

The structural use of aluminium

UDC 669.71:624.014.7

NO COPYING WITHOUT BSI PERMISSION EXCEPT AS PERMITTED BY COPYRIGHT LAW



Document Sharing Hub

Code drafting committee BLCP/55
Structural aluminium
(Secretariat: Institution of Structural Engineers^a)
Mr. S. R. Banks (*Chairman*)

Representing:

Mr. W. J. Meredith } Mr. G. E. Norris }	<i>Aluminium Federation</i>
Mr. G. Wood	<i>Association of Consulting Engineers</i>
Mr. P. Aldworth ^b	<i>British Standards Institution</i>
Mr. J. G. Young	<i>British Welding Research Association^d</i>
Dr. J. B. Menzies	<i>Building Research Station</i>
Mr. L. W. Gold ^c	<i>Greater London Council</i>
Mr. A. L. Hale	<i>Institute of Welding^d</i>
Mr. R. A. Foulkes (Vice Chairman)	<i>Institution of Civil Engineers</i>
Mr. S. R. Banks } Mr. L. P. Bowen } Mr. R. M. Davies } Mr. J. B. Dwight } Mr. J. W. Strong ^e }	<i>Institution of Structural Engineers</i>
Mr. R. J. Hancock	<i>Ministry of Public Building and Works</i>
Mr. A. W. Torry	<i>Royal Aeronautical Society</i>
Mr. F. S. Alexander	<i>Royal Institute of British Architects</i>
Mr. I. J. Philip	<i>Royal Institution of Chartered Surveyors</i>
Mr. W. A. W. Lankshear } Mr. R. McLester }	<i>Co-opted</i>

^a Transferred to the British Standards Institution in July, 1968.

^b Resigned in November, 1967 and replaced by Mr. J. J. Rendell.

^c Deceased August, 1967.

^d Became part of the Welding Institute in March, 1968.

^e Resigned in June, 1965 and replaced by Mr. J. H. Howlett.

The Committee is indebted to the following for valuable assistance in connection with certain sections of the Code: Mr. B.T.B. Baiden, Dr. P.S. Bulson, Mr. T.R. Gurney, Mr. J.R. Hall, Mr. W.L. Perry, Professor K.C. Rockey, Mr. R.E. Smith, Mr. G.H. Sowden, Dr. E.V. Tull and Dr. J.G. Whitman.

This Code of Practice has been prepared by a Committee convened by the Codes of Practice Committee for Building. It was published under the authority of the Executive Board on 18 June 1969

© BSI 11-1999

The following BSI references relate to the work on this Code of Practice:
Committee reference BLCP/55
Draft for comment 67/20192

ISBN 580 05520 5

Amendments issued since publication

Amd. No.	Date of issue	Comments
1129	March 1973	Indicated by a sideline in the margin

Contents

	Page
Foreword	v
1 General	1
1.1 Scope	1
1.2 Definitions and symbols	1
2 Materials	3
2.1 Designation of material	3
2.2 Selection of material	3
2.3 Relevant standards	5
2.4 Structural sections	6
2.5 Tolerances	7
3 Loading	7
3.1 General	7
3.2 Dead load	7
3.3 Live or imposed loads, and impact effects	7
3.4 Wind	8
3.5 Temperature	8
3.6 Other loads	8
4 Design	8
4.1 General	8
4.1.1 Factors affecting design	8
4.1.2 Design requirements	8
4.1.3 Permissible stresses	8
4.1.4 Combined stresses	12
4.1.5 Temperature limitations	13
4.1.6 Thicknesses	13
4.2 Ties	13
4.2.1 Axially loaded ties	13
4.2.2 Eccentrically loaded ties	13
4.3 Struts	14
4.3.1 Axially loaded struts	14
4.3.2 Eccentrically loaded struts	14
4.3.3 Torsional buckling	15
4.3.4 Battened struts	15
4.3.5 Laced struts	22
4.3.6 Welded struts	22
4.3.7 Maximum slenderness ratio	23
4.4 Beams	24
4.4.1 Beams in general: deflection	24
4.4.2 Beams in general: section properties	24
4.4.3 Beams in general: permissible stresses	25
4.4.4 Beams in general: lateral buckling	25
4.4.5 Beams in general: with end loads	30
4.4.6 Built-up beams: construction details	30
4.4.7 Built-up beams: permissible stresses	34
4.5 Thin plates, webs and flanges	40
4.5.1 Local buckling in compression	40
4.5.2 Shear buckling	42
4.5.3 Buckling due to bending, axial compression and shear	42
4.6 Joints	42

	Page
4.6.1 General	42
4.6.2 Bolted and riveted joints	42
4.6.3 Welded joints	44
4.6.4 Glued joints	46
4.6.5 Other joints	46
4.7 Fatigue	46
4.7.1 General	46
4.7.2 Loads and stresses	46
4.7.3 Permissible stresses	47
4.7.4 Classification of structural members	49
5 Testing	68
5.1 General	68
5.2 Static acceptance test	69
5.3 Fatigue acceptance test	70
6 Fabrication and erection	71
6.1 General	71
6.2 Bolting and riveting	72
6.3 Welding	72
6.4 Glued joints	74
6.5 Inspection and safety	74
7 Protection	75
7.1 Protection from environment	75
7.2 Painting	75
7.3 Metal spraying	77
7.4 Metal-to-metal contact surfaces, and bolted and riveted joints	77
7.5 Welded joints	79
7.6 Glued joints	79
7.7 Contact between aluminium and non-metallic materials	79
7.8 Protection against fire	80
Appendix A Nomenclature of aluminium products	81
Appendix B Foreign equivalents of U.K. aluminium alloys	83
Appendix C Supplementary alloys	84
Appendix D Derivation of permissible stresses	86
Appendix E Deduction for holes in members	89
Appendix F Torsional properties of thin-walled open sections	90
Appendix G Torsional buckling	100
Appendix H Lateral buckling of beams	102
Appendix J Stresses in webs of built-up beams	105
Appendix K Local buckling of channels and I-sections	105
Appendix L Design of welded joints	112
Appendix M Edge preparations for welded joints	116
Appendix N Tabulated stresses for fatigue	124
Figure 1 — Permissible compressive stresses in struts	10
Figure 2 — Permissible compressive stresses in beams and thin plates	11
Figure 3 — Values of k_t for plain channels	20
Figure 4 — Values of k_t for lipped channels	21
Figure 5 — Batten dimensions and spacing	23
Figure 6 — Permissible average shear stresses in unstiffened webs and thin plates	26
Figure 7 — Values of k_{lat} for I-sections and channels	28

	Page
Figure 8 — Values of k_{lat} for rectangular sections	29
Figure 9 — Optimum spacing of longitudinal stiffeners	33
Figure 10 — Permissible bending compressive stresses for webs in pure bending	36
Figure 11 — Buckling coefficient k_b for combined bending and axial compression	37
Figure 12 — Limiting ratios of compressive and shear stresses	38
Figure 13 — Permissible average shear stresses in stiffened webs	39
Figure 14 — Maximum and minimum stresses, and stress cycle	48
Figure 15 — Curves relating maximum stress, stress ratio and number of cycles for Class 1 members	50
Figure 16 — Curves relating maximum stress, stress ratio and number of cycles for Class 2 members	52
Figure 17 — Curves relating maximum stress, stress ratio and number of cycles for Class 3 members	54
Figure 18 — Curves relating maximum stress, stress ratio and number of cycles for Class 4 members	56
Figure 19 — Curves relating maximum stress, stress ratio and number of cycles for Class 5 members	58
Figure 20 — Curves relating maximum stress, stress ratio and number of cycles for Class 6 members	60
Figure 21 — Curves relating maximum stress, stress ratio and number of cycles for Class 7 members	62
Figure 22 — Curves relating maximum stress, stress ratio and number of cycles for Class 8 members	64
Figure 23 — Curves relating maximum stress, stress ratio and number of cycles for Class 9 members	66
Figure 24 — Form of compression buckling diagrams	88
Figure 25 — Choice of lines for deduction of holes	89
Figure 26 — Constants for torsion factor for certain fillets and bulbs	93
Figure 27 — Notation for calculating shear-centre position and warping factor	94
Figure 28 — Shear-centre position and warping factor for certain thin-walled sections	99
Figure 29 — Values of the interaction coefficient k	101
Figure 30 — Values of m for plain channels	106
Figure 31 — Values of m for plain I-sections	107
Figure 32 — Values of m for lipped channels	108
Figure 33 — Values of m for lipped I-sections	110
Table 1 — Properties of principal alloys	4
Table 2 — Bolt and rivet materials	5
Table 3 — Filler wire for inert-gas welding	7
Table 4 — Permissible stresses for principal alloys	9
Table 5 — Outstanding-leg deductions for single-bay ties	14
Table 6 — Effective lengths of struts	14
Table 7 — Values of λ_t for struts	16
Table 8 — Values of C_1 and C_2 for webs	25
Table 9 — Condition-of-restraint factor k_1	27
Table 10 — Bending-moment-shape factor k_2	30
Table 11 — Local buckling coefficient m	41
Table 12 — Permissible stresses for bolts and rivets	43

	Page
Table 13 — Hole clearances for bolts and rivets	44
Table 14 — Permissible stresses for welded joints and reduced-strength zones	45
Table 15 — Information for welding procedure	73
Table 16 — Mechanical test requirements for butt-weld procedure and welder approval	74
Table 17 — General protection of aluminium structures	76
Table 18 — Protection at joints of aluminium to aluminium	78
Table 19 — Protection at joints of aluminium to zinc or galvanized steel	78
Table 20 — Protection at joints of aluminium to steel, cast iron or lead	78
Table 21 — Protection at joints of aluminium to corrosion-resisting steel	79
Table 22 — Foreign equivalents of U.K. aluminium alloys	83
Table 23 — Properties of supplementary alloys	85
Table 24 — Permissible stresses for supplementary alloys	86
Table 25A — Specimen calculation of shear-centre position and warping factor	96
Table 25B — Specimen calculation of shear-centre position and warping factor	98
Table 26 — Condition-of-restraint factor k_1	103
Table 27 — Bending-moment-shape factor k_2	104
Table 28 — Cross-section-shape factor k_3	105
Table 29 — Illustrations of welded joints	113
Table 30 — Edge preparations for butt welds without backing bars	117
Table 31 — Edge preparations for butt welds with temporary backing bars	119
Table 32 — Recommended temporary-backing-bar dimensions	120
Table 33 — Edge preparations for butt welds with permanent backing bars	120
Table 34 — Edge preparations for corner welds without backing bars	121
Table 35 — Edge preparations for corner welds with temporary backing bars	122
Table 36 — Edge preparations for corner welds with permanent backing bars	123
Table 37 — Edge preparations for lap and fillet welds	124
Table 38 — Relationship of maximum stress, stress ratio and number of cycles for Class 1 members	125
Table 39 — Relationship of maximum stress, stress ratio and number of cycles for Class 2 members	126
Table 40 — Relationship of maximum stress, stress ratio and number of cycles for Class 3 members	127
Table 41 — Relationship of maximum stress, stress ratio and number of cycles for Class 4 members	128
Table 42 — Relationship of maximum stress, stress ratio and number of cycles for Class 5 members	129
Table 43 — Relationship of maximum stress, stress ratio and number of cycles for Class 6 members	130
Table 44 — Relationship of maximum stress, stress ratio and number of cycles for Class 7 members	131
Table 45 — Relationship of maximum stress, stress ratio and number of cycles for Class 8 members	132
Table 46 — Relationship of maximum stress, stress ratio and number of cycles for Class 9 members	132

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 3763¹⁾), the Code becomes substantially a metric document, the conversions (based on BS 350²⁾) 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.

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 1500-3³⁾ for pressure vessels, and BS 3989⁴⁾ 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 3660⁵⁾ 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
$f_{q \text{ av}}$	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
$p_{q\text{ av}}$	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 729⁶⁾. 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 1974⁷⁾) 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)	(2)	(3)	(3)
			Thickness mm from	to	0.2 % tensile proof stress N/mm ²	Tensile strength N/mm ²
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 √S ₀ 50 mm	(4)	(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
8 7	Same as tensile	118	618	68 900	23 × 10 ⁻⁶	2 710	B
8 —			587				
— 8			618				
— 8			556				
7 7							
— 9							
12 11	118	118	525	65 500	24.5 × 10 ⁻⁶	2 660	A
— —			556				
14 13	Same as tensile	118	386	65 500	23 × 10 ⁻⁶	2 710	B
14 12–16			324				
8 7	Same as tensile	118	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 ^{ab}	—	—	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 1161⁸⁾. 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 4300-1⁹⁾).

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-1¹⁰⁾. For other structures dead loads must be calculated from the unit weights given in BS 648¹¹⁾ 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-1¹⁰⁾ for recommended imposed loads and impact effects on buildings, and to BS 153-3A¹²⁾ 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/mm²

Small figures in parentheses refer to the Notes.

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

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.

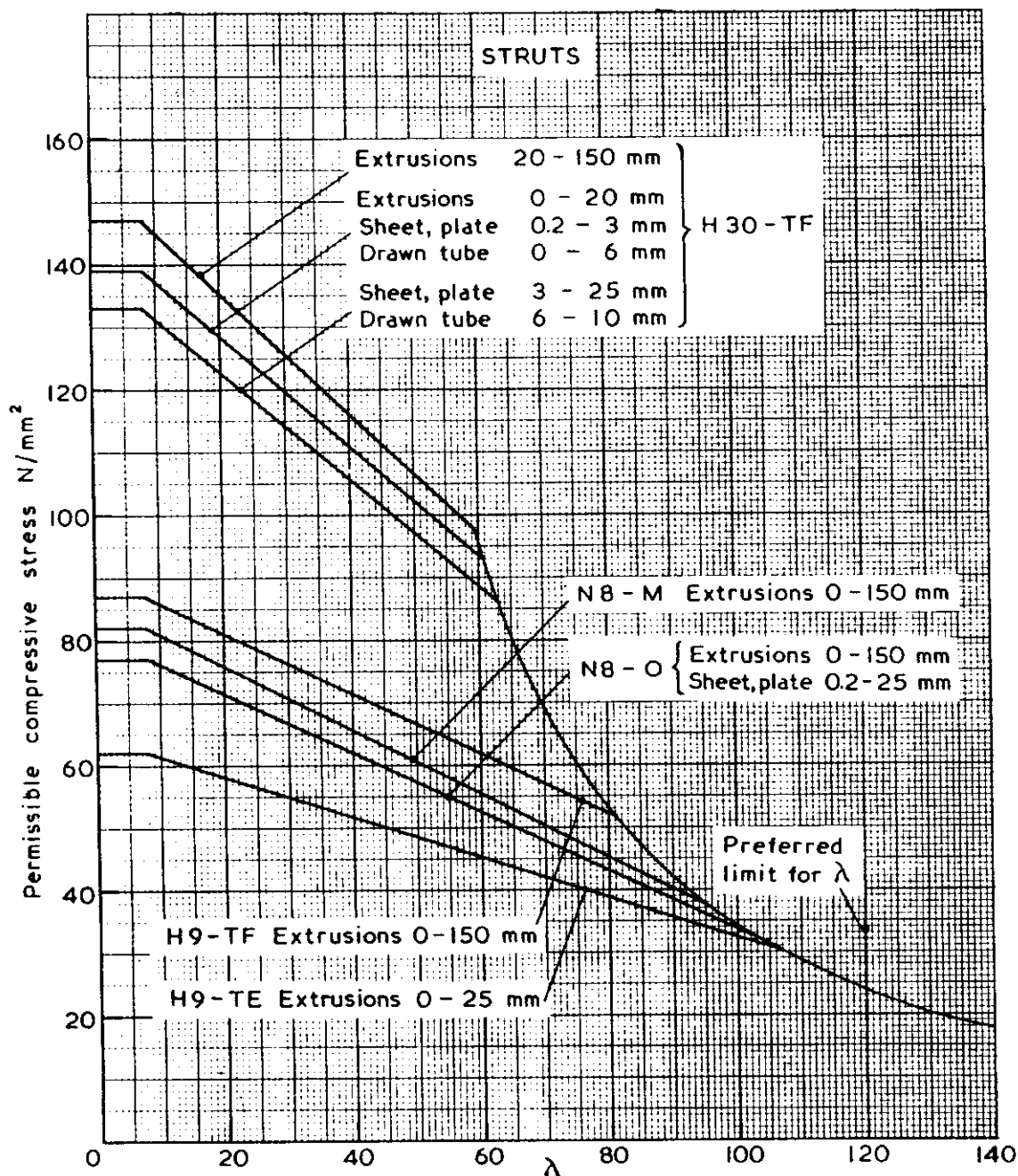
NOTE 3 Applies only when buckling is not the criterion: see 4.3, 4.4 and 4.5.

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.



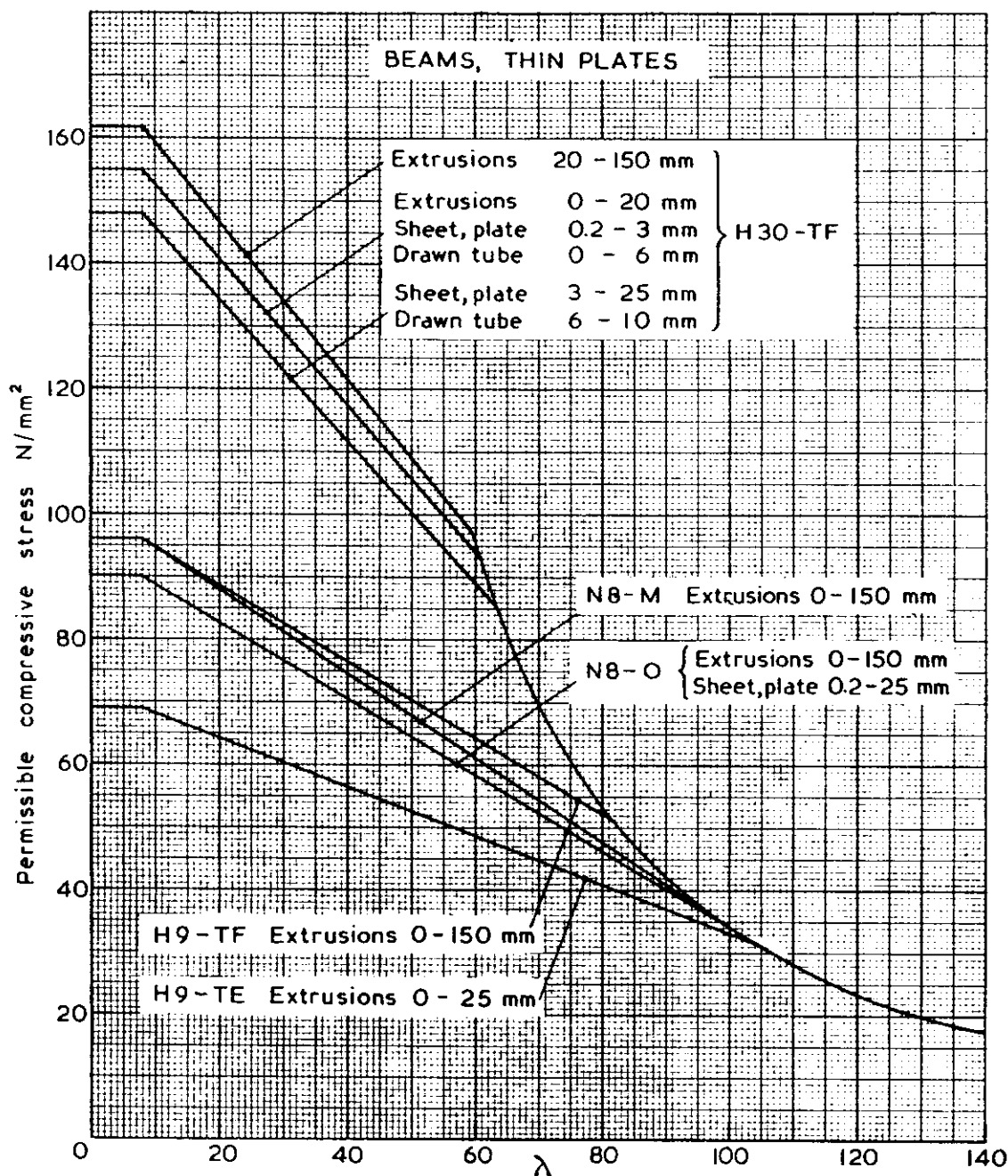
NOTE 1 The graphs do not apply to extruded round tube and hollow sections above 75 mm. thick.

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

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

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

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

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 $f_{eq} \leq 0.9$ 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 $f_{eq} \leq 0.9$ 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 $-330\text{ }^{\circ}\text{F}$ to $150\text{ }^{\circ}\text{F}$ ($-201\text{ }^{\circ}\text{C}$ to $66\text{ }^{\circ}\text{C}$).

4.1.5.2 High temperatures. In the design of structures whose temperature will consistently exceed $150\text{ }^{\circ}\text{F}$ ($66\text{ }^{\circ}\text{C}$) or which will ever exceed $200\text{ }^{\circ}\text{F}$ ($93\text{ }^{\circ}\text{C}$), 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 1500-3¹³⁾.

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 $4 \times 4 \times \frac{1}{2}$ in angle, $A = 1.75 \text{ in}^2$, and for a $100 \times 100 \times 10 \text{ mm}$ 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

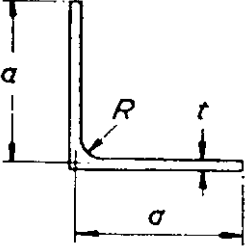
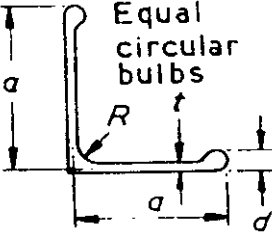
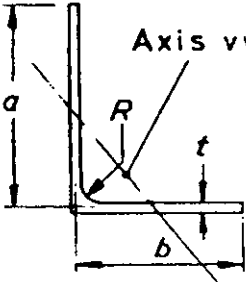
Section	Limits	Value of λ_t
	$\frac{R}{t} \leq 3$	$\frac{5.2 a}{t} - 1.3 \left(\frac{R}{t} \right)^2$
	$\frac{R}{t} \leq 3$ $\frac{d}{t} \leq 2.5$	$\frac{5.2 a}{t} - 1.3 \left(\frac{R}{t} \right)^2 - 2 \left(\frac{d}{t} - 1 \right)^3$ $+ 1.5 \left(\frac{d}{t} - 1 \right) \left(\frac{R}{t} \right)$
	$\frac{R}{t}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

Table 7 — Values of λ_t for struts

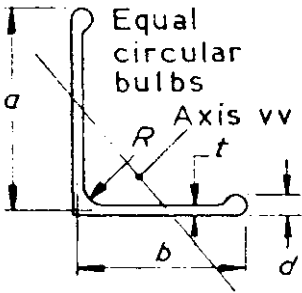
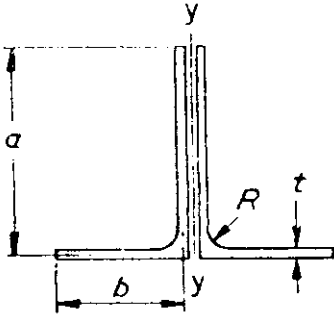
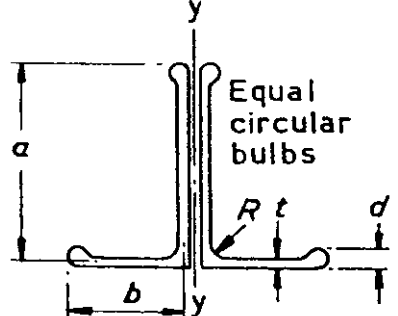
Section	Limits	Value of λ_t
 Equal circular bulbs Axis vv a b t R d	$\frac{R}{t} \leq 3$ $1 < \frac{a}{b} < 2$ $\frac{d}{t} \leq 2.5$	$\sqrt{\lambda_o^2 + \lambda_v^2} \sqrt{\frac{a}{b} - 1}$ where $\lambda_o = 2.6 \left(\frac{a+b}{t} \right) - 1.3 \left(\frac{R}{t} \right)^2$ $- 2 \left(\frac{d}{t} - 1 \right)^3 + 1.5 \left(\frac{d}{t} - 1 \right) \left(\frac{R}{t} \right)$ $\lambda_v = \frac{\ell}{r_v}$
 a b t R y	$R \leq 3$ $0.5 < \frac{a}{b} < 2$	$\sqrt{\lambda_o^2 + \lambda_y^2} \left(\frac{a}{2b} \right)$ where $\lambda_o = 1.9 \left(\frac{a+2b}{t} \right) - 1.3 \left(\frac{R}{t} \right)^2$ $\lambda_y = \frac{\ell}{r_y}$
 Equal circular bulbs a b t R d y	$\frac{R}{t} \leq 3$ $0.5 < \frac{a}{b} < 2$ $\frac{d}{t} \leq 2.5$	$\sqrt{\lambda_o^2 + \lambda_y^2} \left(\frac{a}{2b} \right)$ where $\lambda_o = 1.9 \left(\frac{a+2b}{t} \right) - 1.3 \left(\frac{R}{t} \right)^2$ $- 2 \left(\frac{d}{t} - 1 \right)^3 + 1.5 \left(\frac{d}{t} - 1 \right) \left(\frac{R}{t} \right)$ $\lambda_y = \frac{\ell}{r_y}$
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).		

Table 7 — Values of λ_t for struts

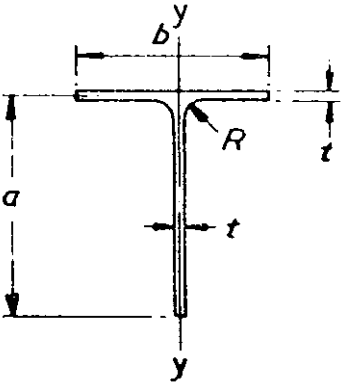
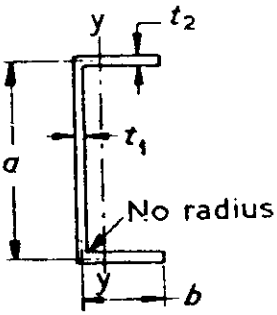
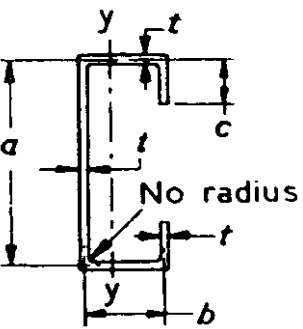
Section	Limits	Value of λ_t
	$\frac{R}{t} \leq 2$ $0.5 < \frac{a}{b} < 1$	$\sqrt{\lambda_o^2 + \lambda_y^2 \left(\frac{0.8 a}{b} \right)}$ where $\lambda_o = \left(\frac{3.2 a + b}{t} \right) - 2 \left(\frac{R}{t} \right)^2$ $\lambda_y = \frac{\ell}{r_y}$
	$R = 0$ $1 < \frac{a}{b} < 3$ $1 < \frac{t_2}{t_1} < 2$	$0.5 \left(\frac{k_t b}{t_1} + \lambda_y \right)$ where k_t is obtained from Figure 3 $\lambda_y = \frac{\ell}{r_y}$ The presence of small fillets ($R \leq 2 t$) has negligible effect on λ_t
	$R = 0$ $1 < \frac{a}{b} < 3$ $\frac{c}{a} \leq 0.3$	$0.5 \left(\frac{k_t b}{t} + \lambda_y \right)$ where k_t is obtained from Figure 4 $\lambda_y = \frac{\ell}{r_y}$ The presence of small fillets ($R \leq 2 t$) 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 $\frac{d}{t} \leq 2.5$	Torsional buckling may be ignored
Closed hollow section		Torsional buckling may be ignored
Others		See Appendix G

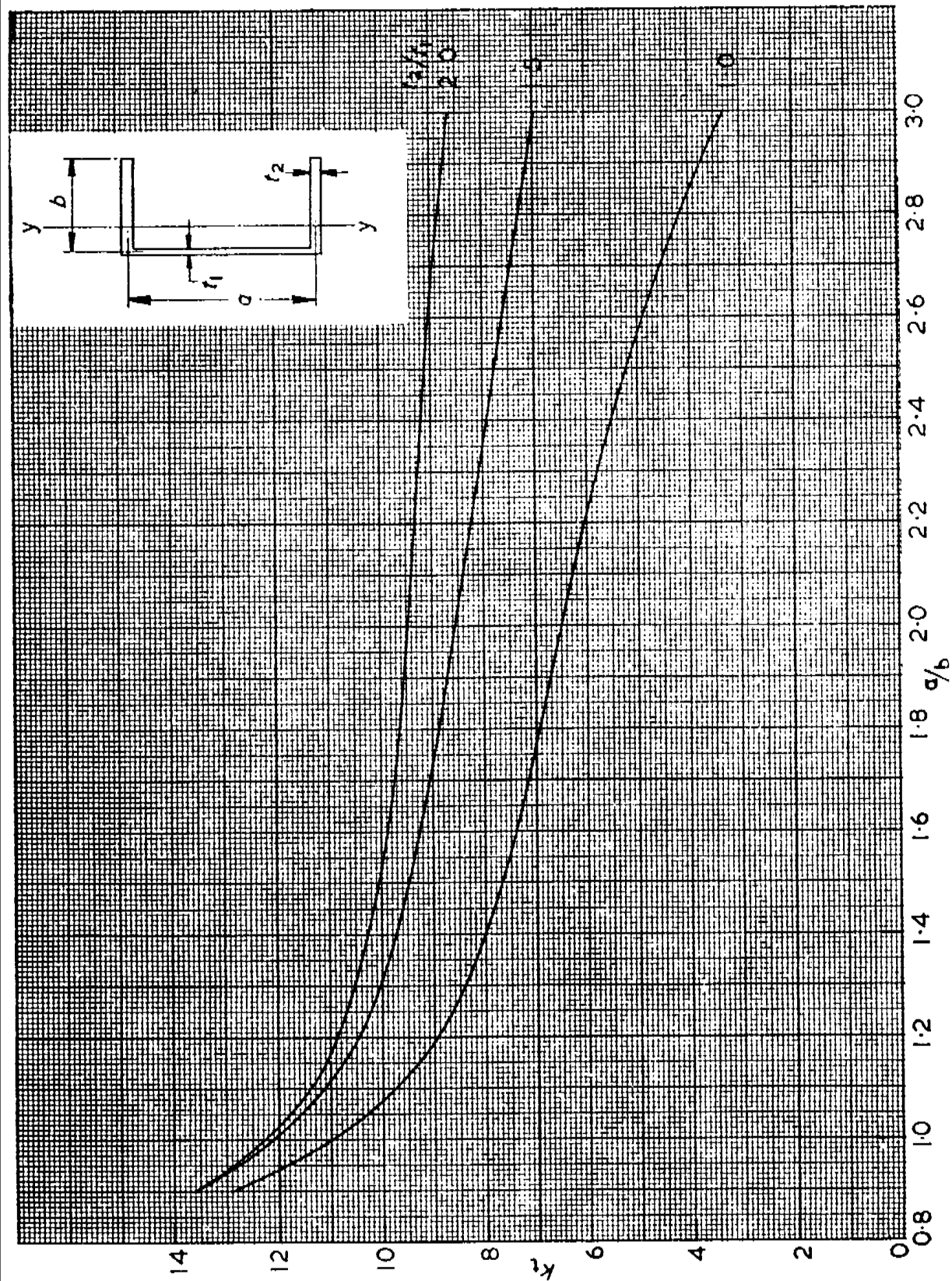
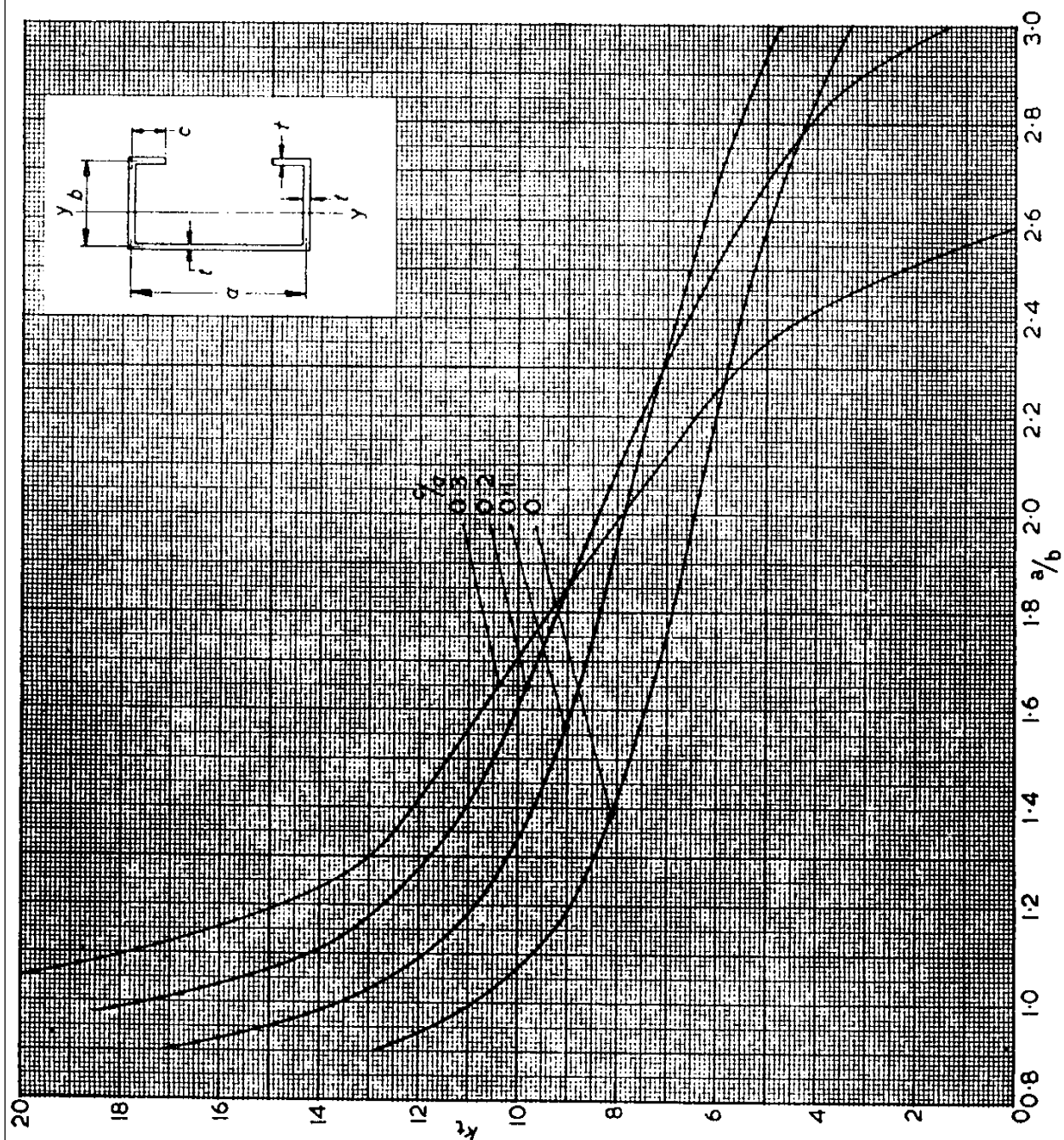


Figure 3 — Values of k_t for plain channels

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 research¹⁴⁾ and by testing.

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

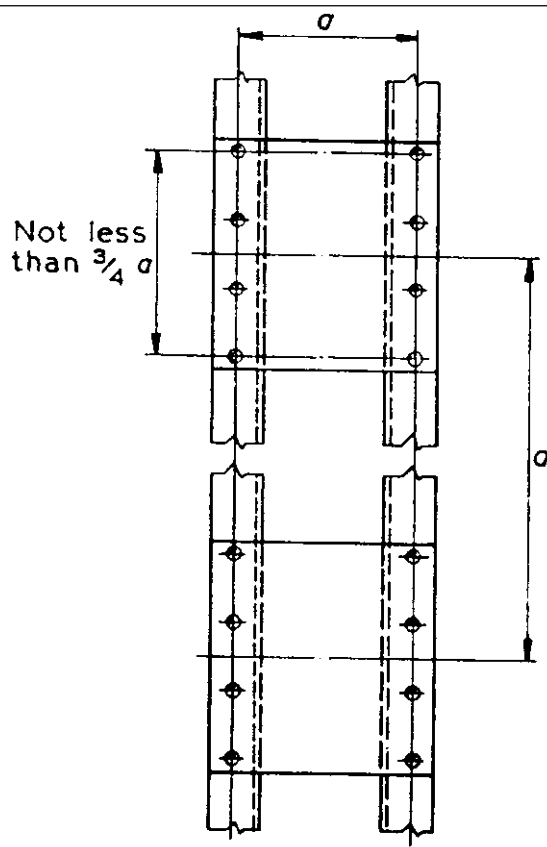


Figure 5 — Batten dimensions and spacing

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 $\lambda = 8$ 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 | $(\text{span, in})^2/11\,000 \text{ in}$
$(\text{span, mm})^2/280\,000 \text{ mm}$ |

For other members the limit of deflection, unless specified in an appropriate British Standard (e.g. BS 466¹⁵⁾), 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 } plate N8-M }	84	156
Others	$150/\sqrt{p_q}$ p_q in tonf/in ² $590/\sqrt{p_q}$ p_q in N/mm ²	$280/\sqrt{p_q}$ p_q in tonf/in 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.

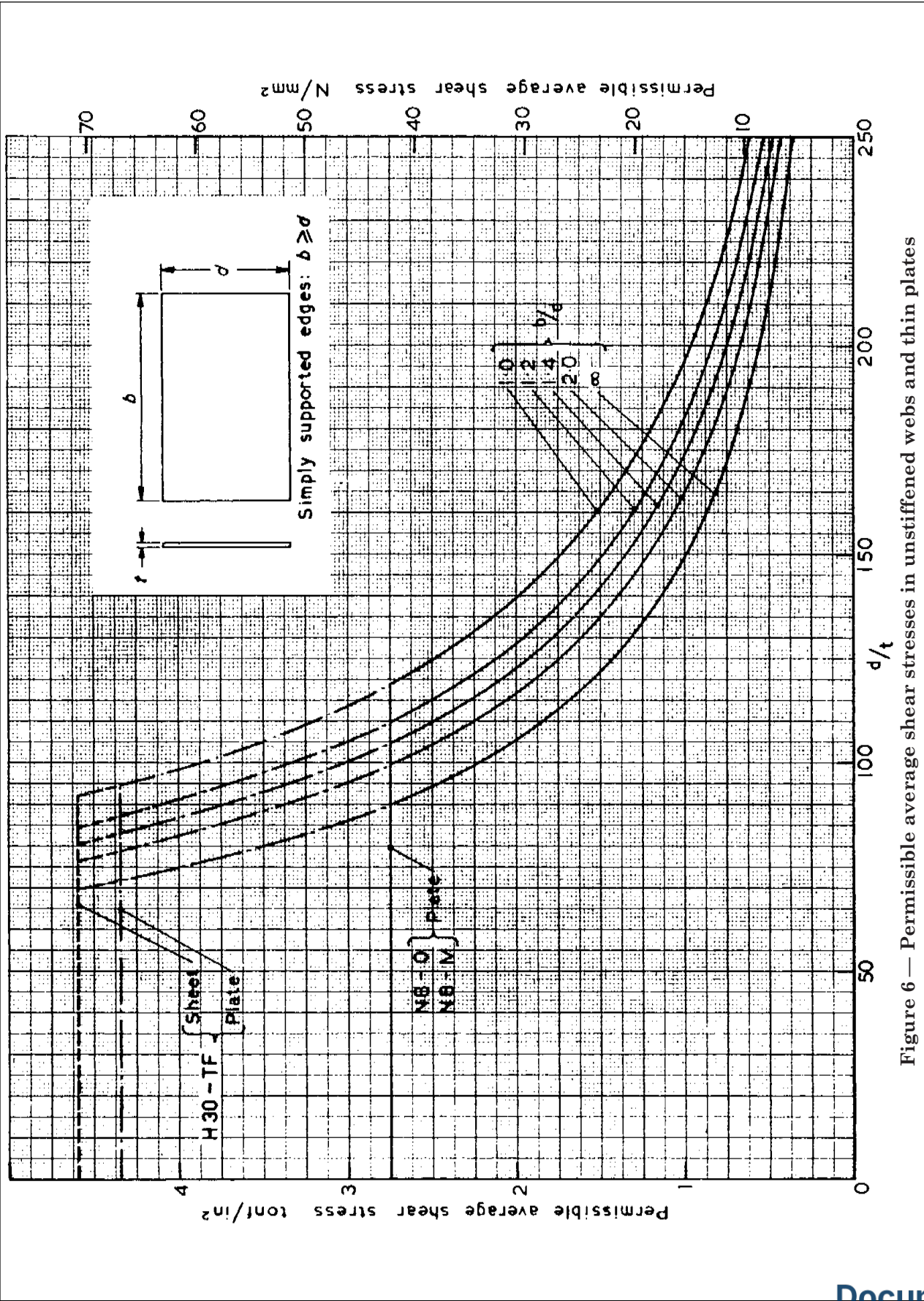


Figure 6 — Permissible average shear stresses in unstiffened webs and thin plates

3) *Other doubly-symmetrical sections.*

$$\lambda_{\text{lat}} = 2.3 \left\{ I_x (I_x - I_y) / J I_y \right\}^{1/4} (\ell_f / y)^{1/2},$$

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 analysis¹⁶⁾. 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.

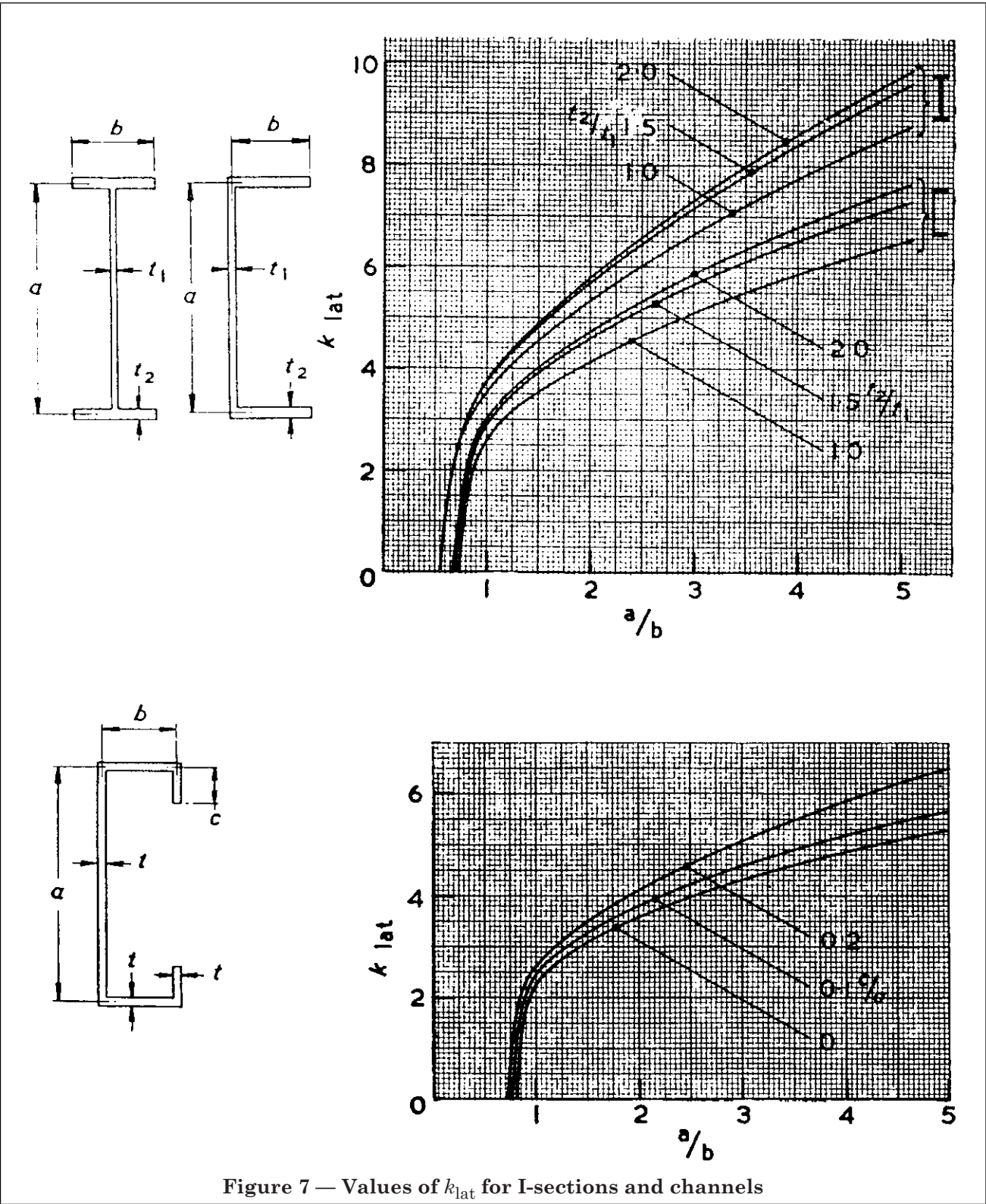


Figure 7 — Values of k_{lat} for I-sections and channels

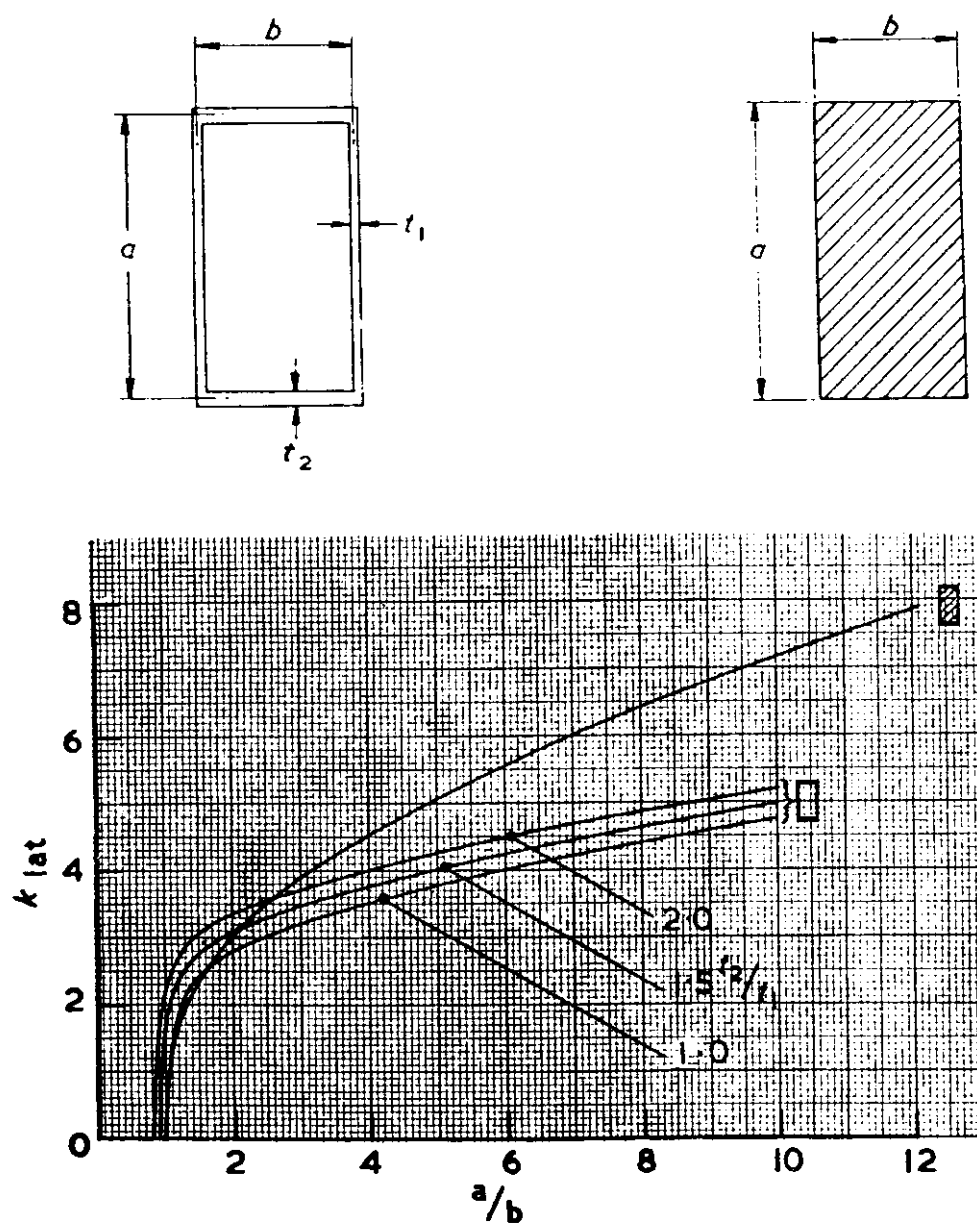
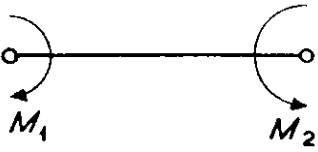
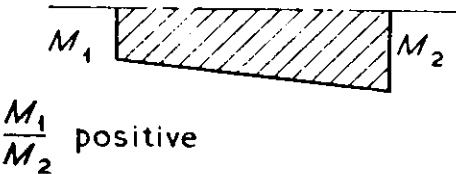
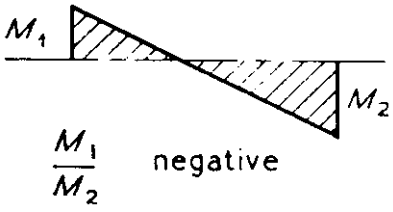


Figure 8 — Values of k_{lat} for rectangular sections

Table 10 — Bending-moment-shape factor k_2

Type of loading	Bending moment diagram between points of lateral support	k_2
	 $\frac{M_1}{M_2}$ positive	$\left(0.6 + 0.4 \frac{M_1}{M_2}\right)$ or 0.4, whichever is greater
	 $\frac{M_1}{M_2}$ negative	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

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

- 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

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

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

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

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 $f_{q\text{ av}}/f_1$ 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 $f_{q\text{ av}}$ 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 $4 dt^3$.

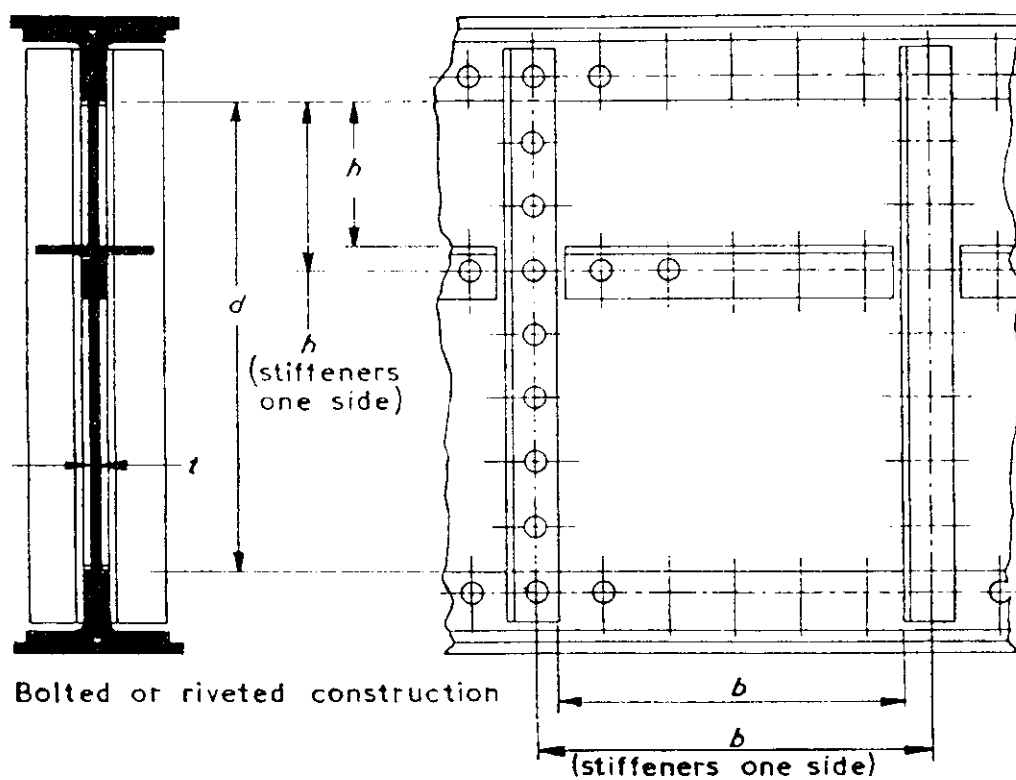
4.4.6.6 Thickness of transverse and longitudinal stiffeners. The outstanding leg of a plate stiffener or a web-attached angle stiffener must be such that the ratio of its width to thickness does not exceed 12, unless its outer edge is continuously stiffened by a bulb or lip of which the effect is to 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

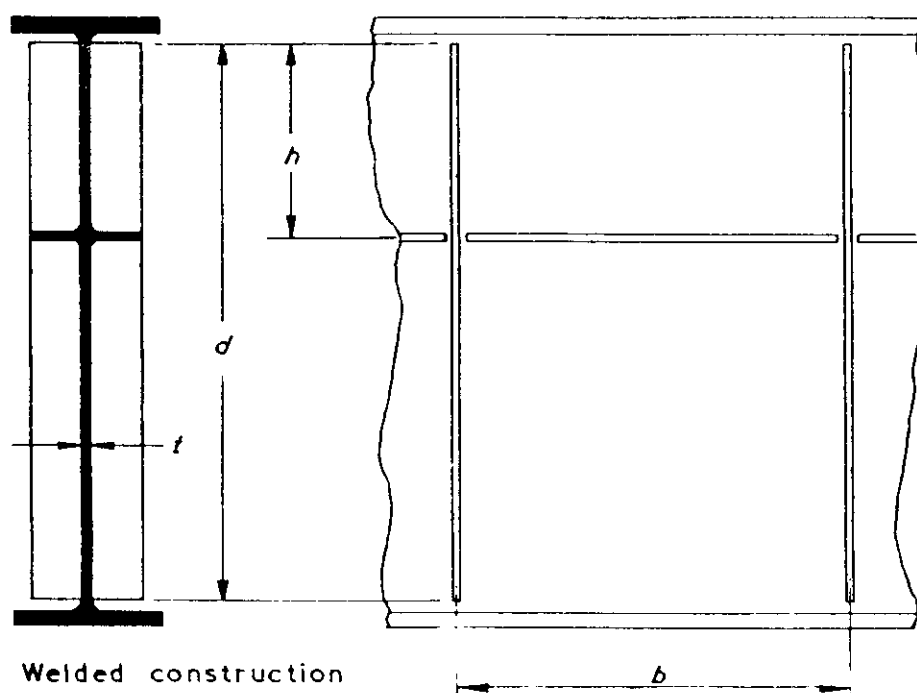
$$13.5 t_s^2 / t,$$

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

t is the thickness of the web.

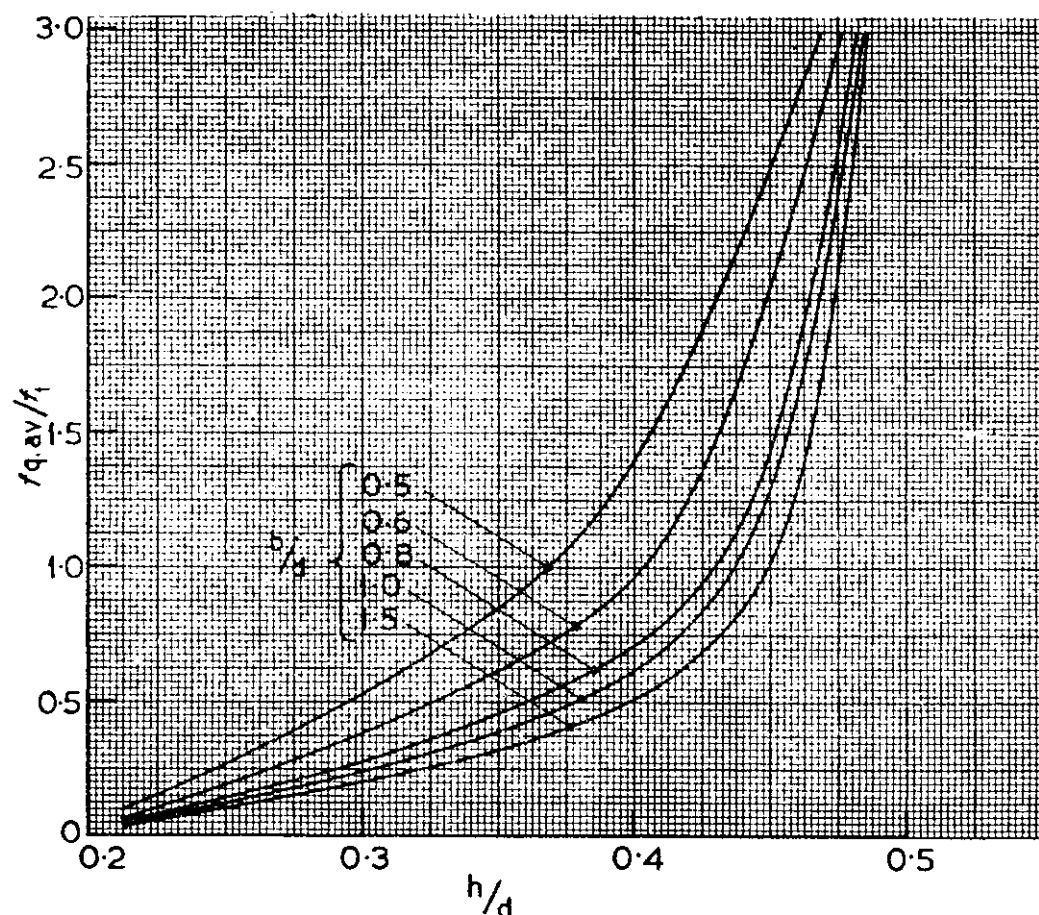


Bolted or riveted construction



Welded construction

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

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

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 ($d/t \leq C_1$ 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.