "Strength of materials", Vol. 2, 1956.

6. J. F. Baker and J. W. Roderick. "The strength of light alloy struts", *Aluminium Development Association Research Report No.* 3, 1948.

7. N.J. Hoff. "Stresses in space-curved rings reinforcing the edges of cut-outs in monocoque fuselages", *Journal Royal Aeronautical Society,* February, 1943.

8. J. H. Argyris. "The open tube", *Aircraft Engineering,* Vol. 26, April, 1954.

Appendix G Torsional buckling

G.1 General

This appendix gives general rules for the torsional buckling of thin-walled struts of open section. They apply to sections not specifically dealt with by the simplified method of **4.3.3**. They also apply to the sections dealt with in **4.3.3** and, in some cases, may result in slightly higher permissible stresses.

The rules enable λ_t to be calculated for a strut. The permissible stress is then read from Figure 1 at $\lambda = \lambda_t$ for the principal alloys; for other alloys, reference should be made to Appendix D.

The section properties may be obtained by the methods given in Appendix F.

Additional data including torsional buckling loads for a wide range of column types, for different end conditions, is given in Reference 1.

G.2 Two axes of symmetry

For a strut whose section has two axes of symmetry, or has point symmetry (e.g. a zed), failure is by pure torsional buckling and the permissible stress is obtained as above at $\lambda = \lambda_t$,

$$\text{where } \lambda_t = \sqrt{\frac{I_p}{0{\cdot}038\,J + \frac{H}{\ell^2}}},$$

I_p is the polar second moment of area about the shear centre,

J is the torsion factor,

H is the warping factor, and

ℓ is the effective length.

The effective length ℓ depends on the warping restraints at the ends; for a strut completely restrained against warping ℓ is 0.5L, while for one with no warping restraint ℓ is L, where L is the length between lateral supports. Practical struts come between these two extremes.

Column buckling about either axis of symmetry is independent of torsional buckling and should be checked separately.

G.3 One axis of symmetry

For a strut whose section has only one axis of symmetry, there is interaction between torsional buckling and column buckling in the plane normal to that axis, resulting in a lower buckling stress than that associated with either mode alone. The permissible stress is obtained as above at $\lambda = k\lambda_t$ or $k\,\ell/r$, whichever is the greater,

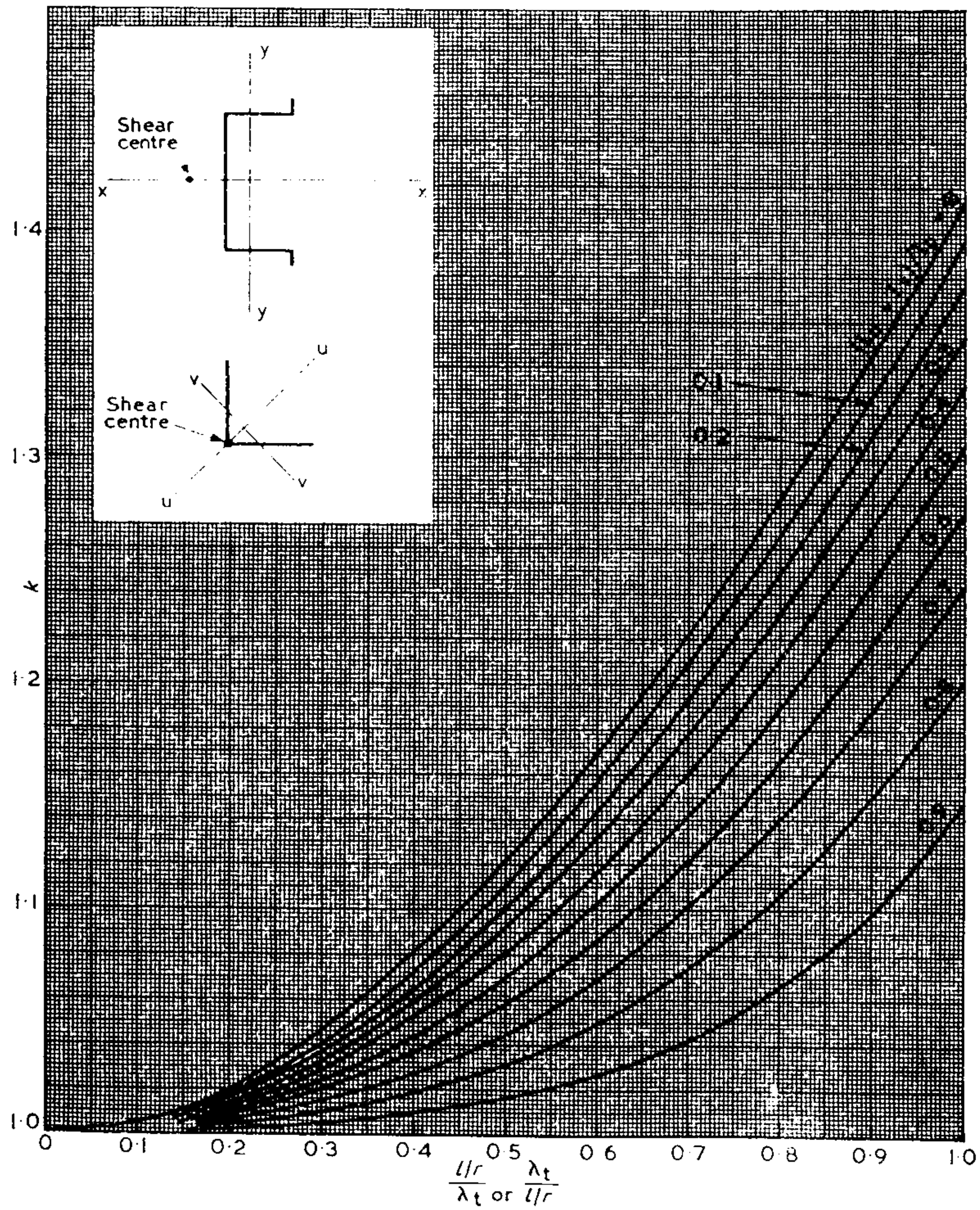


Figure 29 — Values of the interaction coefficient *k*

where *k* is the interaction coefficient from Figure 29,

λ_t is the slenderness ratio for pure torsional buckling as calculated from **G.2**, and

ℓ/r is the slenderness ratio for ordinary column buckling in the plane normal to the axis of symmetry (i.e. about axis x-x or axis u-u).

Column buckling in the plane of the axis of symmetry may take place independently of torsional buckling and should be checked separately.

G.4 No axis of symmetry

For a strut whose section has no symmetry, the interaction between torsional and column buckling is complex, and buckling stress can only be determined by accurate theory (Reference 2) or by test.

Column buckling of unsymmetrical sections does not occur independently of torsional buckling.

References for Appendix G

1. C. P. Hone. "Torsional-flexural buckling of axially-loaded, thin-walled, elastic struts of open cross-section". A paper in "*Thin-walled structures*", Chatto and Windus, 1967.

2. S. P. Timoshenko. "*Strength of materials*", Vol. 2, 1956.

Appendix H Lateral buckling of beams

H.1 Doubly-symmetrical sections not free to move sideways at load points

The methods given in **4.4.4.2** for determining the permissible stresses for lateral buckling of I-sections and of other doubly-symmetrical open sections ignore the effect of warping resistance. This effect is appreciable for thin-walled sections with a width-to-depth ratio exceeding about ¾.

Warping resistance can be taken into account, and a higher permissible stress obtained for such members, by multiplying λ_{lat} by

$$\left(1 + \frac{26\,H}{L^2 J}\right)^{-1/4}$$

where H is the warping factor (see Appendix F),

J is the torsion factor (see Appendix F), and

L is the distance between points of lateral support.

H.2 Doubly-symmetrical sections free to move sideways at load points

For a beam of doubly-symmetrical section which is loaded in such a way that it is free to move sideways at the points of application of the loads, the effective unsupported length ℓ_f of the compression flange to be used in the appropriate equation in **4.4.4.2** is

$$\ell_f = k_1\,k_2\,(L + k_3 y),$$

where L is the distance between points of lateral support,

k_1 is a factor depending on the conditions of restraint at those points (see Table 26),

k_2 is a factor depending on the shape of the bending moment diagram between those points (see Table 27),

k_3 is a factor depending on the shape of the cross-section (see Table 28), and

y is the height of the effective point of load application above the shear centre (in this case the centroid), taken as positive if the point is above the shear centre and as negative if below.

H.3 Sections symmetrical about the minor axis only

For a beam having symmetry about the minor axis only (e.g. a tee with a vertical stem), λ_{lat} may be calculated from the equation in **4.4.4.2** 3) provided ℓ_f is obtained as follows:

1) For a beam which is not free to move sideways at the points of application of the loads,

$$\ell_f = k_1 k_2 \left(L + 5\,g\sqrt{\frac{I_y}{J}}\right), \text{ and}$$

2) For a beam which is free to move sideways at the points of application of the loads, but not for a cantilever,

$$\ell_f = k_1 k_2 \left[L + (5g + 2{\cdot}7y) \sqrt{\frac{I_y}{J}} \right],$$

where L, k_1, k_2 and y have the same meanings as in **H.2**,

I_y is the second moment of area about the minor axis,

J is the torsion factor (see Appendix F), and

g is the distance of the shear centre from the centroid, taken as positive if on the tension side, and negative if not.

Table 26 — Condition-of-restraint factor k_1

Type of member	Condition of restraint at points of lateral support	k_1
Cantilever free to move sideways at unsupported end	Full restraint against twisting and minor-axis bending at the support	1.0
	Full restraint against twisting at the support, but restraint against minor-axis bending confined to that due only to continuity	1.2
	Restraint against twisting and minor-axis bending confined to that due only to continuity	2.5
All other beams and cantilevers	Full restraint against twisting and minor-axis bending	0.7
	Full restraint against twisting, but minor-axis bending unrestrained	1.0
	Restraint against twisting confined to that due to continuity; minor-axis bending unrestrained	1.2

Table 27 — Bending moment shape factor k_2

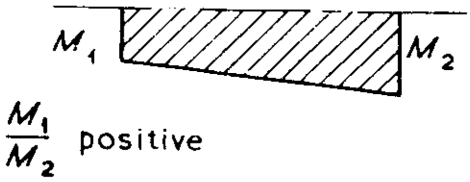
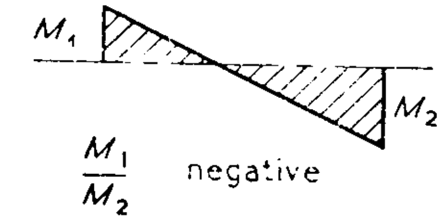
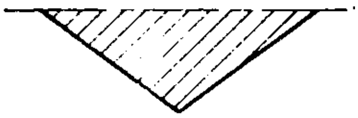
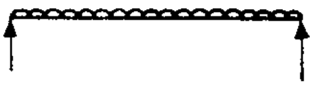
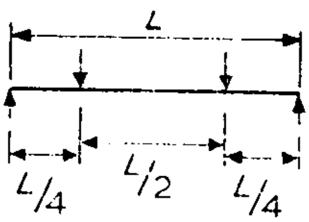
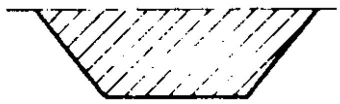
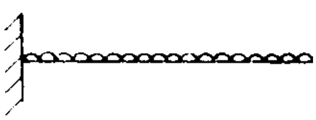
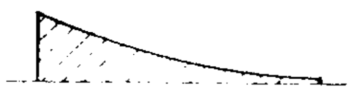
Condition of restraint	Type of loading	Bending moment diagram between points of lateral support	k_2
Beam or part of beam held laterally at points of load application			$\left(0{\cdot}6 + 0{\cdot}4\,\frac{M_1}{M_2}\right)$ or 0.4, whichever is greater. M_2 is numerically greater than, or equal to, M_1
			
Beam or part of beam free to move sideways at points of load application			0.74
			0.89
			0.96
Cantilever free to move sideways at unsupported end			0.78
			0.49

Table 28 — Cross-section-shape factor k_3

Type of cross section	k_3	
	Cantilevers	Beams and parts of beams
I-section	$0.3\ b/t_2$	$0.9\ b/t_2$
Solid rectangular	0.5	1.5
Hollow rectangular	0.7	2.1
Other, symmetrical about the minor axis yy	$0.9\sqrt{I_y/J}$	$2.7\sqrt{I_y/J}$
NOTE b and t_2 are as shown in Figure 7, and I_y and J have the same meanings as in **H.3**.		

Appendix J Stresses in webs of built-up beams

Where flanges or stiffeners or both are such that significant torsional restraint is provided to the web, more economical structures can be designed by using more precise methods than those given in **4.4.7**.

The following papers may be referred to:

1. I. T. Cook and K. C. Rockey. "Shear buckling of clamped and simply supported infinitely long plates reinforced by closed section transverse stiffeners". *Aeronautical Quarterly*. Vol. XIII. Aug. 1962.
2. K. C. Rockey and I. T. Cook, "Influence of the torsional rigidity of transverse stiffeners upon the shear buckling of stiffened plates". *Aeronautical Quarterly*. Vol. XV. May, 1964.
3. C. Massonnet, G. Mazy and A. Tanghe. "General theory of the buckling of orthotropic rectangular plates, clamped or freely supported at the edges, provided with stiffeners parallel to the edges, having considerable flexural and torsional rigidities". *International Association for Bridge and Structural Engineering*. 20th Vol. Publications, 1960.
4. K. C. Rockey. "Aluminium plate girders". *Proceedings of Symposium on Aluminium in Structural Engineering*. Aluminium Federation. London, 1963.

Appendix K Local buckling of channels and I-sections

This appendix gives a more accurate method of determining the permissible stress in local buckling than is obtainable from **4.5.1** and Table 11. It refers to certain thin-walled channels and I-sections, both with and without lips, in uniform axial compression.

The curves given in Figure 30 and Figure 31 apply to plain channels and I-sections respectively, and those in Figure 32 and Figure 33 to lipped channels and I-sections respectively. In the figures,

a is the depth of web (inside flanges),

b is the width of flange or half-flange (to face of web),

t_1 is the web thickness, and

t_2 is the flange thickness,

these dimensions being further defined by the relevant diagrams, which also indicate the areas to be considered for lips.

The procedure for design is as follows:

1) *Plain sections*. For a plain section, the value of the local buckling coefficient m for the entire section is obtained from Figure 30 or Figure 31 by entering with the appropriate values of b/a and t_1/t_2.

2) *Lipped sections*. For a lipped section, the value of m for the entire section is obtained from Figure 32 or Figure 33 by selecting the curve for the appropriate ratio t_1/t_2 and entering it with the appropriate values of b/a and r/t_2, where r is the radius of gyration of the lip about the axis through its centroid and parallel to the parent flange.

In Figure 32 and Figure 33 there are broken lines giving the values of m for hypothetical sections having hinged connection between flange and lip. Such values are minima, because the theory neglects the torsional resistance of a lip.

In each case the permissible stress for the entire section is obtained by entering the appropriate graph of Figure 2 at $\lambda = ma/t_1$.

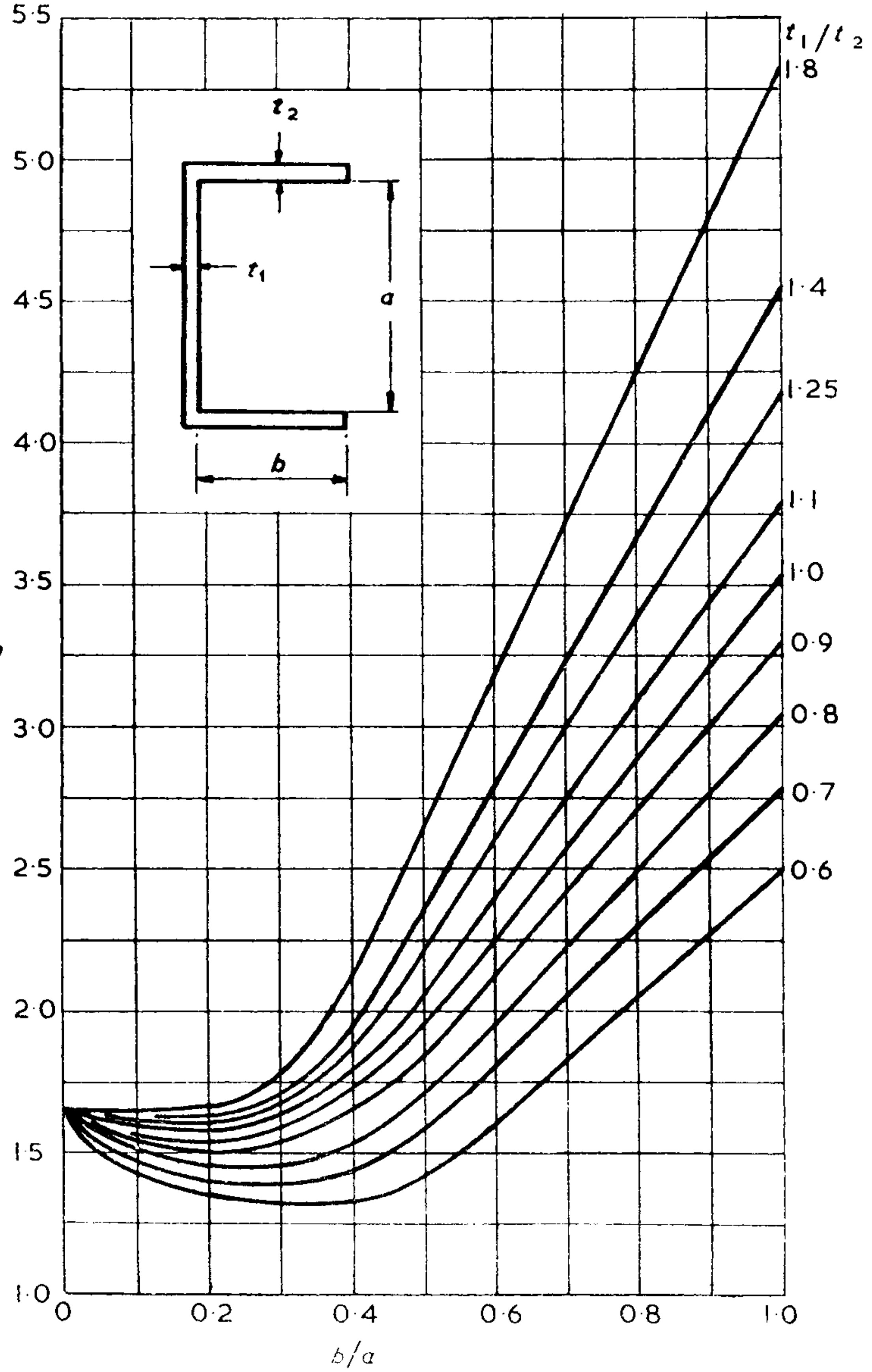


Figure 30 — Values of m for plain channels

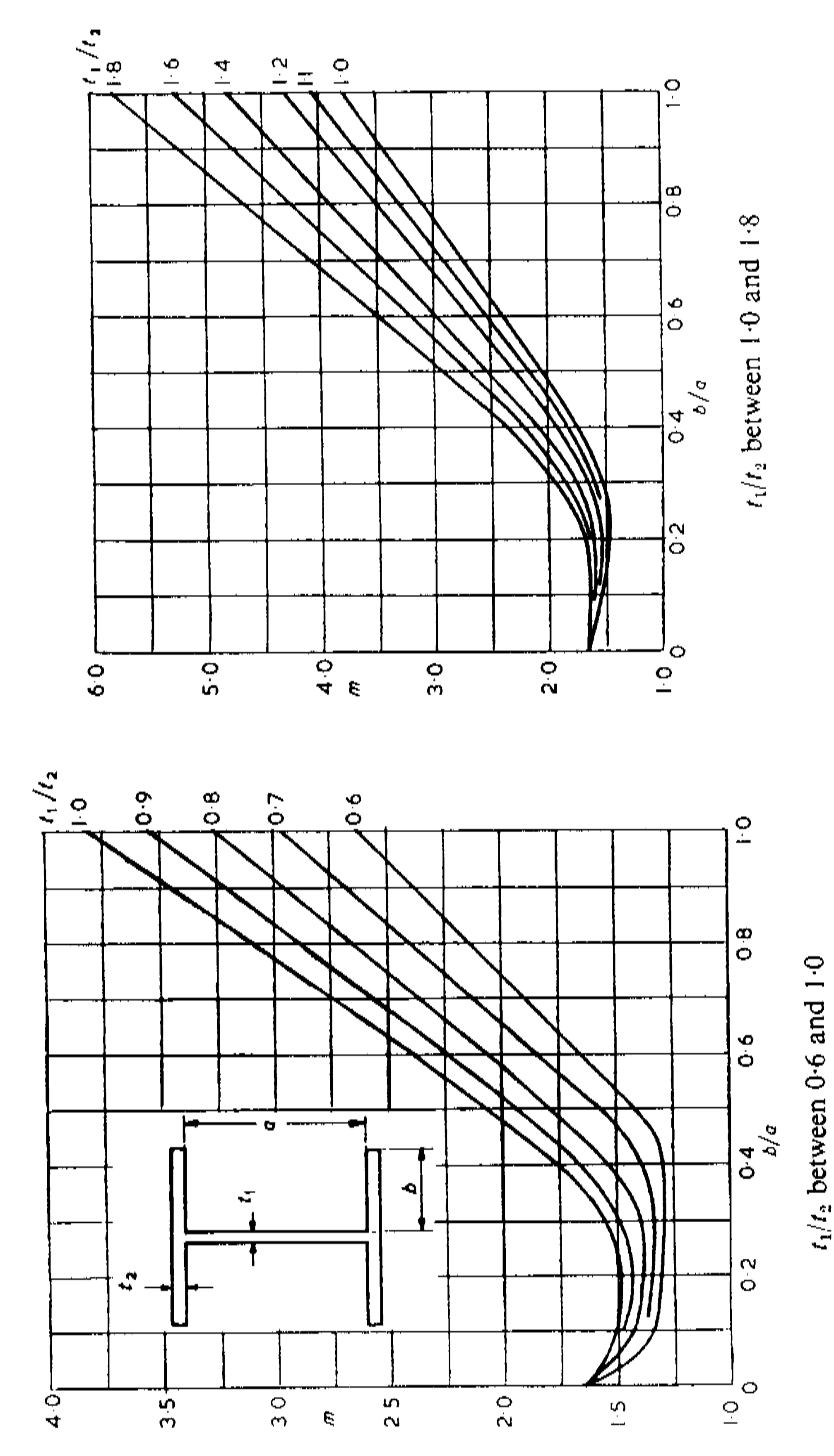


Figure 31 — Values of m for plain I-sections

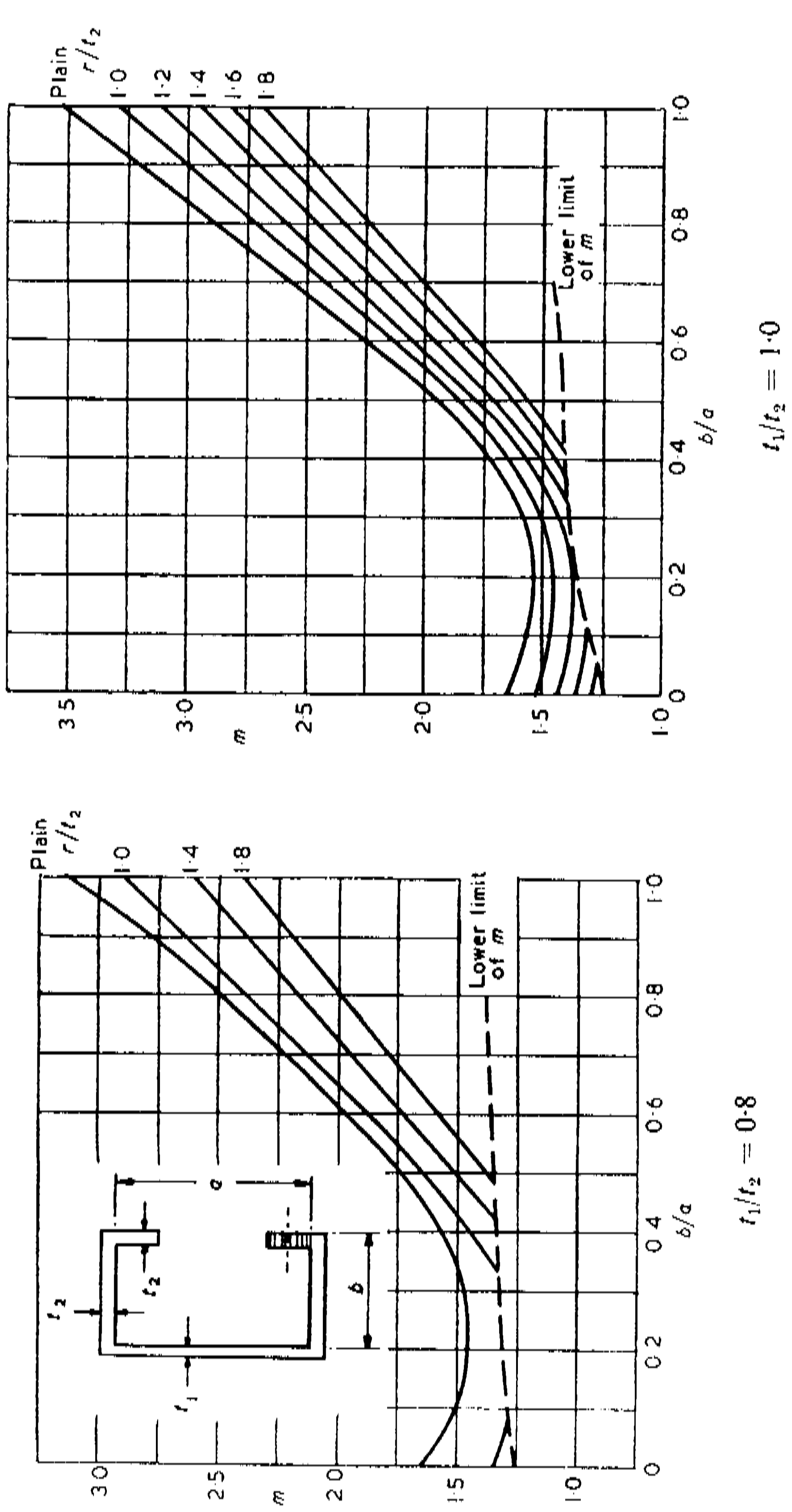


Figure 32 — Values of m for lipped channels

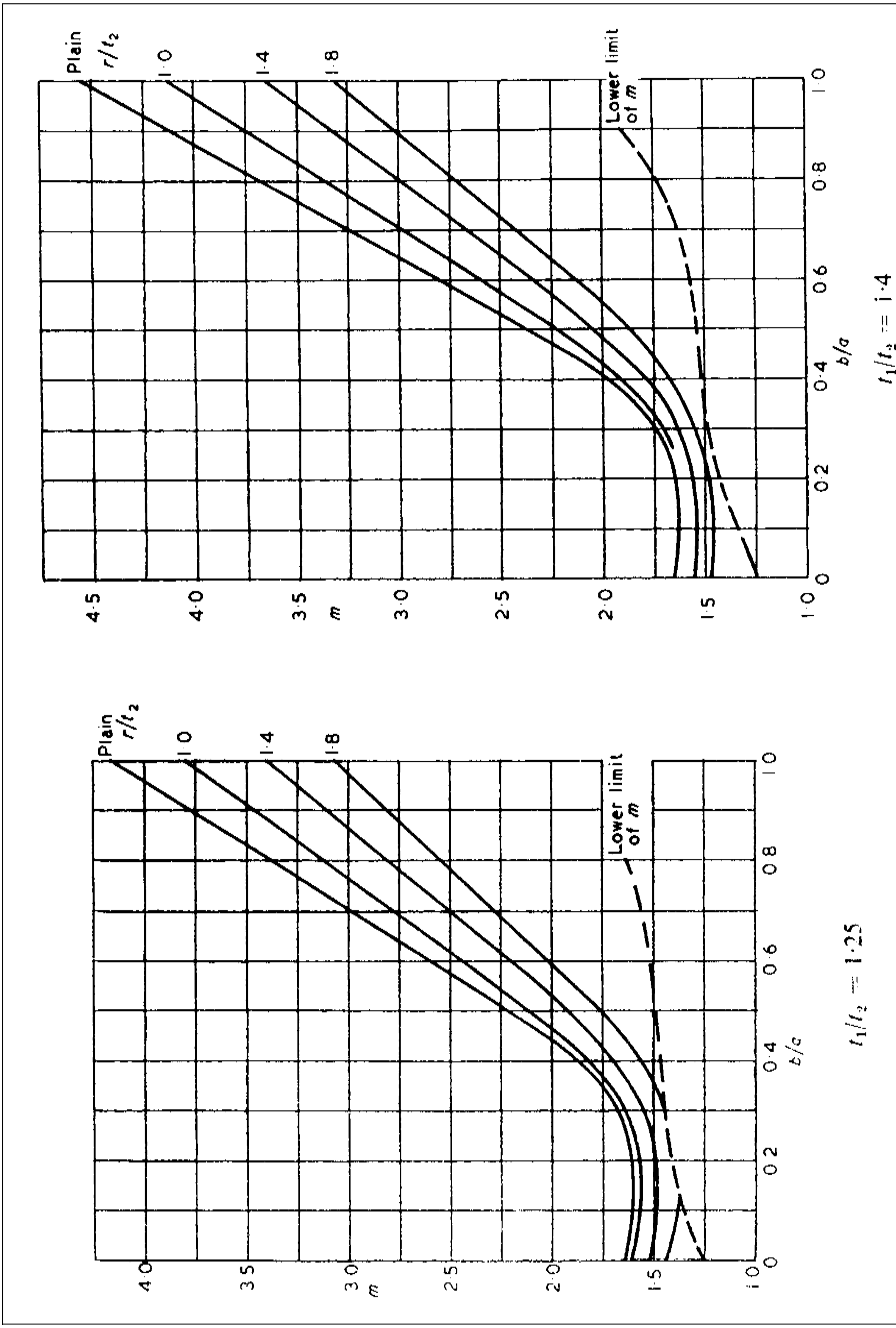


Figure 32 — Values of m for lipped channels *(continued)*

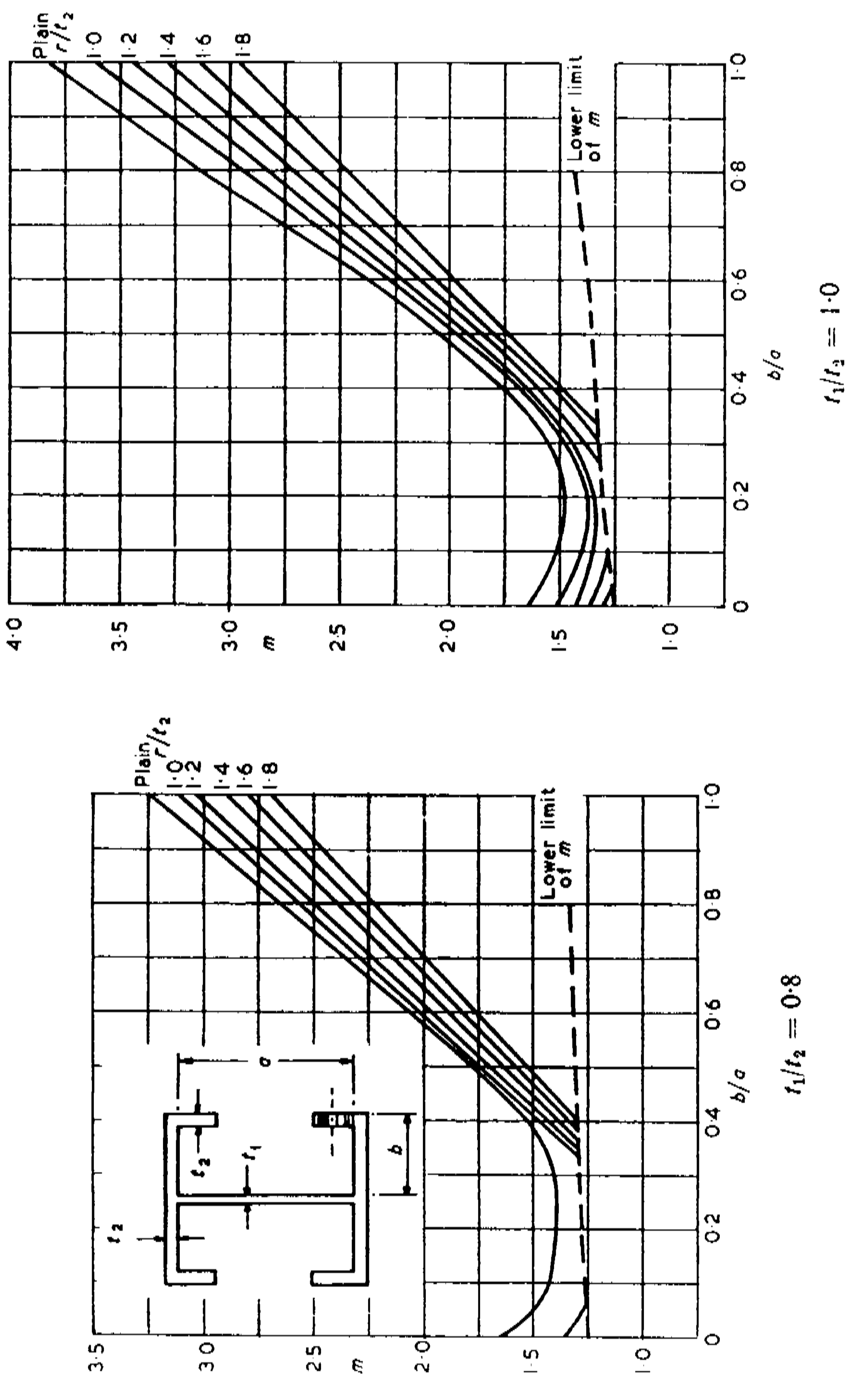
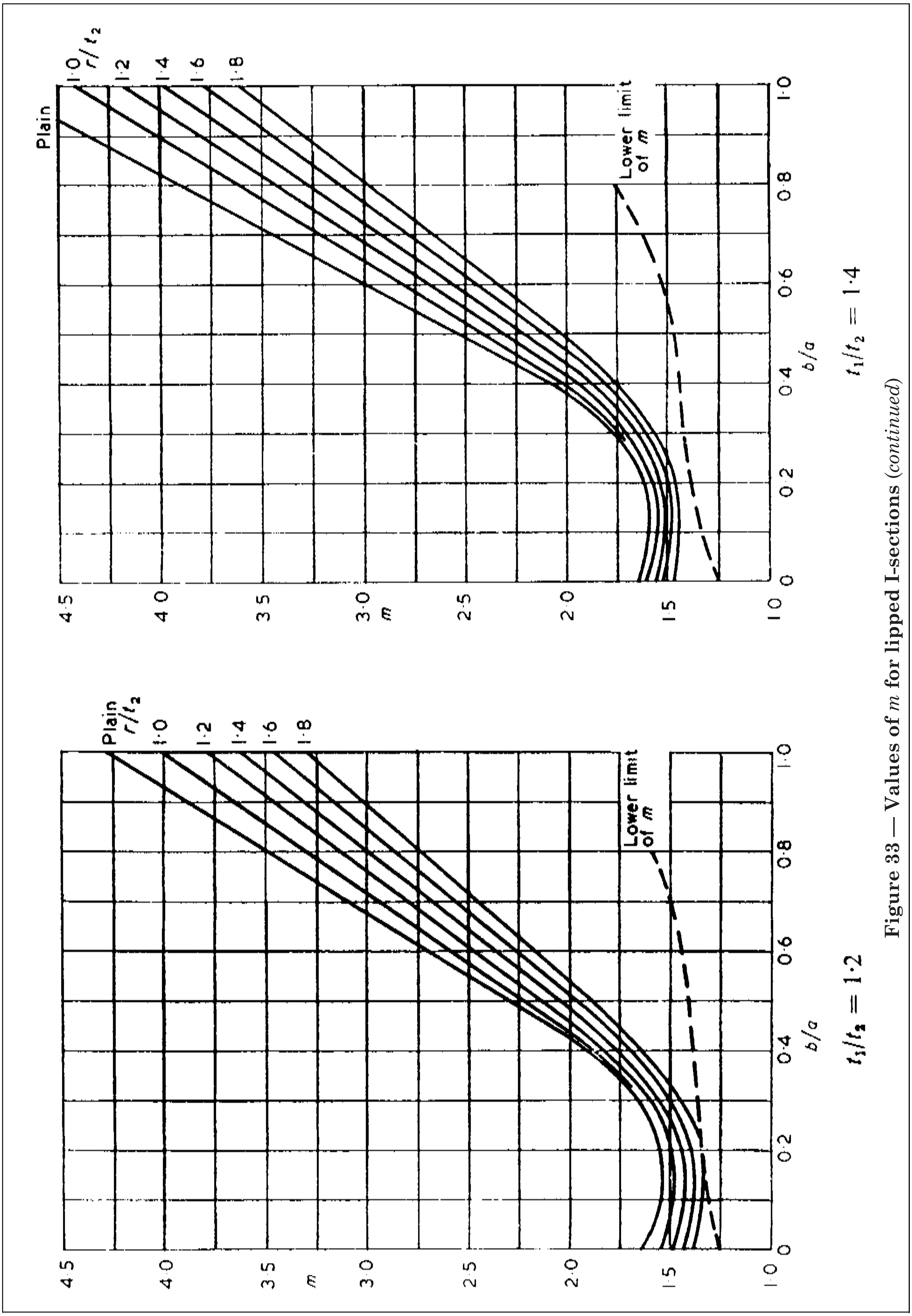


Figure 33 — Values of m for lipped I-sections



$t_1/t_2 = 1{\cdot}2$

$t_1/t_2 = 1{\cdot}4$

Figure 33 — Values of m **for lipped I-sections** *(continued)*

Appendix L Design of welded joints

L.1 General

The versatility of welding enables joints between members to be made in many different ways. However, in selecting the type of joint to be used, the designer should consider:

1) The effect of the joint on the static strength of the member.

2) The effect of the joint on the fatigue strength of the member, and the choice of details to reduce stress concentrations.

3) The detailed arrangement of the joint to enable good-quality welds to be made.

4) The choice of suitable details to avoid corrosion.

5) The effects of welding distortion.

These considerations are dealt with in **L.2** to **L.6**.

L.2 Effect on static strength

In non-heat-treatable alloys in the O and M tempers a welded joint will normally have no effect on the permissible stress. In non-heat-treatable alloys in work-hardened tempers and in heat-treated alloys, however, it will reduce the permissible stress (see **4.6.3.2**). In such latter materials welds should, where possible, be made parallel to the direction of the applied stress; welds transverse to the direction of stress, and which therefore weaken a substantial part of the cross-section, should be avoided or should be arranged to be in regions of low stress.

L.3 Effect on fatigue strength

Every joint creates stress concentrations whose severity should be kept as low as possible whether they arise from the general geometry of the joint as a whole or the local geometry of the actual weld; normally the former will be the more important.

The classification given in **4.7.4** forms a guide for the selection of welded details, and the examples in Table 29 show ways in which the low strength of certain details may be overcome; in each line the best kind of joint is shown on the right-hand side. Those examples that conform to one or other of the classes of member defined in **4.7.4** are so indicated. Those where no class is shown are not permitted under fatigue conditions. Probable locations of fatigue cracks are shown in some of the examples. Where low-strength joints cannot be avoided they should, if possible, be placed at points where the applied stress is low, e.g. on the neutral axis or at a point of contraflexure.

L.4 Arrangement for welding

For good-quality welding the proper edge preparation (see Appendix M) should be used and the detail of the joint should be such that the operator can see the joint and position the torch at the correct angle; the welding sequence also should take accessibility into account.

L.5 Corrosion

Joints should be so detailed that they do not include pockets or crevices capable of retaining moisture or dirt, and are accessible for inspection and maintenance. Cavities should be sealed either by welding or by suitable protective compounds (see **7.5**).

L.6 Distortion

The designer should bear in mind that each deposited weld causes shrinkage and possible distortion. He should endeavour to balance or compensate for this effect so as to maintain the desired dimensions and shape of the finished structure.

In the early stages of design the fabricator should be consulted on the effects of welding sequence and the use of jigs.

Table 29 — Illustrations of welded joints

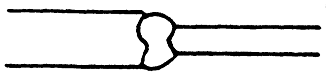
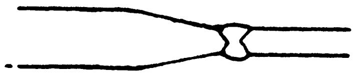
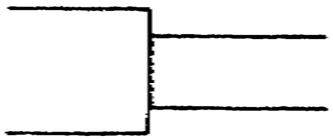
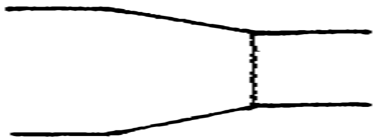
Weld detail	Remarks
 6 (ii)  3 (ii), 4 (i), 5 (i) Lap and butt joints	Where two plates are connected in the same plane it is better to use a butt weld than fillet welds.
 4 (ii)  3 (ii)  2 Weld reinforcement	The flatter the reinforcement the better will be the fatigue strength. For optimum fatigue strength, the weld should be dressed flush in accordance with **4.7.4.1** (Class 2).
 (See **4.7.2**)  3 (ii), 4 (ii), 5 (i)  (See **4.7.2**)  3 (ii), 4 (ii), 5 (i)  (See **4.7.2**)  3 (ii), 4 (ii), 5 (i) Eccentricity, and thickness variation	The eccentricity introduced where a load is transmitted between two members not in alignment results in secondary bending stresses and, consequently, in reduced fatigue performance (see footnote to **4.7.2**). Where a butt joint is made between two members differing in thickness by more than ⅛ in (3.2 mm) or one fifth of the thickness of the thinner, whichever is the lesser, the thicker should be tapered to a slope of about 1 in 5, so that the weld is made between materials of equal thickness. The eccentricity of the joint may be neglected if, as in the case of a flange-splice in a plate-girder, it is rigidly supported.
  3 (ii), 4 (ii), 5 (i) Variation of width	Where a butt joint is made between members of unequal width, the wider should be tapered to the width of the narrower.

Table 29 — Illustrations of welded joints

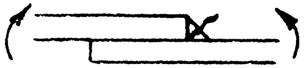
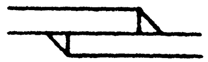
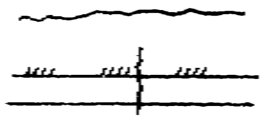
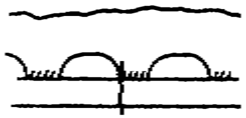
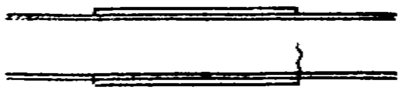
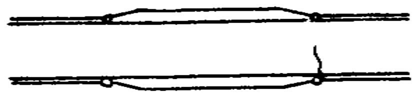
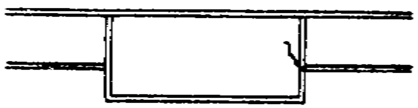
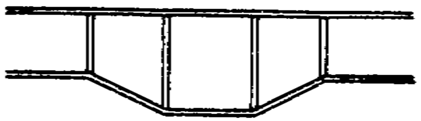
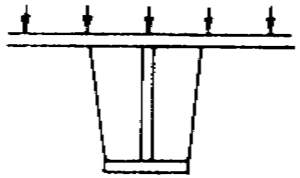
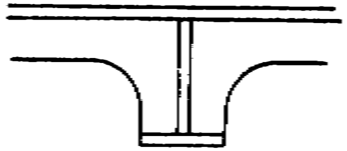
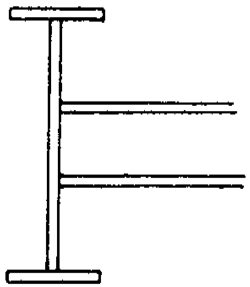
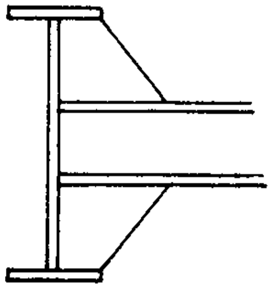
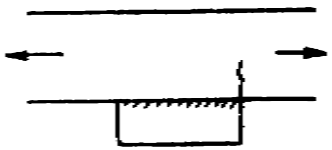
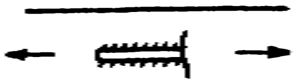
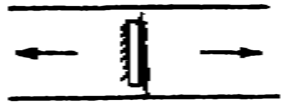
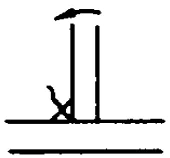
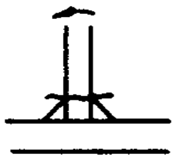
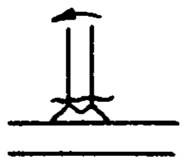
Weld detail	Remarks
 Not permissible if loading tends to open joint  6 (ii)  3 (ii), 4 (ii), 5 (i) Single-lap joints	Lap-joints, unless rigidly supported to prevent flexure, introduce high secondary stresses and are not permitted under fatigue conditions, except where supported as in the case of a joint in a tube. A lap-joint with only one fillet weld is not permitted if the loading tends to open the joint.
 8  8  3 (ii), 4 (i) Intermittent welding	Stress concentrations occur at the ends of intermittent welds and are not reduced in severity by scalloping the edge of the web plate. It is better to use continuous welds, preferably made by a mechanical process.
 8  5 (i)  Classification depends on detailing  Classification depends on detailing Abrupt changes in section	Local strengthening, where required, should be obtained without introducing sudden change in section. It may be more economical to use an increased section over the whole span, the greater cost of material being covered by the saving in cost of fabrication.

Table 29 — Illustrations of welded joints

Weld detail	Remarks
  Classification depends on detailing   Classification depends on detailing Abrupt changes in stiffness	Abrupt changes in stiffness create stress concentrations and should, as far as possible, be avoided. Nevertheless, at any point where load is applied to a member, the member should be made stiff enough to resist that load.
 8  8  5 (ii) Attachments	Attachments, even if carrying insignificant loads, produce server stress concentrations in strength members to which they are welded. Transverse attachments are less harmful than longitudinal ones. Longitudinal welds on the edges of a strength member are particularly to be avoided.
 Not permissible if loading tends to open joint  6 (ii)  6(ii) T-joints	A T-joint normally requires two fillet welds or, preferably, a compound weld. A T-joint with only one fillet weld is not permitted if the loading tends to open the joint.

Appendix M Edge preparations for welded joints

Table 30 to Table 37 give guidance on the choice of edge preparations. The preparations shown are applicable, except where otherwise stated, to both TIG and MIG welding.

The ranges given for preparation angles and other dimensions are not manufacturing tolerances, but give scope for choice for individual cases; whichever angle and other dimensions are used, however, the edge preparation must be identical on both sides of any symmetrical joint.

Where the requirement is for no gap, the accuracy of fit must be such that the gap at any point exceeds neither $^1/_{16}$ in (1.6 mm) nor one tenth of the thickness of the thinner of the members joined.

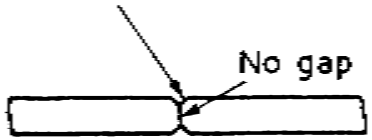
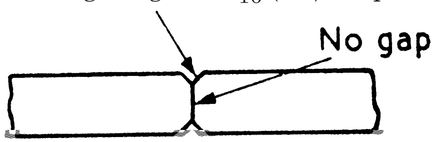
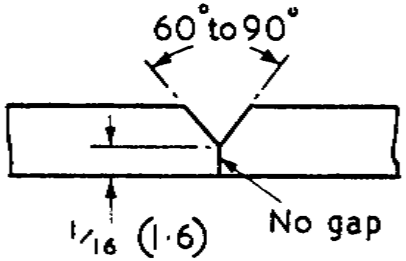
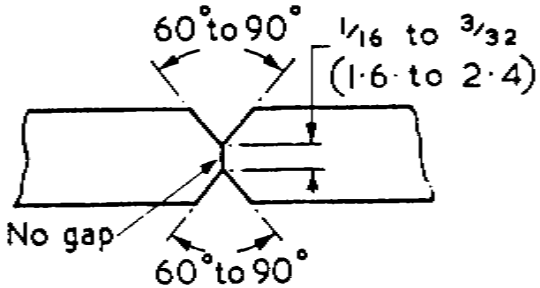
The sighting vee shown in some preparations is an optical aid for the welder; it is not essential to the weld profile.

The welding positions are as defined in BS 499-1[36].

[36] BS 499, "*Welding terms and symbols*", Part 1, "*Welding, brazing and thermal cutting glossary*".

Table 30 — Edge preparations for butt welds without backing bars

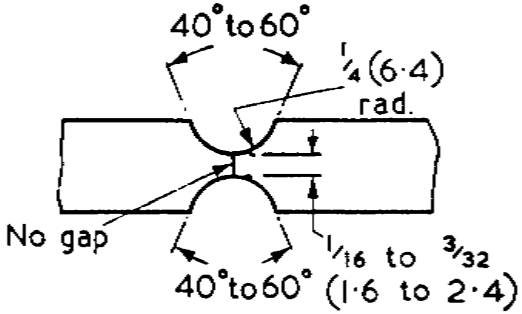
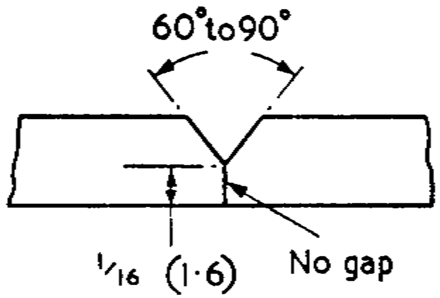
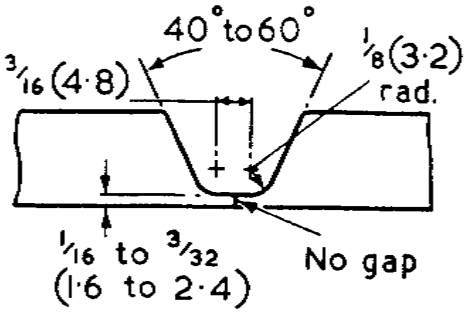
(Dimensions in inches; millimetre equivalents in parentheses)

Thickness	Edge preparation	Procedure	Welding positions
$^1/_8$ to $^3/_{16}$ (3.2 to 4.8)	Sighting vee $^1/_{32}$ to $^1/_{16}$ (0.8 to 1.6) deep 	TIG Manual or mechanized[a]	$^1/_8$ (3.2): Flat $^3/_{16}$ to $^1/_4$ (4.8 to 6.4) Manual: All mechanized: Flat
$^1/_8$ to $^1/_4$ (3.2 to 6.4)		MIG Manual or Mechanized[a]	
$^3/_{16}$ to 1 (4.8 to 25)	Sighting vee $^1/_{16}$ (1.6) deep 	MIG (high current) Mechanized Weld both sides[b]	Flat and horizontal-vertical
$^3/_{16}$ to $^1/_2$ (4.8 to 13)		Manual or mechanized[a]	Manual: All Mechanized: Flat and horizontal-vertical
$^1/_2$ (13) upwards		Manual or mechanized Weld both sides[b]	

[a] Place sealing run on back of weld after chipping or machining to sound metal.
[b] Chip or machine back of first weld before placing first run of second weld.

Table 30 — Edge preparations for butt welds without backing bars

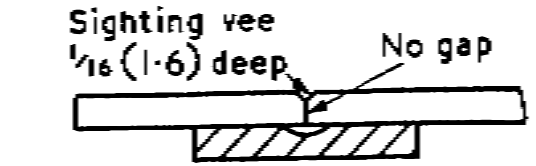
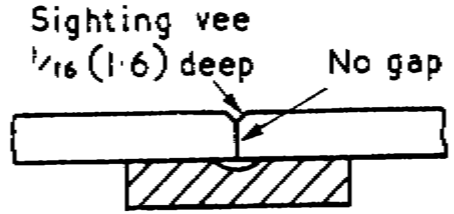
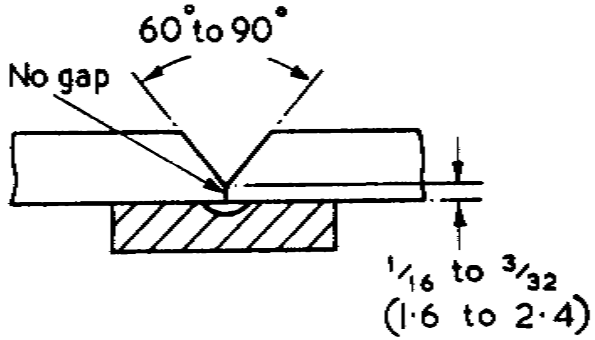
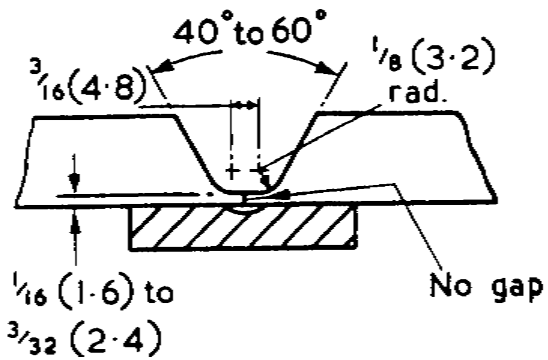
(Dimensions in inches; millimetre equivalents in parentheses)

Thickness	Edge preparation	Procedure	Welding positions
$^3/_4$ (19) upwards		Manual or mechanized Weld both sides[a]	Manual: All Mechanized: Flat and horizontal-vertical
$^1/_8$ to $^3/_8$ (3.2 to 9.6)		MIG (but TIG for root run) Manual or mechanized Use where access to back of joint is impracticable (as with tubes)	
$^3/_{16}$ (4.8) upwards		MIG (but TIG for root run) Manual or mechanized Use where access to back of joint is impracticable (as with tubes)	

[a] Chip or machine back of first weld before placing first run of second weld.

Table 31 — Edge preparations for butt welds with temporary backing bars[a]

(Dimensions in inches; millimetre equivalents in parentheses)

Thickness	Edge preparation[a]	Procedure	Welding positions
$^1/_8$ to $^1/_4$ (3.2 to 6.4)		Manual Weld one side only	Flat
$^1/_8$ to $^3/_4$ (3.2 to 19)		MIG (high current) Mechanized Weld one side only	Flat
$^3/_{16}$(4.8) upwards		Manual or mechanized Weld one side only	Manual: All Mechanized: Flat and horizontal-vertical
$^1/_4$(6.4) upwards		Manual or mechanized Weld one side only (TIG for root run particularly with tubes)	

[a] Backing-bar dimensions are given in Table 32.

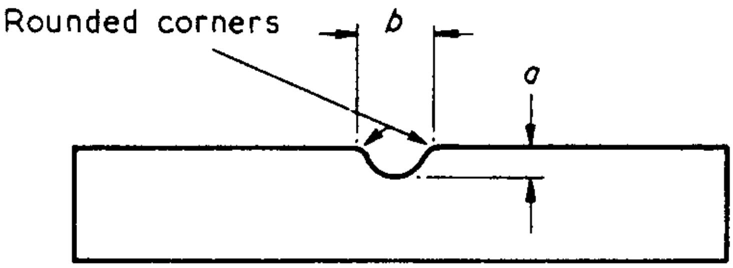


Table 32 — Recommended temporary-backing-bar dimensions

(Dimensions in inches; millimetre equivalents in parentheses)

Parent metal thickness	*a*	*b*
1/8 to 3/16 (3.2 to 4.8)	1/16 (1.6)	3/16 (4.8)
3/16 (4.8) upwards	1/8 (3.2)	1/4 (6.4)
Backing bars should preferably be of corrosion-resisting steel or bright mild steel.		

Table 33 — Edge preparations for butt welds with permanent backing bars[a]

(Dimensions in inches; millimetre equivalents in parentheses)

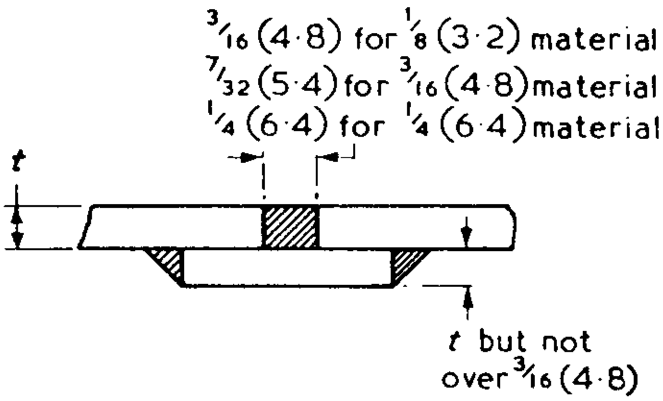
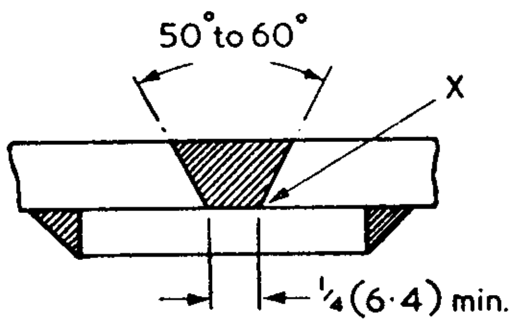
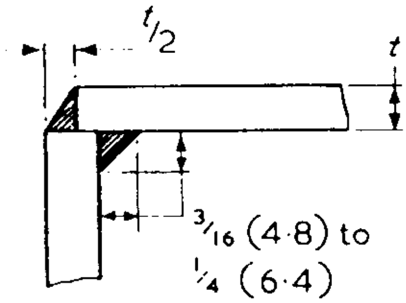
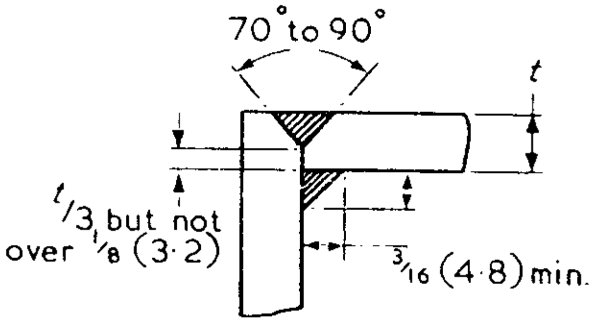
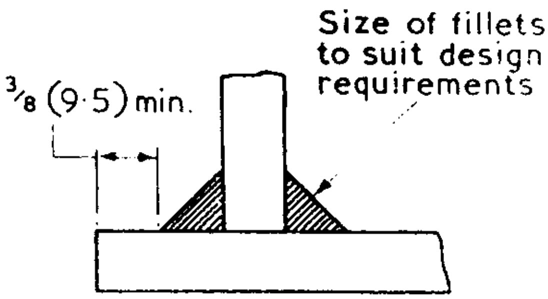
<table>
<tr><th>Thickness</th><th>Edge preparation</th><th>Procedure</th><th>Welding positions</th></tr>
<tr><td>1/8 to 1/4
(3.2 to 6.4)</td><td>
</td><td>MIG
Manual or mechanized</td><td>Flat</td></tr>
<tr><td>1/4
(6.4) upwards</td><td>
</td><td>MIG
Manual or mechanized
Fuse toes X before completing joint</td><td>Manual: All
Mechanized: Flat and horizontal-vertical</td></tr>
<tr><td colspan="4">[a] Permanent backing must be of same alloy as parent metal; it may be a structural section.</td></tr>
</table>

Table 34 — Edge preparations for corner welds without backing bars

(Dimensions in inches; millimetre equivalents in parentheses)

Thickness	Edge preparation	Procedure	Welding positions
$^{1}/_{4}$ to $^{3}/_{8}$ (6.4 to 9.5)		Manual or mechanized[a]	Manual: All (but preferably flat)
$^{3}/_{16}$ (4.8) upwards			Mechanized: Flat and horizontal-vertical
$^{1}/_{8}$ (3.2) upwards		Manual or mechanized	

[a] Place root run of outer weld first. Chip or machine back from inside, wherever possible, before placing inside run.

Table 35 — Edge preparations for corner welds with temporary backing bars

(Dimensions in inches; millimetre equivalents in parentheses)

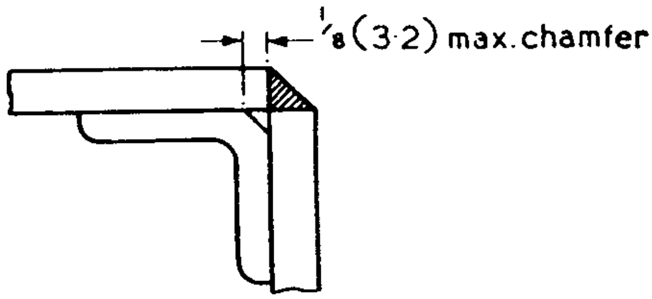
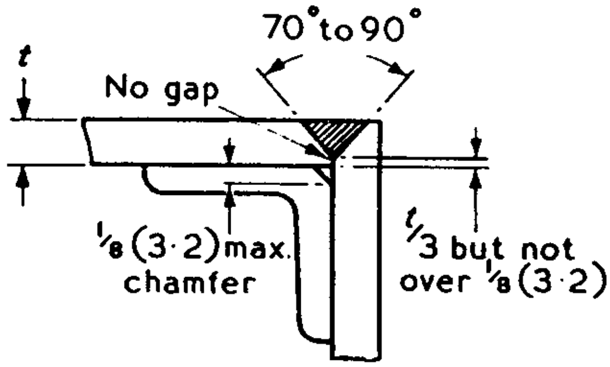
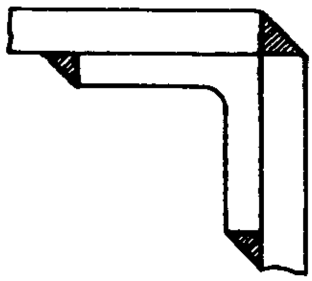
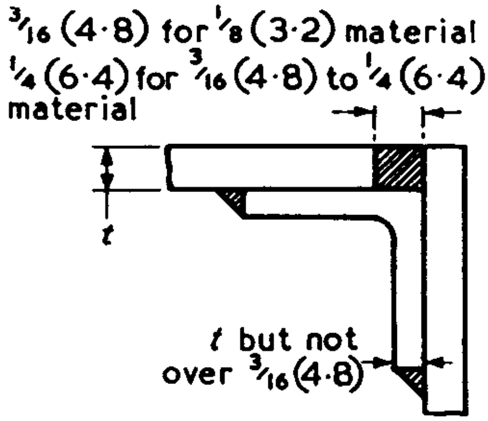
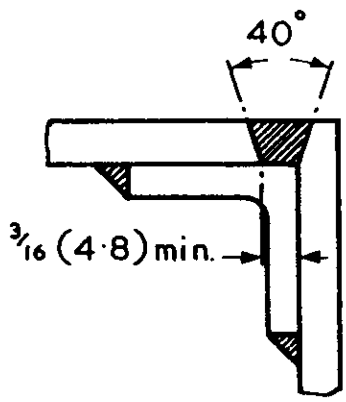
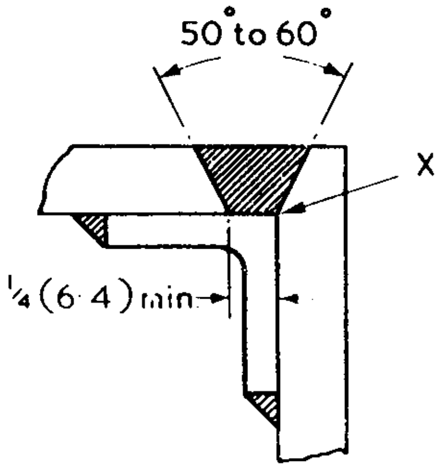
Thickness	Edge preparation	Procedure	Welding positions
All		Manual or mechanized	Manual: All (but preferable flat) Mechanized: Flat and horizontal-vertical
			

Table 36 — Edge preparations for corner welds with permanent backing bars[a]

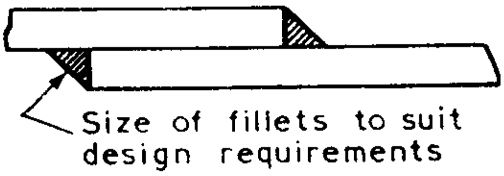
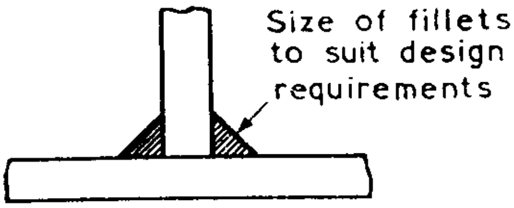
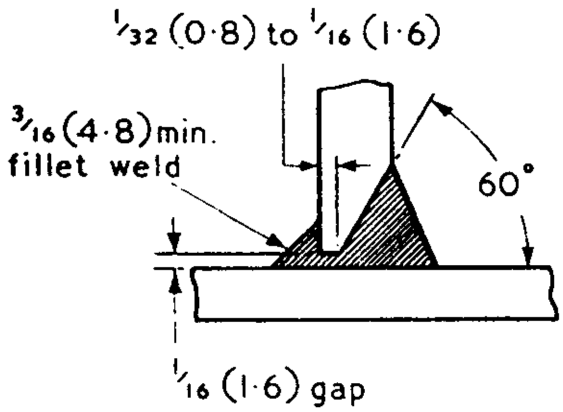
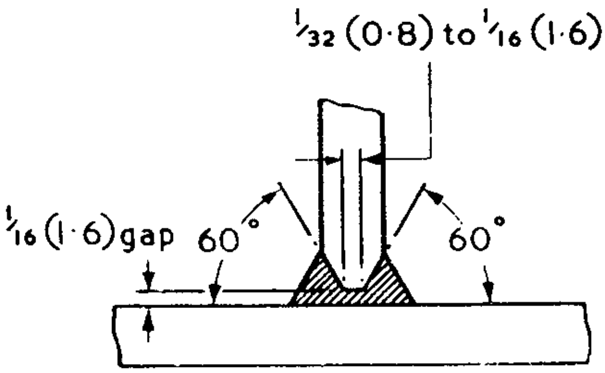
(Dimensions in inches; millimetre equivalents in parentheses)

Thickness	Edge preparation	Procedure	Welding positions
$^1/_8$ to $^1/_2$ (3.2 to 13)			
$^1/_8$ to $^1/_4$ (3.2 to 6.4)		Manual or mechanized	
$^1/_4$ to $^3/_8$ (6.4 to 9.5)			Manual: All (but preferably flat) Mechanized: Flat and horizontal-vertical
$^3/_8$ (9.5) upwards		Manual or mechanized Fuse toes X before completing joint	

[a] Permanent backing bar must be of same alloy as parent metal.

Table 37 — Edge preparations for lap and fillet welds

(Dimensions in inches; millimetre equivalents in parentheses)

<table>
<tr><th>Thickness</th><th>Edge preparation</th><th>Procedure</th><th>Welding positions</th></tr>
<tr><td rowspan="2">All</td><td>
</td><td rowspan="2">Manual or mechanized</td><td rowspan="4">Manual: All (but preferably flat)
Mechanized: Flat and horizontal-vertical</td></tr>
<tr><td>
</td></tr>
<tr><td>$^3/_{16}$ to $^1/_2$ (4.8 to 13)</td><td>
</td><td>Manual or mechanized[a]</td></tr>
<tr><td>$^3/_8$ (9.5) upwards</td><td>
</td><td>Manual or mechanized[a]</td></tr>
<tr><td colspan="4">[a] Place sealing run on back of weld after chipping or machining to sound metal.
[b] Chip or machine back of first weld before placing first run of second weld.</td></tr>
</table>

Appendix N Tabulated stresses for fatigue

The relationship between maximum stress, stress ratio and number of cycles, given graphically in Figure 15 to Figure 23 for the nine classes of member defined in **4.7.4**, are tabulated in this Appendix for the convenience of designers familiar with this method of presentation.

In the derivation of the tabulated quantities, the curves in Figure 15 to Figure 23 were in some cases slightly adjusted. The values, moreover, are rounded to two significant figures. In case of doubt, the curves of Figure 15 to Figure 23 are the definitive reference.

Table 38 — Relationship of maximum stress, stress ratio and number of cycles for class 1 members

a. Maximum stress tensile

f_{min}/f_{max}	f_{max} in tonf/in^2 (N/mm^2) for number of cycles as below:				
	100 000	600 000	2 000 000	10 000 000	100 000 000
0.6	—	15 (230)	13 (200)	12 (190)	12 (190)
0.5	15 (230)	12 (190)	11 (170)	9.5 (150)	9.5 (150)
0.4	12 (190)	10 (150)	9.0 (140)	8.0 (120)	8.0 (120)
0.3	11 (170)	8.8 (140)	7.8 (120)	7.6 (120)	7.6 (120)
0.2	9.4 (150)	7.8 (120)	7.4 (110)	7.2 (110)	7.2 (110)
0.1	8.3 (130)	7.4 (110)	7.1 (110)	6.9 (110)	6.9 (110)
0.0	7.6 (120)	7.1 (110)	6.8 (110)	6.6 (100)	6.6 (100)
– 0.1	7.3 (110)	6.8 (110)	6.5 (100)	6.3 (97)	6.3 (97)
– 0.2	7.0 (110)	6.5 (100)	6.3 (97)	6.1 (94)	6.1 (94)
– 0.3	6.7 (100)	6.3 (97)	6.0 (93)	5.8 (90)	5.8 (90)
– 0.4	6.5 (100)	6.1 (94)	5.8 (90)	5.6 (86)	5.6 (86)
– 0.5	6.2 (96)	5.8 (90)	5.6 (86)	5.4 (83)	5.4 (83)
– 0.6	6.0 (93)	5.6 (86)	5.4 (83)	5.2 (80)	5.2 (80)
– 0.7	5.8 (90)	5.5 (85)	5.2 (80)	5.1 (79)	5.1 (79)
– 0.8	5.6 (86)	5.3 (82)	5.0 (77)	4.9 (76)	4.9 (76)
– 0.9	5.5 (85)	5.1 (79)	4.9 (76)	4.7 (73)	4.7 (73)
– 1.0	5.3 (82)	5.0 (77)	4.7 (73)	4.6 (71)	4.6 (71)

b. Maximum stress compressive

f_{min}/f_{max}	f_{max} in tonf/in^2 (N/mm^2) for number of cycles as below:				
	100 000	600 000	2 000 000	10 000 000	100 000 000
– 0.1	– 14 (– 220)	– 13 (– 200)	– 13 (– 200)	– 13 (– 200)	– 13 (– 200)
– 0.2	– 12 (– 190)	– 11 (– 170)	– 11 (– 170)	– 10 (– 150)	– 10 (– 150)
– 0.3	– 10 (– 150)	– 9.7 (– 150)	– 9.3 (– 140)	– 9.0 (– 140)	– 9.0 (– 140)
– 0.4	– 9.2 (– 140)	– 8.6 (– 130)	– 8.2 (– 130)	– 7.9 (– 120)	– 7.9 (– 120)
– 0.5	– 8.2 (– 130)	– 7.6 (– 120)	– 7.5 (– 110)	– 7.1 (– 110)	– 7.1 (– 110)
– 0.6	– 7.4 (– 110)	– 6.9 (– 110)	– 6.6 (– 100)	– 6.4 (– 99)	– 6.4 (– 99)
– 0.7	– 6.7 (– 100)	– 6.3 (– 97)	– 6.0 (– 93)	– 5.8 (– 90)	– 5.8 (– 90)
– 0.8	– 6.2 (– 96)	– 5.8 (– 90)	– 5.5 (– 85)	– 5.3 (– 82)	– 5.3 (– 82)
– 0.9	– 5.7 (– 88)	– 5.3 (– 82)	– 5.1 (– 79)	– 4.9 (– 76)	– 4.9 (– 76)
– 1.0	– 5.3 (– 82)	– 5.0 (– 77)	– 4.7 (– 73)	– 4.6 (– 71)	– 4.6 (– 71)

Table 39 — Relationship of maximum stress, stress ratio and number of cycles for class 2 members

a. Maximum stress tensile

f_{min}/f_{max}	f_{max} in tonf/in^2 (N/mm^2) for number of cycles as below:				
	100 000	**600 000**	**2 000 000**	**10 000 000**	**100 000 000**
0.6	—	—	—	9.7 (150)	9.2 (140)
0.5	—	—	9.1 (140)	7.7 (120)	7.4 (110)
0.4	—	9.0 (140)	7.6 (120)	6.8 (110)	6.5 (100)
0.3	9.1 (140)	7.7 (120)	6.8 (110)	6.2 (96)	6.1 (94)
0.2	8.0 (120)	6.9 (110)	6.3 (97)	5.8 (90)	5.7 (89)
0.1	7.1 (110)	6.4 (99)	6.0 (93)	5.5 (85)	5.4 (83)
0.0	6.4 (99)	6.0 (93)	5.7 (89)	5.3 (82)	5.1 (79)
– 0.1	6.1 (94)	5.8 (90)	5.5 (85)	5.1 (79)	4.9 (76)
– 0.2	5.9 (91)	5.5 (85)	5.3 (82)	4.9 (76)	4.8 (74)
– 0.3	5.7 (88)	5.3 (82)	5.1 (79)	4.7 (73)	4.6 (71)
– 0.4	5.5 (85)	5.1 (79)	4.9 (76)	4.5 (69)	4.4 (68)
– 0.5	5.3 (82)	5.0 (77)	4.7 (73)	4.4 (68)	4.3 (66)
– 0.6	5.1 (79)	4.8 (74)	4.6 (71)	4.2 (65)	4.1 (63)
– 0.7	4.9 (76)	4.6 (71)	4.4 (68)	4.1 (63)	4.0 (61)
– 0.8	4.8 (74)	4.5 (69)	4.3 (66)	4.0 (61)	3.9 (60)
– 0.9	4.6 (71)	4.3 (66)	4.2 (65)	3.9 (60)	3.8 (59)
– 1.0	4.5 (69)	4.2 (65)	4.0 (62)	3.7 (57)	3.6 (56)

b. Maximum stress compressive

f_{min}/f_{max}	f_{max} in tonf/in^2 (N/mm^2) for number of cycles as below:				
	100 000	**600 000**	**2 000 000**	**10 000 000**	**100 000 000**
– 0.1	—	—	—	—	– 10 (– 150)
– 0.2	—	– 9.7 (– 150)	– 9.3 (– 140)	– 8.6 (– 130)	– 8.4 (– 130)
– 0.3	– 8.9 (– 140)	– 8.3 (– 130)	– 8.0 (– 120)	– 7.4 (– 110)	– 7.2 (– 110)
– 0.4	– 7.8 (– 120)	– 7.3 (– 110)	– 7.0 (– 110)	– 6.5 (– 100)	– 6.3 (– 97)
– 0.5	– 7.0 (– 110)	– 6.5 (– 100)	– 6.3 (– 97)	– 5.8 (– 90)	– 5.6 (– 86)
– 0.6	– 6.3 (– 97)	– 5.9 (– 91)	– 5.6 (– 86)	– 5.2 (– 80)	– 5.1 (– 79)
– 0.7	– 5.7 (– 88)	– 5.4 (– 83)	– 5.1 (– 79)	– 4.8 (– 74)	– 4.6 (– 71)
– 0.8	– 5.2 (– 80)	– 4.9 (– 76)	– 4.7 (– 73)	– 4.4 (– 68)	– 4.2 (– 65)
– 0.9	– 4.8 (– 74)	– 4.5 (– 69)	– 4.4 (– 68)	– 4.0 (– 61)	– 3.9 (– 60)
– 1.0	– 4.5 (– 69)	– 4.2 (– 65)	– 4.0 (– 62)	– 3.7 (– 57)	– 3.6 (– 56)

Table 40 — Relationship of maximum stress, stress ratio and number of cycles for class 3 members

a. Maximum stress tensile

f_{min}/f_{max}	f_{max} in tonf/in² (N/mm²) for number of cycles as below:				
	100 000	**600 000**	**2 000 000**	**10 000 000**	**100 000 000**
0.8	—	—	—	13 (200)	12 (190)
0.7	—	13 (200)	11 (170)	8.7 (130)	7.9 (120)
0.6	13 (200)	9.8 (150)	8.0 (120)	6.5 (100)	5.9 (91)
0.5	10 (150)	7.8 (120)	6.4 (99)	5.2 (80)	4.7 (73)
0.4	8.6 (130)	6.5 (100)	5.3 (82)	4.5 (69)	4.3 (66)
0.3	7.4 (110)	5.7 (88)	4.7 (73)	4.2 (65)	4.0 (62)
0.2	6.4 (99)	5.1 (79)	4.4 (68)	4.0 (62)	3.8 (59)
0.1	5.7 (88)	4.7 (73)	4.2 (65)	3.8 (59)	3.6 (56)
0.0	5.1 (79)	4.4 (68)	4.0 (62)	3.6 (56)	3.4 (53)
– 0.1	4.9 (76)	4.2 (65)	3.8 (59)	3.4 (53)	3.2 (49)
– 0.2	4.8 (74)	4.1 (65)	3.7 (57)	3.3 (51)	3.1 (48)
– 0.3	4.6 (71)	3.9 (60)	3.5 (54)	3.2 (49)	2.9 (45)
– 0.4	4.4 (68)	3.8 (59)	3.4 (53)	3.0 (46)	2.8 (43)
– 0.5	4.3 (66)	3.7 (57)	3.3 (51)	2.9 (45)	2.7 (42)
– 0.6	4.1 (63)	3.5 (54)	3.2 (49)	2.8 (43)	2.6 (40)
– 0.7	4.0 (62)	3.4 (53)	3.1 (48)	2.7 (42)	2.5 (39)
– 0.8	3.9 (60)	3.3 (51)	3.0 (46)	2.6 (40)	2.4 (37)
– 0.9	3.8 (59)	3.2 (49)	2.9 (45)	2.5 (39)	2.3 (36)
– 1.0	3.6 (56)	3.1 (48)	2.8 (43)	2.4 (37)	2.2 (34)

b. Maximum stress compressive

f_{min}/f_{max}	f_{max} in tonf/in² (N/mm²) for number of cycles as below:				
	100 000	**600 000**	**2 000 000**	**10 000 000**	**100 000 000**
0.2	—	—	—	– 14 (– 220)	– 14 (– 220)
0.1	—	– 14 (– 220)	– 13 (– 200)	– 10 (– 150)	– 9.7 (– 150)
0.0	– 12 (– 190)	– 10 (– 150)	– 9.6 (– 150)	– 7.9 (– 120)	– 7.4 (– 110)
– 0.1	– 9.8 (– 150)	– 8.5 (– 130)	– 7.7 (– 120)	– 6.5 (– 100)	– 6.0 (– 93)
– 0.2	– 8.3 (– 130)	– 7.1 (– 110)	– 6.5 (– 100)	– 5.5 (– 85)	– 5.1 (– 79)
– 0.3	– 7.1 (– 110)	– 6.1 (– 94)	– 5.5 (– 85)	– 4.7 (– 73)	– 4.3 (– 66)
– 0.4	– 6.3 (– 97)	– 5.4 (– 83)	– 4.9 (– 76)	– 4.2 (– 65)	– 5.8 (– 59)
– 0.5	– 5.6 (– 86)	– 4.8 (– 74)	– 4.3 (– 66)	– 3.7 (– 57)	– 3.4 (– 53)
– 0.6	– 5.1 (– 79)	– 4.3 (– 66)	– 3.9 (– 60)	– 3.4 (– 53)	– 3.1 (– 48)
– 0.7	– 4.6 (– 71)	– 3.9 (– 60)	– 3.5 (– 54)	– 3.1 (– 48)	– 2.8 (– 43)
– 0.8	– 4.2 (– 65)	– 3.6 (– 56)	– 3.3 (– 51)	– 2.8 (– 43)	– 2.6 (– 40)
– 0.9	– 3.9 (– 60)	– 3.3 (– 51)	– 3.0 (– 46)	– 2.6 (– 40)	– 2.4 (– 37)
– 1.0	– 3.6 (– 56)	– 3.1 (– 48)	– 2.8 (– 43)	– 2.4 (– 37)	– 2.2 (– 34)

Table 41 — Relationship of maximum stress, stress ratio and number of cycles for class 4 members

a. Maximum stress tensile

f_{min}/f_{max}	f_{max} in tonf/in^2 (N/mm^2) for number of cycles as below:				
	100 000	**600 000**	**2 000 000**	**10 000 000**	**100 000 000**
0.8	—	—	—	9.9 (150)	8.9 (140)
0.7	—	—	8.5 (130)	6.6 (100)	5.9 (91)
0.6	—	8.0 (120)	6.4 (99)	4.9 (76)	4.4 (68)
0.5	9.0 (140)	6.4 (99)	5.1 (79)	3.9 (60)	3.5 (54)
0.4	7.5 (120)	5.3 (82)	4.2 (65)	3.5 (54)	3.0 (46)
0.3	6.4 (99)	4.6 (71)	3.8 (59)	3.3 (51)	2.9 (45)
0.2	5.6 (86)	4.2 (65)	3.5 (54)	3.1 (48)	2.7 (42)
0.1	5.0 (77)	3.9 (60)	3.3 (51)	2.9 (45)	2.6 (40)
0.0	4.6 (71)	3.7 (57)	3.2 (49)	2.8 (43)	2.5 (39)
– 0.1	4.4 (68)	3.6 (56)	3.1 (48)	2.7 (42)	2.4 (37)
– 0.2	4.2 (65)	3.4 (53)	2.9 (45)	2.6 (40)	2.3 (36)
– 0.3	4.1 (63)	3.3 (51)	2.8 (43)	2.4 (37)	2.2 (34)
– 0.4	3.9 (60)	3.2 (49)	2.7 (42)	2.3 (36)	2.1 (32)
– 0.5	3.8 (59)	3.0 (46)	2.6 (40)	2.3 (36)	2.0 (31)
– 0.6	3.6 (56)	2.9 (45)	2.5 (39)	2.2 (34)	1.9 (29)
– 0.7	3.5 (54)	2.8 (43)	2.5 (39)	2.1 (32)	1.8 (28)
– 0.8	3.4 (53)	2.7 (42)	2.4 (37)	2.0 (31)	1.8 (28)
– 0.9	3.3 (51)	2.7 (42)	2.3 (36)	2.0 (31)	1.7 (26)
– 1.0	3.1 (48)	2.6 (40)	2.2 (34)	1.9 (29)	1.6 (25)

b. Maximum stress compressive

f_{min}/f_{max}	f_{max} in tonf/in^2 (N/mm^2) for number of cycles as below:				
	100 000	**600 000**	**2 000 000**	**10 000 000**	**100 000 000**
0.1	—	—	– 9.7 (– 150)	– 8.1 (– 130)	– 7.1 (– 110)
0.0	—	– 8.6 (– 130)	– 7.4 (– 110)	– 6.2 (– 96)	– 5.4 (– 83)
– 0.1	– 8.6 (– 130)	– 7.0 (– 110)	– 6.0 (– 93)	– 5.1 (– 79)	– 4.4 (– 68)
– 0.2	– 7.2 (– 110)	– 5.9 (– 91)	– 5.1 (– 79)	– 4.3 (– 66)	– 3.7 (– 57)
– 0.3	– 6.2 (– 96)	– 5.0 (– 77)	– 4.4 (– 68)	– 3.7 (– 57)	– 3.2 (– 49)
– 0.4	– 5.4 (– 83)	– 4.4 (– 68)	– 3.9 (– 60)	– 3.3 (– 51)	– 2.8 (– 43)
– 0.5	– 4.9 (– 76)	– 4.0 (– 62)	– 3.5 (– 54)	– 2.9 (– 45)	– 2.5 (– 39)
– 0.6	– 4.4 (– 68)	– 3.6 (– 56)	– 3.1 (– 48)	– 2.6 (– 40)	– 2.3 (– 36)
– 0.7	– 4.0 (– 62)	– 3.3 (– 51)	– 2.8 (– 43)	– 2.4 (– 37)	– 2.1 (– 32)
– 0.8	– 3.7 (– 57)	– 3.0 (– 46)	– 2.6 (– 40)	– 2.2 (– 34)	– 1.9 (– 29)
– 0.9	– 3.4 (– 53)	– 2.8 (– 43)	– 2.4 (– 37)	– 2.0 (– 31)	– 1.8 (– 28)
– 1.0	– 3.1 (– 48)	– 2.6 (– 40)	– 2.2 (– 34)	– 1.9 (– 29)	– 1.6 (– 25)

Table 42 — Relationship of maximum stress, stress ratio and number of cycles for class 5 members

a. Maximum stress tensile

f_{min}/f_{max}	f_{max} in tonf/in^2 (N/mm^2) for number of cycles as below:				
	100 000	**600 000**	**2 000 000**	**10 000 000**	**100 000 000**
0.8	—	—	—	8.7 (130)	7.6 (120)
0.7	—	9.5 (150)	7.5 (120)	5.8 (90)	5.1 (79)
0.6	—	7.2 (110)	5.6 (86)	4.4 (68)	3.8 (59)
0.5	8.2 (130)	5.7 (88)	4.5 (69)	3.5 (54)	3.0 (46)
0.4	6.8 (110)	4.8 (74)	3.7 (57)	3.0 (46)	2.7 (42)
0.3	5.9 (91)	4.1 (63)	3.3 (51)	2.8 (43)	2.5 (39)
0.2	5.1 (79)	3.7 (57)	3.1 (48)	2.6 (40)	2.3 (36)
0.1	4.6 (71)	3.4 (53)	2.9 (45)	2.5 (39)	2.2 (34)
0.0	4.2 (65)	3.3 (51)	2.8 (43)	2.3 (36)	2.1 (32)
– 0.1	4.0 (62)	3.2 (49)	2.7 (42)	2.2 (34)	2.0 (31)
– 0.2	3.8 (59)	3.0 (46)	2.6 (40)	2.1 (32)	1.9 (29)
– 0.3	3.7 (57)	2.9 (45)	2.5 (39)	2.0 (31)	1.8 (28)
– 0.4	3.6 (56)	2.8 (43)	2.4 (37)	1.9 (29)	1.7 (26)
– 0.5	3.4 (53)	2.7 (42)	2.3 (36)	1.9 (29)	1.6 (25)
– 0.6	3.3 (51)	2.6 (40)	2.3 (36)	1.8 (28)	1.6 (25)
– 0.7	3.2 (49)	2.5 (39)	2.2 (34)	1.7 (26)	1.5 (23)
– 0.8	3.1 (48)	2.5 (39)	2.1 (32)	1.7 (26)	1.5 (23)
– 0.9	3.0 (46)	2.4 (37)	2.1 (32)	1.6 (25)	1.4 (22)
– 1.0	2.9 (45)	2.3 (36)	2.0 (31)	1.5 (23)	1.3 (20)

b. Maximum stress compressive

f_{min}/f_{max}	f_{max} in tonf/in^2 (N/mm^2) for number of cycles as below:				
	100 000	**600 000**	**2 000 000**	**10 000 000**	**100 000 000**
0.2	—	—	—	– 9.5 (– 150)	– 8.7 (– 130)
0.1	—	– 9.7 (– 150)	– 8.4 (– 130)	– 6.7 (– 100)	– 5.9 (– 91)
0.0	– 9.7 (– 150)	– 7.6 (– 120)	– 6.5 (– 100)	– 5.1 (– 79)	– 4.5 (– 69)
– 0.1	– 7.9 (– 120)	– 6.2 (– 96)	– 5.3 (– 82)	– 4.2 (– 65)	– 3.6 (– 56)
– 0.2	– 6.6 (– 100)	– 5.2 (– 80)	– 4.5 (– 69)	– 3.5 (– 54)	– 3.0 (– 46)
– 0.3	– 5.7 (– 88)	– 4.5 (– 69)	– 3.8 (– 59)	– 3.0 (– 46)	– 2.6 (– 40)
– 0.4	– 5.0 (– 77)	– 4.0 (– 62)	– 3.4 (– 53)	– 2.7 (– 42)	– 2.3 (– 36)
– 0.5	– 4.5 (– 69)	– 3.5 (– 54)	– 3.0 (– 46)	– 2.4 (– 37)	– 2.1 (– 32)
– 0.6	– 4.0 (– 62)	– 3.2 (– 49)	– 2.7 (– 42)	– 2.1 (– 32)	– 1.9 (– 29)
– 0.7	– 3.7 (– 57)	– 2.9 (– 45)	– 2.5 (– 39)	– 2.0 (– 31)	– 1.7 (– 26)
– 0.8	– 3.4 (– 53)	– 2.7 (– 42)	– 2.3 (– 36)	– 1.8 (– 28)	– 1.6 (– 25)
– 0.9	– 3.1 (– 48)	– 2.5 (– 39)	– 2.1 (– 32)	– 1.7 (– 26)	– 1.5 (– 23)
– 1.0	– 2.9 (– 45)	– 2.3 (– 36)	– 2.0 (– 31)	– 1.5 (– 23)	– 1.3 (– 20)

Table 43 — Relationship of maximum stress, stress ratio and number of cycles for class 6 members

a. Maximum stress tensile

f_{min}/f_{max}	f_{max} in tonf/in^2 (N/mm^2) for number of cycles as below:				
	100 000	**600 000**	**2 000 000**	**10 000 000**	**100 000 000**
0.8	—	—	9.6 (150)	7.0 (110)	5.3 (82)
0.7	—	8.3 (130)	6.4 (99)	4.7 (73)	4.2 (65)
0.6	9.1 (140)	6.2 (96)	4.8 (74)	3.5 (54)	3.1 (48)
0.5	7.2 (110)	5.0 (77)	3.8 (59)	2.8 (43)	2.5 (39)
0.4	6.0 (93)	4.1 (63)	3.2 (49)	2.4 (37)	2.3 (36)
0.3	5.2 (80)	3.5 (54)	2.7 (42)	2.3 (36)	2.1 (32)
0.2	4.5 (70)	3.2 (49)	2.6 (40)	2.2 (34)	2.0 (31)
0.1	4.0 (62)	3.0 (46)	2.5 (39)	2.0 (31)	1.8 (28)
0.0	3.8 (59)	2.9 (45)	2.4 (37)	1.9 (29)	1.7 (26)
– 0.1	3.6 (56)	2.8 (43)	2.3 (36)	1.9 (29)	1.7 (26)
– 0.2	3.5 (54)	2.7 (42)	2.2 (34)	1.8 (28)	1.6 (25)
– 0.3	3.3 (51)	2.6 (40)	2.1 (32)	1.7 (26)	1.5 (23)
– 0.4	3.2 (49)	2.5 (39)	2.1 (32)	1.6 (25)	1.4 (22)
– 0.5	3.1 (48)	2.4 (37)	2.0 (31)	1.6 (25)	1.4 (22)
– 0.6	3.0 (46)	2.3 (36)	1.9 (29)	1.5 (23)	1.3 (20)
– 0.7	2.9 (45)	2.2 (34)	1.9 (29)	1.4 (22)	1.3 (20)
– 0.8	2.8 (43)	2.1 (32)	1.8 (28)	1.4 (22)	1.2 (19)
– 0.9	2.7 (42)	2.1 (32)	1.7 (26)	1.3 (20)	1.2 (19)
– 1.0	2.6 (40)	2.0 (31)	1.7 (26)	1.3 (20)	1.1 (17)

b. Maximum stress compressive

f_{min}/f_{max}	f_{max} in tonf/in^2 (N/mm^2) for number of cycles as below:				
	100 000	**600 000**	**2 000 000**	**10 000 000**	**100 000 000**
0.3	—	—	—	– 9.7 (– 150)	– 9.1 (– 140)
0.2	—	—	– 8.5 (– 130)	– 6.5 (– 100)	– 5.9 (– 91)
0.1	– 9.9 (– 150)	– 7.5 (– 120)	– 6.4 (– 99)	– 4.9 (– 76)	– 4.3 (– 66)
0.0	– 7.9 (– 120)	– 6.0 (– 93)	– 5.1 (– 79)	– 3.9 (– 60)	– 3.4 (– 53)
0.1	– 6.6 (– 100)	– 5.0 (– 77)	– 4.2 (– 65)	– 3.2 (– 49)	– 2.8 (– 43)
– 0.2	– 5.6 (– 86)	– 4.3 (– 66)	– 3.6 (– 56)	– 2.8 (– 43)	– 2.4 (– 37)
– 0.3	– 4.9 (– 76)	– 3.8 (– 59)	– 3.2 (– 49)	– 2.4 (– 37)	– 2.1 (– 32)
– 0.4	– 4.3 (– 66)	– 3.3 (– 51)	– 2.8 (– 43)	– 2.2 (– 31)	– 1.9 (– 29)
– 0.5	– 3.9 (– 60)	– 3.0 (– 46)	– 2.5 (– 39)	– 1.9 (– 29)	– 1.7 (– 26)
– 0.6	– 3.5 (– 54)	– 2.7 (– 42)	– 2.3 (– 36)	– 1.8 (– 28)	– 1.5 (– 23)
– 0.7	– 3.2 (– 49)	– 2.5 (– 39)	– 2.1 (– 32)	– 1.6 (– 25)	– 1.4 (– 22)
– 0.8	– 3.0 (– 46)	– 2.3 (– 36)	– 2.0 (– 51)	– 1.5 (– 23)	– 1.3 (– 20)
– 0.9	– 2.8 (– 43)	– 2.2 (– 34)	– 1.8 (– 28)	– 1.4 (– 22)	– 1.2 (– 19)
– 1.0	– 2.6 (– 40)	– 2.0 (– 31)	– 1.7 (– 26)	– 1.3 (– 20)	– 1.1 (– 17)

Table 44 — Relationship of maximum stress, stress ratio and number of cycles for class 7 members

a. Maximum stress tensile

f_{min}/f_{max}	f_{max} in tonf/in^2 (N/mm^2) for number of cycles as below:				
	100 000	**600 000**	**2 000 000**	**10 000 000**	**100 000 000**
0.8	—	—	8.1 (150)	5.7 (88)	5.0 (77)
0.7	—	7.2 (110)	5.4 (83)	3.8 (59)	3.3 (51)
0.6	8.1 (130)	5.4 (83)	4.1 (63)	2.9 (45)	2.5 (39)
0.5	6.5 (100)	4.3 (66)	3.2 (49)	2.3 (36)	2.0 (31)
0.4	5.4 (83)	3.6 (56)	2.7 (42)	2.0 (31)	1.9 (29)
0.3	4.6 (71)	3.1 (48)	2.3 (36)	1.9 (29)	1.7 (26)
0.2	4.1 (63)	2.9 (45)	2.2 (34)	1.8 (28)	1.6 (25)
0.1	3.6 (56)	2.7 (42)	2.1 (32)	1.7 (26)	1.5 (23)
0.0	3.4 (53)	2.5 (39)	2.0 (31)	1.6 (25)	1.4 (22)
– 0.1	3.3 (51)	2.4 (37)	1.9 (29)	1.5 (23)	1.3 (20)
– 0.2	3.1 (48)	2.3 (36)	1.8 (28)	1.4 (22)	1.3 (20)
– 0.3	3.0 (46)	2.2 (34)	1.8 (28)	1.4 (22)	1.2 (19)
– 0.4	2.9 (45)	2.1 (32)	1.7 (26)	1.3 (20)	1.2 (19)
– 0.5	2.8 (43)	2.0 (31)	1.6 (25)	1.3 (20)	1.1 (17)
– 0.6	2.6 (40)	1.9 (29)	1.6 (25)	1.2 (19)	1.1 (17)
– 0.7	2.6 (40)	1.9 (29)	1.5 (23)	1.2 (19)	1.0 (15)
– 0.8	2.5 (39)	1.8 (28)	1.5 (23)	1.1 (17)	1.0 (15)
– 0.9	2.4 (37)	1.8 (28)	1.4 (22)	1.1 (17)	0.93 (14)
– 1.0	2.3 (36)	1.7 (26)	1.4 (22)	1.0 (15)	0.90 (14)

b. Maximum stress compressive

f_{min}/f_{max}	f_{max} in tonf/in^2 (N/mm^2) for number of cycles as below:				
	100 000	**600 000**	**2 000 000**	**10 000 000**	**100 000 000**
0.3	—	—	—	7.7 (– 120)	– 6.6 (– 100)
0.2	—	– 8.4 (– 130)	– 7.0 (– 110)	– 5.2 (– 80)	– 4.4 (– 68)
0.1	– 8.5 (– 130)	– 8.3 (– 97)	– 5.2 (– 80)	– 3.9 (– 60)	– 3.3 (– 51)
0.0	– 6.8 (– 110)	– 5.1 (– 79)	– 4.2 (– 65)	– 3.1 (– 48)	– 2.7 (– 42)
– 0.1	– 5.7 (– 88)	– 4.3 (– 66)	– 3.5 (– 54)	– 2.6 (– 40)	– 2.2 (– 34)
– 0.2	– 4.9 (– 76)	– 3.6 (– 56)	– 3.0 (– 46)	– 2.2 (– 34)	– 1.9 (– 29)
– 0.3	– 4.3 (– 66)	– 3.2 (– 49)	– 2.6 (– 40)	– 2.0 (– 31)	– 1.7 (– 26)
– 0.4	– 3.8 (– 59)	– 2.8 (– 43)	– 2.3 (– 36)	– 1.7 (– 26)	– 1.5 (– 23)
– 0.5	– 3.4 (– 53)	– 2.5 (– 39)	– 2.1 (– 32)	– 1.6 (– 25)	– 1.3 (– 20)
– 0.6	– 3.1 (– 48)	– 2.3 (– 36)	– 1.9 (– 29)	– 1.4 (– 22)	– 1.2 (– 19)
– 0.7	– 2.9 (– 45)	– 2.1 (– 32)	– 1.7 (– 26)	– 1.3 (– 20)	– 1.1 (– 17)
– 0.8	– 2.6 (– 40)	– 2.0 (– 31)	– 1.6 (– 25)	– 1.2 (– 19)	– 1.0 (– 15)
– 0.9	– 2.5 (– 39)	– 1.8 (– 28)	– 1.5 (– 23)	– 1.1 (– 17)	– 1.0 (– 15)
– 1.0	– 2.3 (– 36)	– 1.7 (– 26)	– 1.4 (– 22)	– 1.0 (– 15)	– 0.90 (– 14)

Table 45 — Relationship of maximum stress, stress ratio and number of cycles for class 8 members

a. Maximum stress tensile

f_{min}/f_{max}	f_{max} in tonf/in^2 (N/mm^2) for number of cycles as below:				
	100 000	**600 000**	**2 000 000**	**10 000 000**	**100 000 000**
0.9	—	—	—	8.5 (130)	7.2 (110)
0.8	—	8.3 (130)	6.0 (93)	4.2 (65)	3.6 (56)
0.7	9.0 (140)	5.5 (85)	4.0 (62)	2.8 (43)	2.4 (37)
0.6	6.7 (100)	4.2 (65)	3.0 (46)	2.1 (32)	1.8 (28)
0.5	5.4 (83)	3.3 (51)	2.4 (37)	1.7 (26)	1.4 (22)
0.4	4.5 (69)	2.7 (42)	2.0 (31)	1.5 (23)	1.3 (20)
0.3	3.9 (60)	2.4 (37)	1.8 (28)	1.4 (22)	1.2 (19)
0.2	3.4 (53)	2.2 (34)	1.7 (26)	1.3 (20)	1.1 (17)
0.1	3.1 (49)	2.1 (32)	1.6 (25)	1.2 (19)	1.0 (15)
0.0	2.9 (45)	2.0 (31)	1.5 (23)	1.2 (19)	0.95 (15)
– 0.1	2.8 (43)	1.9 (29)	1.4 (22)	1.1 (17)	0.89 (14)
– 0.2	2.7 (42)	1.8 (28)	1.4 (22)	1.1 (17)	0.84 (13)
– 0.3	2.5 (39)	1.7 (26)	1.3 (20)	1.0 (15)	0.80 (12)
– 0.4	2.4 (37)	1.7 (26)	1.3 (20)	0.96 (15)	0.76 (12)
– 0.5	2.3 (35)	1.6 (25)	1.2 (19)	0.92 (14)	0.72 (11)
– 0.6	2.2 (34)	1.6 (25)	1.2 (19)	0.88 (14)	0.69 (11)
– 0.7	2.1 (32)	1.5 (23)	1.1 (17)	0.84 (13)	0.66 (10)
– 0.8	2.0 (31)	1.4 (22)	1.1 (17)	0.81 (13)	0.63 (9.7)
– 0.9	2.0 (31)	1.4 (22)	1.1 (17)	0.78 (12)	0.60 (9.3)
– 1.0	1.9 (29)	1.4 (22)	1.1 (17)	0.75 (12)	0.58 (9.0)

b. Maximum stress compressive

f_{min}/f_{max}	f_{max} in tonf/in^2 (N/mm^2) for number of cycles as below:				
	100 000	**600 000**	**2 000 000**	**10 000 000**	**100 000 000**
0.4	—	—	—	– 8.7 (– 130)	– 6.9 (– 110)
0.3	–	– 9.1 (– 140)	– 7.1 (– 110)	– 4.9 (– 76)	– 3.9 (– 60)
0.2	– 8.6 (– 130)	– 6.3 (– 97)	– 4.9 (– 76)	– 3.5 (– 54)	– 2.7 (– 42)
0.1	– 6.6 (– 100)	– 4.8 (– 74)	– 3.8 (– 59)	– 2.7 (– 42)	– 2.1 (– 32)
0.0	– 5.1 (– 79)	– 3.9 (– 60)	– 3.1 (– 49)	– 2.2 (– 34)	– 1.7 (– 26)
– 0.1	– 4.6 (– 71)	– 3.3 (– 51)	– 2.6 (– 40)	– 1.8 (– 28)	– 1.4 (– 22)
– 0.2	– 3.9 (– 60)	– 2.8 (– 43)	– 2.2 (– 34)	– 1.6 (– 25)	– 1.2 (– 19)
– 0.3	– 3.5 (– 54)	– 2.5 (– 39)	– 1.9 (– 29)	– 1.4 (– 22)	– 1.1 (– 17)
– 0.4	– 3.1 (– 49)	– 2.2 (– 34)	– 1.7 (– 26)	– 1.2 (– 19)	– 0.95 (– 15)
– 0.5	– 2.8 (– 43)	– 2.0 (– 31)	– 1.6 (– 25)	– 1.1 (– 17)	– 0.86 (– 13)
– 0.6	– 2.6 (– 40)	– 1.8 (– 28)	– 1.4 (– 22)	– 1.0 (– 15)	– 0.79 (– 12)
– 0.7	– 2.4 (– 37)	– 1.7 (– 26)	– 1.3 (– 20)	– 0.94 (– 15)	– 0.72 (– 11)
– 0.8	– 2.2 (– 34)	– 1.6 (– 25)	– 1.2 (– 19)	– 0.86 (– 13)	– 0.67 (– 10)
– 0.9	– 2.0 (– 31)	– 1.5 (– 23)	– 1.1 (– 17)	– 0.80 (– 12)	– 0.62 (– 9.6)
– 1.0	– 1.9 (– 29)	– 1.4 (– 22)	– 1.1 (– 17)	– 0.75 (– 12)	– 0.58 (– 9.0)

Table 46 — Relationship of maximum stress, stress ratio and number of cycles for class 9 members

a. Maximum stress tensile

f_{min}/f_{max}	f_{max} in tonf/in² (N/mm²) for number of cycles as below:				
	100 000	**600 000**	**2 000 000**	**10 000 000**	**100 000 000**
0.9	—	—	9.7 (150)	6.2 (96)	5.2 (80)
0.8	—	6.9 (110)	4.9 (76)	3.1 (48)	2.6 (40)
0.7	7.7 (120)	4.6 (71)	3.2 (49)	2.1 (32)	1.7 (26)
0.6	5.7 (88)	3.4 (53)	2.4 (37)	1.6 (25)	1.3 (20)
0.5	4.6 (71)	2.7 (42)	1.9 (29)	1.2 (19)	1.0 (15)
0.4	3.8 (59)	2.3 (36)	1.6 (25)	1.1 (17)	0.92 (14)
0.3	3.3 (51)	2.0 (31)	1.4 (22)	1.1 (17)	0.84 (13)
0.2	3.0 (46)	1.8 (28)	1.3 (20)	1.0 (15)	0.79 (12)
0.1	2.8 (43)	1.7 (26)	1.2 (19)	0.95 (15)	0.74 (11)
0.0	2.6 (40)	1.6 (25)	1.2 (19)	0.90 (14)	0.70 (11)
– 0.1	2.5 (39)	1.6 (25)	1.1 (17)	0.86 (13)	0.66 (10)
– 0.2	2.4 (37)	1.5 (23)	1.1 (17)	0.82 (13)	0.62 (9.6)
– 0.3	2.2 (34)	1.4 (22)	1.1 (17)	0.78 (12)	0.58 (9.0)
– 0.4	2.1 (32)	1.4 (22)	1.0 (15)	0.75 (12)	0.55 (8.5)
– 0.5	2.0 (31)	1.3 (20)	1.0 (15)	0.72 (11)	0.53 (8.2)
– 0.6	1.9 (29)	1.3 (20)	0.96 (15)	0.69 (11)	0.50 (7.7)
– 0.7	1.9 (29)	1.2 (19)	0.93 (14)	0.67 (10)	0.48 (7.4)
– 0.8	1.8 (28)	1.2 (19)	0.90 (14)	0.64 (9.9)	0.46 (7.1)
– 0.9	1.7 (26)	1.1 (17)	0.88 (14)	0.62 (9.6)	0.44 (6.8)
– 1.0	1.6 (25)	1.1 (17)	0.85 (13)	0.60 (9.3)	0.42 (6.5)

b. Maximum stress compressive

f_{min}/f_{max}	f_{max} in tonf/in² (N/mm²) for number of cycles as below:				
	100 000	**600 000**	**2 000 000**	**10 000 000**	**100 000 000**
0.4	—	—	– 8.3 (– 130)	– 5.9 (– 91)	– 4.2 (– 65)
0.3	—	– 6.4 (– 99)	– 5.1 (– 79)	– 3.6 (– 56)	– 2.5 (– 39)
0.2	– 7.2 (– 110)	– 4.7 (– 73)	– 3.7 (– 57)	– 2.5 (– 39)	– 1.8 (– 28)
0.1	– 5.6 (– 86)	– 3.7 (– 57)	– 2.9 (– 45)	– 2.0 (– 31)	– 1.4 (– 22)
0.0	– 4.6 (– 71)	– 3.1 (– 48)	– 2.4 (– 37)	– 1.6 (– 25)	– 1.2 (– 19)
– 0.1	– 3.9 (– 60)	– 2.6 (– 40)	– 2.0 (– 31)	– 1.4 (– 22)	– 0.99 (– 15)
– 0.2	– 3.4 (– 53)	– 2.3 (– 36)	– 1.7 (– 26)	– 1.2 (– 19)	– 0.86 (– 13)
– 0.3	– 3.0 (– 46)	– 2.0 (– 31)	– 1.5 (– 23)	– 1.0 (– 15)	– 0.76 (– 12)
– 0.4	– 2.7 (– 42)	– 1.8 (– 28)	– 1.4 (– 22)	– 0.94 (– 15)	– 0.68 (– 11)
– 0.5	– 2.4 (– 37)	– 1.6 (– 25)	– 1.2 (– 19)	– 0.85 (– 13)	– 0.62 (– 9.6)
– 0.6	– 2.2 (– 34)	– 1.5 (– 23)	– 1.1 (– 17)	– 0.79 (– 12)	– 0.56 (– 8.6)
– 0.7	– 2.0 (– 31)	– 1.4 (– 22)	– 1.0 (– 15)	– 0.73 (– 11)	– 0.52 (– 8.0)
– 0.8	– 1.9 (– 29)	– 1.3 (– 20)	– 0.97 (– 15)	– 0.68 (– 11)	– 0.48 (– 7.4)
– 0.9	– 1.8 (– 28)	– 1.2 (– 19)	– 0.91 (– 14)	– 0.64 (– 9.9)	– 0.45 (– 6.9)
– 1.0	– 1.6 (– 25)	– 1.1 (– 17)	– 0.85 (– 13)	– 0.60 (– 9.3)	– 0.42 (– 6.5)

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