IS 8147 (1976): Code of Practice for Use of Aluminium Alloys in Structures [CED 7: Structural Engineering and structural sections]

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Indian Standard

CODE OF PRACTICE FOR USE OF ALUMINIUM ALLOYS IN STRUCTURES

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Indian Standard
CODE OF PRACTICE FOR USE OF ALUMINIUM ALLOYS IN STRUCTURES

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0. FOREWORD

0.1 This Indian Standard was adopted by the Indian Standards Institution on 3 June 1976, after the draft finalized by the Structural Engineering Sectional Committee had been approved by the Structural and Metals Division Council and Civil Engineering Division Council.

0.2 The code is intended to serve as a guide for the design and fabrication of aluminium alloys in all types of structures except bridges and pressure vessels.

0.3 The designations of alloys mentioned in this code are in accordance with the system prescribed in IS : 6051-1970*. The old designations of alloys which are still in use are given in parenthesis.

0.4 Although emphasis is laid on the more common alloys, namely 64430 (H30), 65032(H20), 63400(H9) and 54300(N8), classified as principal alloys, provision is made for design with the other alloys referred in various Indian Standards (*see* **4.4**), classified as secondary alloy and also with non-standard tempers and heat treatment conditions. This code does not preclude the use of non-standard alloys (that is, other than the principal and secondary alloys), but they should not be used without careful consideration of their relevant physical and chemical properties. Consultation with manufacturers is also essential. Example of such alloys are those of Al-Zn-Mg group which are heat-treatable and useful for use in structures by virtue of their having self-ageing properties whereby they regain their strength after welding.

0.5 Permissible stresses are based on internationally accepted 0·2 percent proof stress as a reference datum.

0.6 The behaviour of thin walled open sections in torsion and local buckling have been dealt with in detail. The general increase in static permissible stresses is supported by the inclusion of specific rules for the design of members subjected to fluctuating loads.

0.7 The protection of aluminium structures have been detailed in appropriate tables for various service environments.

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*Code designation of aluminium and its alloys.

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

0.9 Provision is made for the acceptance of a structure should stress analysis not be feasible. Tests more realistic than hitherto required are prescribed.

0.10 In this code, numerical values are given in both SI and metric units, the latter in paranthesis. It is proposed to changeover to SI units completely in the near future.

0.11 In the formulation of this code assistance has been derived from the following publications:

CSA Standard S 157-1969. The structural use of aluminium in buildings. Canadian Standards Association.

BS Code of practice CP 118 : 1969. The structural use of aluminium. British Standards Institution.

SECTION I GENERAL

1. SCOPE

1.1 This code of practice covers the use of structural aluminium alloys in all types of structures except for bridges and pressure vessels. It deals with the following alloys:

a) *Principal alloys* — 64430 (H30), 65032 (H20), 63400 (H9) and 54300 (N8)

b) *Secondary alloys* — 24345 (H15) 31000 (N3) 52000 (N4) and 53000 (N5)

1.2 The provisions of this code are generally applicable to rivetted, bolted and welded construction.

1.3 This code gives only general guidance as regards the various loads to be considered in design. For the actual values of loading to be used in the design, reference should be made to IS : 875-1964*.

2. TERMINOLOGY

2.1 For the purpose of this code, the definitions given in IS : 812-1957† and, IS : 5047 (Part I)-1969‡ and the following shall apply:

2.1.1 *Engineer* — The person responsible for the design and satisfactory completion of the structure, as covered by this code or a person authorized by him.

*Code of practice for structural safety of buildings: Loading standards (*revised*).

†Glossary of terms relating to welding and cutting of metals.

‡Glossary of terms for aluminium alloys: Part I Unwrought and wrought metals.

2.1.2 *Manufacturer* — The producer of the aluminium alloys extrusions, plate or other commodities.

2.1.3 *Strength Member* — A primary structural member designed to carry important and calculated loads.

2.1.4 *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 subsidary attachment like a ladder or a pipe-support (or a connection to such a part).

3. SYMBOLS

3.1 The following symbols together with those given in various clauses and appendices 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
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 heat-affected zone at weld
p_{wq}	Permissible shear stress in heat-affected zone at weld
p_{wt}	Permissible tensile stress in heat-affected 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
$\lambda = \frac{l}{r}$	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_g	Slenderness ratio at junction of straight line and hyperbola
λ_t	Slenderness ratio for pure torsional buckling

4. MATERIALS

4.1 General — The material shall have the chemical composition, condition and mechanical properties as specified in the relevant clauses of Indian standard specifications given in **4.4.1**.

4.2 Designation of Material

4.2.1 The designations of material used in this code are in accordance with the system specified in IS : 6051-1970*. Guidelines in nomenclature of various alloys are given in Appendix A. Foreign standard equivalents of these alloys are given in Appendix B for information.

4.2.2 *Durability Rating* — In order to formulate rules for the protection of aluminium structures durability rating according to environments are given in Table 18 to 22.

4.3 Selection of Material

4.3.1 *Principal Alloys* — The four 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 frame structures, 64430 WP (H30 WP) is the normal choice on the ground of strength, durability and economy; it is supplied as plates, extruded sections (both solid and hollow) sheet, tube and forgings. It is weldable but with considerable reduction of strength near the welds.

The alloy 65032 (H20) is a medium strength alloy and has similar applications as 64430 (H30) in general structures.

The alloy 63400 (H9) combines moderate strength with high durability and a good surface finish that response well to anodizing. Like 64430 (H30) it also loses parts of its strength on welding.

The alloy 54300 (N8) is highly durable and strong for welded structures and platework. It shows less reduction in strength after welding.

4.3.2 *Secondary Alloys* — Four other alloys often used in general and structural engineering are described and listed with their properties in Appendix C.

4.3.3 *Alloys with Non-standard Properties* — The alloys referred in **4.3.2** and **4.3.1** are sometimes used in non-standard tempers and condition (*see* **7.4.3**).

4.3.4 *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.

4.3.4.1 One of the important alloys under this category is a newly introduced alloy 74530 which is Al-Zn-Mg alloy. It is available in plates or extrusion and combines good strength and weldability. Its properties of natural ageing confers the advantage of recovery of strength after welding.

*Code for designation of aluminium and its alloys.

TABLE 1 PROPERTIES OF PRINCIPAL ALLOYS

(*Clause* 4.3.1)

Alloy	Condition*	Form*	Thickness*† mm From	Thickness*† mm To	0·2 Percent Tensile Proof Stress‡ N/mm² (kgf/mm²)	Tensile Strength‡ N/mm² (kgf/mm²)	Elongation‡ Percent on 50 mm	0·2 Percent Compressive Proof Stress§ N/mm² (kgf/mm²)	Bearing Strength§ N/mm² (kgf/mm²)	Modulus of Elasticity¶ N/mm² (kgf/mm²)	Coefficient Linear Expansion‖ Per °C	Density kg/m³	Durability Rating**
(1)	(2)	(3)	(4)		(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
64430 (H30)	WP	Extrusion	—	6·3	255 (26·0)	295 (30·1)	7	255 (26·0)	618 (63·0)	68900 (7025)	23×10^{-6}	2 710	B
			6·3	150††	270 (27·5)	310 (31·6)		270 (27·5)					
		Sheet, plate	—	6·3	250 (25·4)	295 (30·1)	8	250 (25·4)	587 (59·8)				
			6·3	25	240 (24·4)	285 (29·1)		240 (24·4)					
		Drawn tube	—	1·6	250 (25·4)	310 (31·6)	7	250 (25·4)	618 (63·0)				
			1·6	10	240 (24·4)	285 (29·1)	9	240 (24·4)					
65032 (H20)	WP	Extrusion	—	150††	235 (24·0)	280 (28·5)	7	235 (24·0)	556 (56·6)	68900 (7025)	24×10^{-6}	2 710	B
		Sheet, plate	—	6·3			5						
			6·3	25			8						
63400 (H9)	WP	Extrusion	—	150	155 (15·8)	190 (19·4)	7	155 (15·8)	386 (39·4)	65500 (6680)	23×10^{-5}	2 710	B
	P		—	3·15	140 (14·3)	175 (17·8)		140 (14·3)	324 (33·0)				
			3·15	12·5	110 (11·2)	155 (15·8)		110 (11·2)					
54300 (N8)	M	Extrusion	—	150††	130 (13·2)	275 (28·0)	11	130 (13·2)	556 (56·6)	68900 (7025)	$24·5 \times 10^{-6}$	2 660	A
		Plate	6·3	25	125 (12·7)	280 (28·5)	12	125 (12·7)					
	O	Extrusion	—	150††	130 (13·2)	280 (28·5)	13	118	525 (53·3)				
		Sheet, plate	—	6·3	130 (13·2)	265 (27·0)	12-16		556 (56·6)				
			6·3	25	115 (11·7)	270 (27·6)	16						

*For other condition, forms and thickness, refer relevant Indian Standard, (*see* **4.4.1**).

†Each thickness range includes its upper limits.

‡Specifies minimum values.

§Minimum expected value (*see* Appendix F).

¶For modulus of risidity multiply by 0·38.

‖Applies to range 20°C to 100°C.

***See* **4.2.2.**

††For round tube and hollow sections the properties do not apply above 75 mm.

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However, this material is susceptible to stress corrosion and its satisfactory performance is dependent on correct method of fabrication and manufacturer. It is essential that there should be direct collaboration between engineer and manufacturer concerning the extent of use and the likely service condition.

4.3.5 *Bolts and Rivets* — Table 2 gives the common bolt and rivet material 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* **13.4**). Steel bolts shall be galvanized, cadmium plating may, however be specified for steel bolts for important connections. Alloy 24345-WP (H 15-WP) bolts with anodized finish may be used for improved resistance to corrosion. Rivets of alloys 64430-WP (H 30-WP) and 24345-W (H 15-W) are more readily driven immediately after solution heat-treatment. The period before driving may be extended by cold storage.

4.3.6 *Filler Wire* — Filler wires for inert-gas tungston-arc and metal-arc welding shall be as given in Table 3. For welds between dissimilar alloys, the advice of the manufacturer shall be sought.

4.4 Relevant Standard Specifications

4.4.1 Section plates, sheets and other forms shall comply with the following Indian Standards as appropriate:

IS : 733-1975 Wrought aluminium and aluminium alloys, bars, rods and sections (for general engineering purposes) (*second revision*).

IS : 734-1975 Wrought aluminium and aluminium alloys, forging stock and forgings (for general engineering purposes) (*second revision*).

IS : 736-1974 Wrought aluminium and aluminium alloys, plate (for general engineering purposes) (*second revision*).

IS : 737-1974 Wrought aluminium and aluminium alloys, sheet and strip (for general engineering purposes) (*second revision*).

IS : 738-1966 Wrought aluminium and aluminium alloys, drawn tube (for general engineering purposes) (*revised*).

IS : 739-1966 Wrought aluminium and aluminium alloys, wire (for general engineering purposes) (*revised*).

IS : 740-1966 Wrought aluminium and aluminium alloys, rivet stock (for general engineering purposes) (*revised*).

IS : 1284-1975 Wrought aluminium alloys, bolt and screw stock (for general engineering purposes) (*second revision*).

IS : 1285-1975 Wrought aluminium and aluminium alloys, extruded round tube and hollow sections (for general engineering purposes) (*second revision*).

TABLE 2 BOLT AND RIVET MATERIALS

(*Clause* 4.3.5)

Item	Material	Process	Alloys Joined		Durability Rating
			Principal	Secondary	
Bolts	64430-WP (H30-WP)	—	All	All except 24345 (H15)	Same as alloys joined
			—	24345 (H15)	C
	24345-WP*† (H15-WP)	—	—	24345 (H15)	C
	Steel†	—	All	All except 24345 (H15) outdoors	‡
	Corrosion resisting steel	—	All	All	
Rivets	64430-W* (H30-W)	Cold driven	All	All except 24345 (H15)	Same as alloys joined
	24345-W* (H15-W)		—	24345 (H15)	C
	53000-0 (N5-0)	Cold driven	All	All except 24345 (H15)	Same as alloys joined
		Hot driven			
	Steel	Cold driven	All	All	‡
		Hot driven	All	All except 24345 (H15)	

*See 9.2.1.
†See 4.3.5.
‡See 21.

TABLE 3 FILLER RODS OR WIRES FOR INERT GAS WELDING

(*Clause* 4.3.6)

PARENT ALLOY	FILLER WIRE (In Order of Preference)	DURABILITY RATING OF ASSEMBLY
63400, 64430, 65032	NG 21, NG 6	B
54300	NG 6	A
31000	NG 3 (NG 21, NG 6)*	A
52000, 53000	NG 6	A

NOTE — When welded assemblies in 63400, 64430 or 65032 are to be subsequently anodized, NG 6 filler wire should be used, to obtain optimum colour match between weld and parent metal.

*NG 21 or NG 6 should be used if conditions are non-corrosive.

4.4.2 *Bolts* — Aluminium and steel bolts shall comply with the following Indian Standards as appropriate:

IS : 730-1971 Fasteners for corrugated sheet roofing (*revised*).

IS : 1363-1967 Black hexagon bolts, nuts and lock nuts (dia 6 to 39 mm) and black hexagon screws (dia 6 to 24 mm) (*first revision*).

IS : 1364-1967 Precision and semi-precision hexagon bolts, screws nuts and lock huts (dia range 6 to 39 mm) (*first revision*).

IS : 2389-1968 Precision hexagon bolts, screws, nuts and lock nuts (dia range 1·6 to 5 mm) (*first revision*).

IS : 2585-1968 Black square bolts and nuts (dia range 6 to 39 mm) and black square screws (dia range 6 to 24 mm) (*first revision*).

IS : 4218-1967 ISO metric screw threads

IS : 6113-1967 Aluminium fasteners for building purposes.

4.4.3 *Rivets* — Aluminium and steel solid rivets shall comply with the following Indian Standards as appropriate:

IS : 1929-1961 Rivets for general purposes (12 to 48 mm diameter).

IS : 2155-1962 Rivets for general purposes (below 12 mm diameter).

IS : 2998-1965 Cold forged steel rivets for cold closing.

4.4.4 *Filler Wire for Welding* — Filler wire for welding shall comply with IS : 1278-1972* and IS : 5897-1970†.

*Specification for filler rods and wires for gas welding (*first revision*).

†Specification for aluminium alloy welding rods and wires and magnesium alloy welding rods.

4.4.5 *Forging and Casting* — Forging and casting shall comply with IS : 734-1967* and IS : 617-1959† respectively.

4.5 Structural Sections

4.5.1 *General* — Aluminium structural sections are normally produced by extrusion. The low cost of die gives great flexibility in producing a large variety of sections.

4.5.2 *Standard Extruded Sections*

4.5.2.1 The following Indian Standards may be referred for properties of various angles, beams and channels. Larger sections than those covered by these standards may be obtained by arrangement with the manufacturer.

IS : 3908-1966	Aluminium equal leg angles
IS : 3909-1966	Aluminium unequal leg angles
IS : 3921-1966	Aluminium channels
IS : 5384-1969	Aluminium I-beams
IS : 6445-1971	Aluminium tee sections
IS : 6449-1971	Aluminium bulb angles for marine use
IS : 6475-1971	Aluminium tee bars for marine use
IS : 6476-1971	Aluminium bulb plates for marine use.

4.5.2.2 The stability of thin walled sections is improved by enlarging the root fillet and reinforcing the tees with bulbs or tips.

4.5.3 *Non-standard Extruded Section* — 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 manufactured.

4.5.4 *Hollow Sections* — Box sections, twin web beams and many other hollow sections are available.

4.5.5 *Tubes* — Tubular sections, not necessarily circular, are produced by extrusion or, alternatively by cold-drawing from comparatively thick walled extrusion blooms.

4.5.6 *Special Sections* — It is often advantageous to design special extruded sections for a particular structures in order to obtain more economical design and fabrication.

4.5.7 *Sections Formed from Sheet* — It is sometimes advantageous to employ sections formed from sheet or strip by roll-forming or by bending.

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*Wrought aluminium and aluminium alloys, forging stock and forgings (for general engineering purposes) (*first revision*).

†Aluminium and aluminium alloy ingots and castings for general engineering purposes (*revised*).

4.6 Manufacturing Tolerances — Weight and dimensional tolerances of all products including rivets bolts, nuts etc used in structures shall conform to the latest appropriate Indian Standards.

5. PLANS AND DRAWINGS

5.1 Plans, drawings and stress sheets shall be prepared according to IS : 696-1972* and IS : 962-1967†.

5.1.1 *Plans* — The plans (design drawings) shall show the complete design with sizes, sections, and the relative locations of the various members. Floor levels, column centres, and offsets shall be dimensioned. Plans shall be drawn to a scale large enough to convey the information adequately. Plans shall indicate the type of construction to be employed; and shall be supplemented by such data on the assumed loads, shears, moments and axial forces to be resisted by all members and their connections, as may be required for the proper preparation of shop drawings.

5.1.2 *Shop Drawings* — Shop drawings, giving complete information necessary for the fabrication of the component parts of the structure including the location, type, size, length and detail of all welds, shall be prepared in advance of the actual fabrication. They shall clearly distinguish between shop and field rivets, bolts and welds. For additional information to be included on drawings for designs based on the use of welding, reference shall be made to the appropriate Indian Standards. Shop drawings shall be made in conformity with the best modern practice, with due regard to speed and economy in fabrication and erection. A marking diagram allotting distinct identification marks to each separate pieces on work shall be prepared. The diagram shall be sufficient to ensure convenient assembly and erection at site.

5.2 Symbols for welding used on plans and shop drawings shall be according to IS : 813-1961‡.

SECTION II LOADS

6. TYPES OF LOADS

6.1 General — For the purpose of computing the maximum stresses in any structure or member of a structure, the following forces shall be taken into account, where applicable:

a) Dead loads,

b) Live loads,

*Code of practice for general engineering drawings (*second revision*).

†Code of practice for architectural and building drawings (*first revision*).

‡Scheme of symbols for welding.

c) Dynamic effects,

d) Wind loads,

e) Seismic loads,

f) Erection loads, and

g) Temperature effects.

6.1.1 The dead loads, live loads, dynamic effects, wind loads and seismic loads to be assumed in design of buildings shall be as specified in IS : 875-1964*. Erection loads and temperature effects shall be considered as specified under **6.2** and **6.3**.

6.2 Erection Loads — All loads required to be carried by the structure or any part of it due to storage or positioning of construction material and erection equipment including all loads due to operation of such equipment, shall be considered as 'erection loads'. Proper provision shall be made, including temporary bracings to take care of all stresses due to erection loads. The structure as a whole and all parts of the structure in conjunction with the temporary bracings shall be capable of sustaining these erection loads, without exceeding the permissible stresses as specified in Section III of this code.

6.3 Temperature Effects

6.3.1 Expansion and contraction due to changes in temperature of the materials of a structure shall be considered and adequate provision made for the effects produced.

6.3.2 The temperature range varies for different localities and under different diurnal and seasonal conditions. The absolute maximum and minimum temperatures which may be expected in different localities in the country are indicated on the maps of India in Appendices D and E respectively. These appendices may be used for guidance in assessing the maximum variations of temperature for which provision for expansion and contraction has to be allowed in the structure.

6.3.3 The temperatures indicated on the maps in Appendices D and E are the air temperatures in the shade. The range of variation in temperature of the building materials may be appreciably greater or less than the variation of air temperature and is influenced by the conditions of exposure and the rate at which the materials composing the structure absorb or radiate heat. This difference in temperature variations of the material and air should be given due consideration.

6.4 Load Combinations — The various loads specified in **6.1** should be combined in accordance with the stipulation in the appropriate design

*Code of practice for structural safety of buildings: Loading standards (*revised*).

sections. In the absence of such recommendations, however, the following load combinations, given for general guidance may be adopted:

a) Dead load alone;
b) Dead load plus partial or full live load whichever causes the most critical condition in the structures;
c) Dead load plus wind or seismic loads;
d) Dead load plus such part of or whole of the specified live load whichever is most likely to occur in combination with the specified wind or seismic loads plus wind or seismic loads; and
e) Dead loads plus such part of the live loads as would be imposed on the structure during the period of erection plus wind or seismic loads plus erection loads.

NOTE—For design purposes, wind load and seismic forces shall be assumed not be act simultaneously. Both forces shall, however be investigated separately and adequately provided for.

SECTION III DESIGN

7. DESIGN CRITERIONS

7.1 General — All parts of the structural framework shall be capable of sustaining the most adverse combination of the dead loads, live loads, wind loads, seismic forces where applicable, and any other forces or loads to which the building may be subjected. The calculated stresses in the structural members and in bolts, rivets and welds shall not exceed the appropriate values given in this standard.

7.2 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 percent proof stress, corresponding to a permanent strain of 0·002. This stress is analogous to the yield stress of structural steel.

7.2.1 The design procedure for aluminium structures is basically the same as for steel. Consideration shall be given to the stability of the structure as 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.

7.3 Design Requirements — During designing, care shall be taken to ensure that as far as possible, all members and connection are readily accessible for maintenance and the pockets and crevices likely to entrap water, dirt or condensation are avoided.

The structure shall be capable of sustaining the most adverse combination of stresses and shall be examined preferably at an early stage, to assess the possibility of failure by fatigue (*see* **10**).

7.4 Permissible Stresses

7.4.1 *Principal Alloys* — Permissible stresses for the structural 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 value have been obtained by the procedures given in Appendix F and apply to unwelded member under static loading.

Slender members tend to buckle and for these, the permissible stresses shall be obtained in accordance with **8.2**, **8.3** and **8.4**, values for flexural and torsional buckling of struts are given in Fig. 1 and values for lateral buckling of beams and local buckling of thin plates in Fig. 2. The construction of these graphs from the data given in Table 4 is described in Appendix F. The quoted shear stresses are permissible maximum values for use in **7.5.3**, **7.5.4** and **8.3.3.2**. Permissible average shear stresses for webs and thin plates which tend to buckle are dealt with in **8.3.3.2**, **8.3.7**, and **8.4.2**.

The permissible axial and bending stresses shall be used in conjunction with the appropriate effective area (*see* **8.1.2**, **8.2.3** and **8.3.2**).

The permissible bearing stresses listed in Table 4 are for joints in single shear. Increases for joints in double shear and reduction for small edge distances of bolts or rivets are described in **9.2**.

7.4.2 *Secondary Alloys* — The permissible stresses for secondary alloys are given in Appendix C.

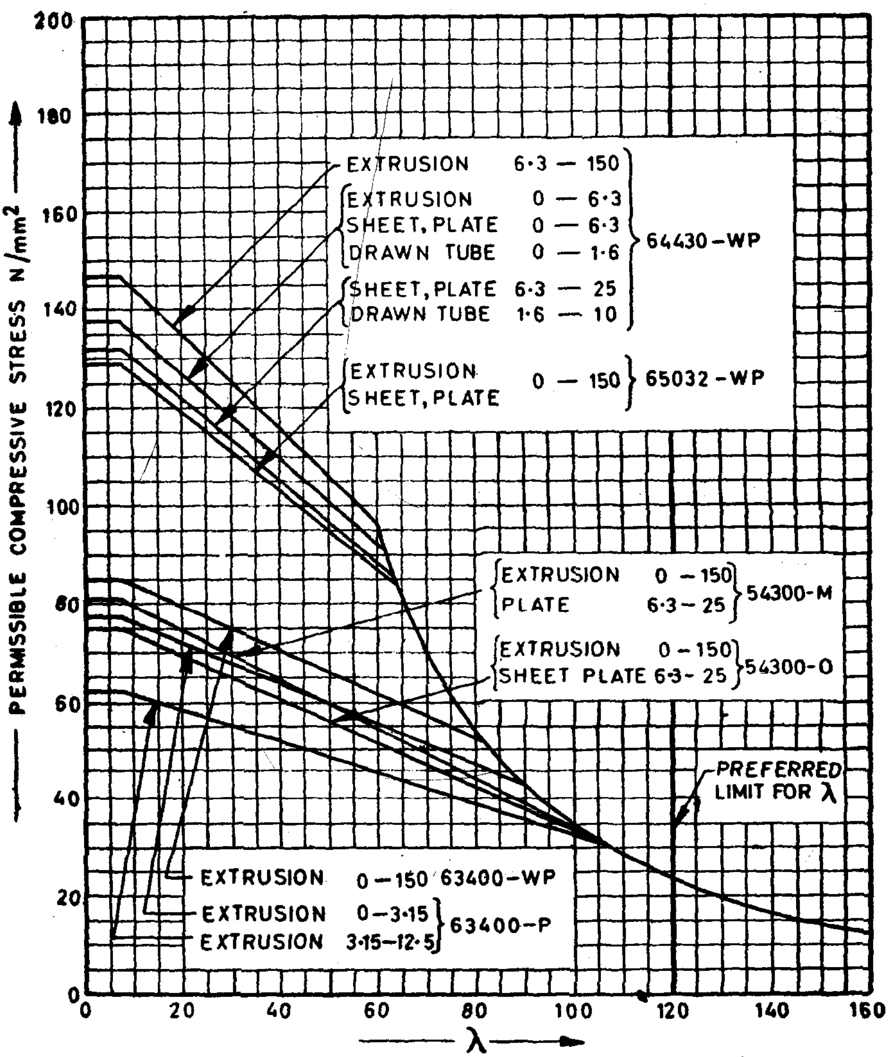
7.4.3 *Alloys with Non-standard Properties* — Permissible stresses may be obtained as described in Appendix F for any of the structural alloys for which a reputable manufacturer either guarantees higher minimum properties than those specified in the relevant Indian Standards (*see* **4.4**) or guarantees minimum properties, for a non-heat-treatable alloy, in a temper not so specified. These permissible stresses may, with the engineer's agreement, be used for design.

7.4.4 *Other Alloys* — The procedure given in Appendix F may also be used as a guide for obtaining permissible stresses for other alloys (*see* **4.3.4**).

7.4.5 *Joints* — The permissible stresses for bolts, rivets, welded joints and welded members are given in **9**.

7.4.6 *Increase in Permissible Stresses Provided Fatigue is not a Consideration* (*see* **10.2**) — The permissible stresses may be exceeded as follows.

7.4.6.1 *Wind or seismic loads* — When effect of wind or seismic load is taken into account the permissible stresses in structural members as specified in Table 4 and Table 25 may be exceeded by 25 percent. No increase in permissible stresses shall, however, be allowed in case the structure is designed primarily for wind loads, and/or when fatigue is a consideration.



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

2. For clarity the small differences in properties of the following have been ignored.

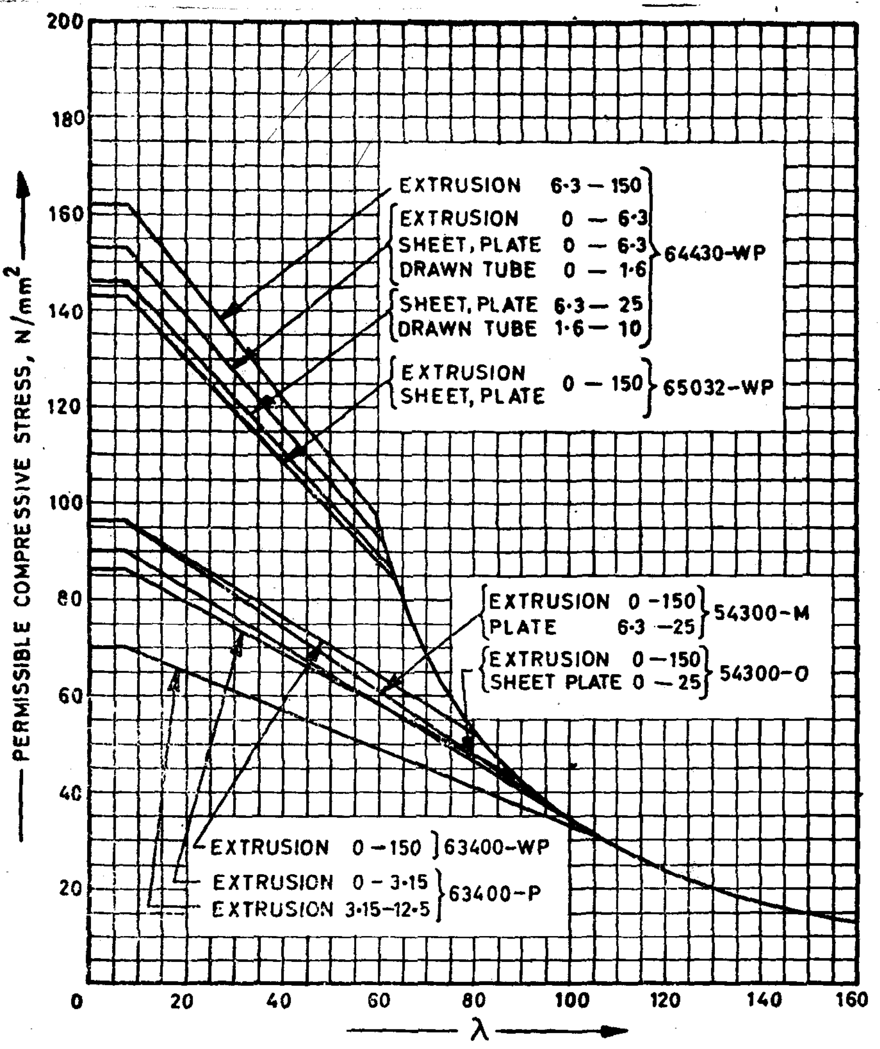
a) Extrusion up to 6·3 mm; sheet, plate up to 6·3 mm and drawn tube up to 1·6 mm for 64430-WP.

b) Extrusion and plate of 54300-M.

3. For column buckling $\lambda = l/r$ (*see* **8.2.2**).

4. For torsional buckling $\lambda = \lambda_t$ (*see* **8.2.4**).

FIG. 1 PERMISSIBLE COMPRESSIVE STRESSES IN STRUTS



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

2. For clarity the small difference in properties of the following have been ignored.

a) Extrusion up to 6·3 mm; sheet, plate up to 6·3 mm and drawn tube up to 1·6 mm for 64430-WP.

b) Extrusion and plate of 54300-M.

c) Extrusion and sheet, plate of 54300-O.

3. For beams (lateral buckling)

$$\lambda = \lambda_{lat} \text{ (see 8.3.1)}$$

4. For thin plates (local buckling)

$$\lambda = \frac{mb}{t} \text{ (see 8.4.1)}$$

FIG. 2 PERMISSIBLE COMPRESSIVE STRESSES IN BEAMS AND THIN PLATES

TABLE 4 PERMISSIBLE STRESSES FOR PRINCIPAL ALLOYS IN N/mm² (kgf/mm²)

(*Clause* 7.4.1)

Alloy	Condition*	Form*	Thickness*† mm From	Thickness*† mm To	Axial‡ p_t	Axial‡ p_c	Bending‡ p_{bt}	Bending‡ p_{bc}	Shear‡ p_q	Bearing§ p_b	λ_0‖
(1)	(2)	(3)	(4)	(5)	(6)		(7)		(8)	(9)	(10)
64430 (H30)	WP	Extrusions	—	6·3	139 (14·2)		154 (15·7)		83 (8·4)	222 (22·6)	61
			6·3	150¶	147 (15·0)		162 (16·5)		88 (9·0)		59
		Sheet, plate	—	6·3	137 (14·0)		152 (15·5)		82 (8·3)	212 (21·6)	62
			6·3	25	132 (13·5)		146 (14·9)		79 (8·0)		63
		Drawn tube	—	1·6	137 (14·0)		152 (15·5)		83 (8·4)	222 (22·6)	62
			1·6	10	132 (13·5)		146 (14·9)		79 (8·0)		63
65032 (H20)	WP	Extrusion	—	150¶	129 (13·1)		143 (14·6)		77 (7·8)	201 (20·5)	64
		Sheet, plate	—	25							
63400 (H9)	WP	Extrusion	—	—	85 (8·6)		96 (9·8)		51 (5·2)	139 (14·2)	83
	P		—	3·15	77 (7·8)		86 (8·8)		46 (4·7)	117 (11·9)	89
			3·15	12·5	62 (6·3)		70 (7·1)		37 (3·8)		105
54300 (N8)	M	Extrusion	—	150¶	82 (8·3)		96 (9·8)		49 (5·0)	201 (20·5)	97
		Plate	6·3	25	80 (8·1)		94 (9·6)		48 (4·9)		99
	O	Extrusion	—	150¶	82 (8·3)	76 (7·7)	96 (9·8)	91 (9·3)	49 (5·0)	201 (20·5)	103
		Sheet, Plate	—	6·3	81 (8·2)	76 (7·7)	94 (9·6)	89 (9·1)			
			6·3	25	75 (7·6)	76 (7·7)	88 (9·9)	90 (9·2)	45 (4·6)		

*For other conditions, forms and thickness, refer relevant Indian Standards (*see* **4.4.1**).
†Each thickness range includes its upper limit.
‡Applies only when buckling is not the criterion (*see* **8.2, 8.3** and **8.4**).
§Joints in single shear (*see* **9.2.1**).
‖*See* Appendix F.
¶For round tube and hollow section the permissible stresses do not apply above 75 mm.

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7.4.6.2 *Erection loads*

a) *Without wind or seismic forces* — For members carrying erection loads only or erection loads combined with forces other than those resulting from wind or seismic forces, the permissible stresses on the members or its connections may be exceeded by 15 percent.

b) *With wind or seismic forces* — When erection loads are considered together with wind or seismic loads, the permissible stresses may be exceeded by 25 percent.

7.4.6.3 In no case shall the member or its connection have less carrying capacity than that needed if the wind, seismic or erection loads are neglected.

7.5 Combined Stresses

7.5.1 *Combined Bending and Axial Tension* — Members subject to bending and axial tension shall be so proportioned that:

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

where

f_t = the axial tensile stress,

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

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

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

7.5.2 *Combined Bending and Axial Compression* — Members subject to bending and axial compression shall 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 = the axial compressive stress;

p_c = the permissible axial compressive stress obtained from Table 4 and Fig. 1;

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

p_{bc} = the permissible bending compressive stress obtained from Table 4 and Fig. 2; and

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

E = the modulus of elasticity, and

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

7.5.3 *Combined Bending and Sheet* — Members subject to bending and shear shall be so proportioned that $f_{eq} \leqslant 0{\cdot}9$ times the minimum 0·2 percent proof stress:

where

f_{eq} = the equivalent stress, equal to either $\sqrt{(f^2_{bt} + 3f^2_q)}$ or $\sqrt{(f^2_{bc} + 3f^2_q)}$,

f_q = the maximum shear stress, and

f_{bt} and f_{bc} have the same meanings as in **7.5.1** and **7.5.2** respectively.

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

For webs of built-up beams and for thin plates, reference shall also be made to **8.3.7** and **8.4**.

7.5.4 *Combined Bearing, Bending and Shear* — Members subject to bearing, bending and shear shall be so proportioned that $f_{eq} \leqslant 0{\cdot}9$ times the minimum 0·2 percent proof stress:

where

f_{eq} = the equivalent stress, equal to either

$\sqrt{(f^2_{bt} + f^2_b + f_{bt}f_b + 3f^2_q)}$ or

$\sqrt{(f^2_{bc} + f^2_b - f_{bc}f_b + 3f^2_q}$

f_b = the bearing stress, and

f_{bt}, f_{bc} and f_q have the same meanings as in **7.5.1**, **7.5.2** and **7.5.3** respectively.

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

For webs of built-up beams and for thin plates, reference shall also be made to **8.3.7** and **8.4**.

7.6 Temperature Limitations

7.6.1 *Ordinary and Low Temperatures* — The design requirements of this code apply without modification to structures subject to temperatures in the range (−200°C to 65°C).

7.6.2 *High Temperatures* — In the design of structures whose temperature will consistently exceed 65°C or which will ever exceed 90°C, expert advice shall be obtained on such modifications in design as may be necessary.

7.7 Thickness — Structural sections should not be thinner than 1·2 mm and stressed-skin elements (for example diaphragms, webs and sheet panels) not thinner than 1·0 mm. Thicknesses should be sufficient to give reasonable resistance to accidental damage.

7.8 Deflections — Deflection shall be limited by the function of the member to ensure satisfactory performance. Special consideration shall be given to structural elements supporting machinery or other sources of shock and vibration. Deflection in general building construction shall be limited as specified in **8.3.1**.

7.9 Camber — Cambering of trusses, beams or girders, where required, shall be specified in the design plans. Trusses and built-up girders with spans of 15 m or more shall be cambered for the deflection due to the dead load plus half the live load.

8. DESIGN OF MEMBERS

8.1 Design of Tension Members

8.1.1 *Slenderness Ratio*

8.1.1.1 Slenderness ratio of any tension member, in which there is possibility of reversal of stresses even where the reversal is due only to wind, shall not exceed 180.

The same limit applies when the ties are meant for outdoor service or in application which involve shock, vibratory or incidental lateral loads.

8.1.1.2 For all other ties not governed by **8.1.1.1** slenderness ratio shall not exceed $250 + 2{\cdot}9f$ where f is the minimum axial stress in N/mm^2 sustained by the member.

8.1.2 *Axially Loaded Ties* — The permissible axial load in **a tie is** the permissible tensile stress (*see* Table 4), multiplied by the net sectional area.

8.1.2.1 *Net sectional area* — The net sectional area being the gross sectional area minus deduction as follows for holes and for loss of strength due to welding:

a) 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 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 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 = the hole pitch,

g = the hole gauge, and

t = the thickness of the holed material.

Appendix G illustrates a typical example for deduction of holes in members.

Hole clearances for bolts and rivets shall be as given in Table 14.

b) The deduction for loss of strength due to welding is the sum of the areas of the heat affected zone (*see* **9.3.2**) in a cross section multiplied by $\frac{p_t - p_{wt}}{p_t}$, the governing cross section being the one with the largest heat affected area, where p_t is the permissible axial tensile stress (*see* Table 4) and p_{wt} is the permissible axial tensile stress in heat affected zones (*see* Table 15).

8.1.3 *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 **8.1.2**. The proportions of outstanding leg area to be deducted are given in Table 5.

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
64430 63400	0·6 A	0·2 A
54300	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. For a 100 × 100 × 10 mm angle, A = 900 mm^2.

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

For end bays of multiple-bay angles, channels and tees, the effective area shall 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 **8.1.2**.

8.2 Design of Compression Members

8.2.1 *Effective Length*

8.2.1.1 Effective length l of a compression member for the purpose of determining allowable axial stresses shall be assumed in accordance with

Table 6, where L is the actual length of the member measured between the centres of effective lateral supports. In the case of a compression member provided with a cap or base, the point of lateral support shall be assumed to be in the plane of the top of the cap or bottom of the base.

TABLE 6 EFFECTIVE LENGTH OF STRUTS

TYPE	EFFECTIVE LENGTH l OF MEMBER
Effectively held in position and restrained in direction at both ends	0·67 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 at the other end effectively restrained in direction but not held in position	L
Effectively held in position and restrained in direction at one end and at the other end partially restrained in direction but not held in position	1·5 L
Effectively held in position and restrained in direction at one end but not held in position or restrained in direction at the other end	2·0 L

NOTE — For battened struts, the effective length l should be increased by 10 percent.

8.2.1.2 Effective lengths l for typical cases of trussed structures shall be taken from Table 7.

8.2.2 *Slenderness Ratio*

8.2.2.1 *General* — The slenderness ratio λ of a compression member shall be taken as the ratio of the effective length l, as determined by **8.2.1** to the corresponding radius of gyration r. The slenderness ratio of tension members shall be taken as the unbraced length L to the corresponding radius of gyration.

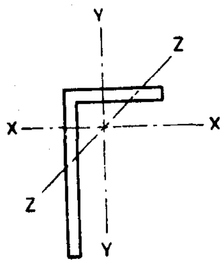
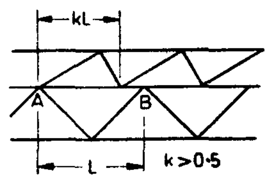
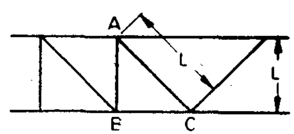
8.2.2.2 The effective slenderness ratio of a compression member subjected to shock or vibratory loads or where lateral loads on a member can occur, shall not exceed 120.

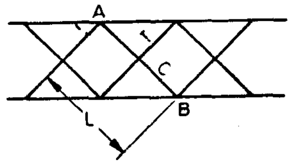
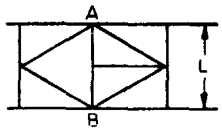
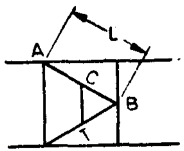
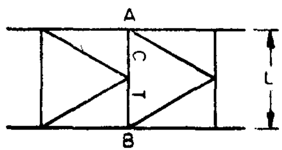
8.2.2.3 For compression members not governed by **8.2.2.2**, slenderness ratio shall not exceed 180.

8.2.3 *Axially Loaded Struts* — With struts, the main requirement is resistance to column buckling (that is, overall flexural buckling), for which the permissible average stress on the gross area is obtained from the appropriate graph in Fig. 1 at $\lambda = l/r$ where l is the effective length as given in Tables 6 and 7 and r is the appropriate radius of gyration.

TABLE 7 EFFECTIVE LENGTH OF TRUSSED STRUCTURES (TYPICAL CASES)

(*Clause* 8.2.1.2)

<table>
<tr><th colspan="3" rowspan="2">Member</th><th colspan="4">Effective length l</th></tr>
<tr><th rowspan="2">Axis XX</th><th rowspan="2">Axis YY</th><th colspan="2">Axis ZZ (Single angle)</th></tr>
<tr><th colspan="3"></th><th>1 bolt</th><th>2 bolts</th></tr>
<tr><td rowspan="2">
For internal members Axis Y-Y is parallel to the plane of bracing</td><td></td><td>AB</td><td>L</td><td>kL</td><td colspan="2">$\frac{1 + 2k}{3}$</td></tr>
<tr><td></td><td>AB
AC</td><td>L</td><td>L</td><td>0·8 L</td><td>0·7 L</td></tr>
</table>

	*AB*	0·5 *L*	0·5 *L*	0·45 *L*	0·4 *L*
	*AB*	0·5 *L*	*L*	0·5 *L*	0·45 *L*
	*AB*	0·5 *L*	*L*	0·5 *L*	0·45 *L*
	*AB*	0·45 *L*	0·5 *L*	0·4 *L*	0·35 *L*

NOTE — *C* = Compression, *T* = Tension, *T* = *C*

Two further requirements, applying more partic
thin-walled section, are resistance to torsional buckling and to local buckling. The permissible stresses for struts subject to these types of buckling shall be obtained from **8.2.5** and **8.4.1** respectively.

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

8.2.4 *Eccentrically Loaded Struts*

8.2.4.1 *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 shall not exceed 0·4 p_c. The value of p_c is the permissible stress obtained from Fig. 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.

8.2.4.2 *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 **8.2.3** provided that they satisfy the following requirements:

a) They shall be designed as integral members and shall 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, shall be designed to carry its share of the load as a strut between adjacent fastenings.

b) The components at each end of the strut shall be connected together with not less than two rivets or close-fitting bolts, or the equivalent in welding, and there shall not be fewer than two additional connections equally spaced in the length of the strut. Where the connected legs are 100 mm or more wide, not less than two rivets or close-fitting bolts shall be used in each connection and shall 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 shall be the same as those in the end-connections. Where the connections are welded, both pairs of edges at the connection shall 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 shall pass through solid washers or packings; welds shall be made to full-width solid packings.

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

8.2.4.3 *Others* — Any other eccentrically loaded strut shall be designed for the combined axial load and bending moment (*see* **7.5.2**).

8.2.5 *Torsional Buckling* — Torsional buckling is the type of failure in which the middle part of a struct 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 shall be read from Fig. 1 at $\lambda = \lambda_t$. Values of λ_t for certain sizes of some common sections are given in Table 8; these expressions, which for channels depend on the factor k_t presented in Fig. 3 and 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 $\frac{k_t h}{t_2}$, where the symbols, are as defined in Table 8.

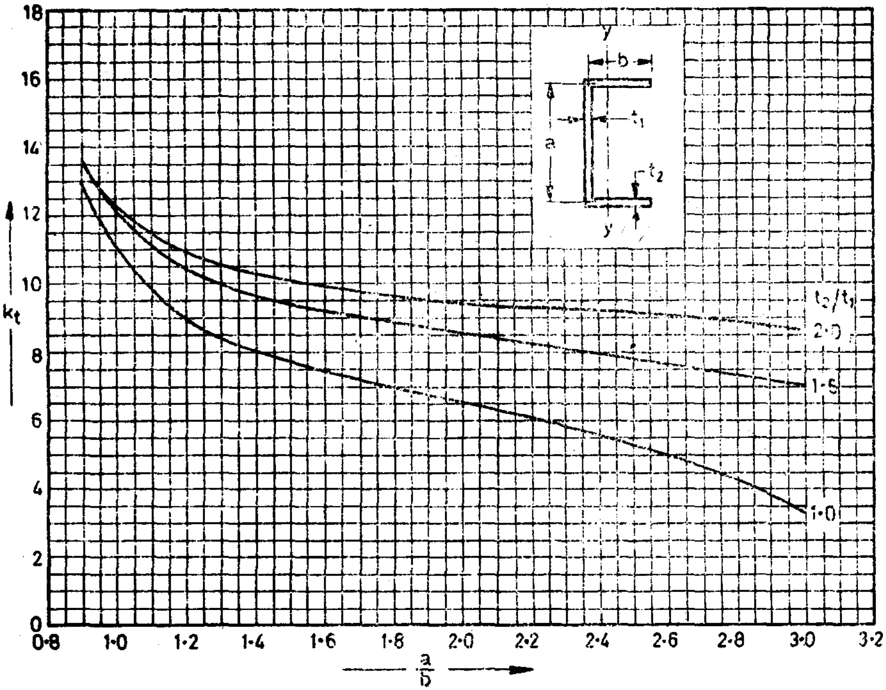


Fig. 3 Values of k_t for Plain Channels

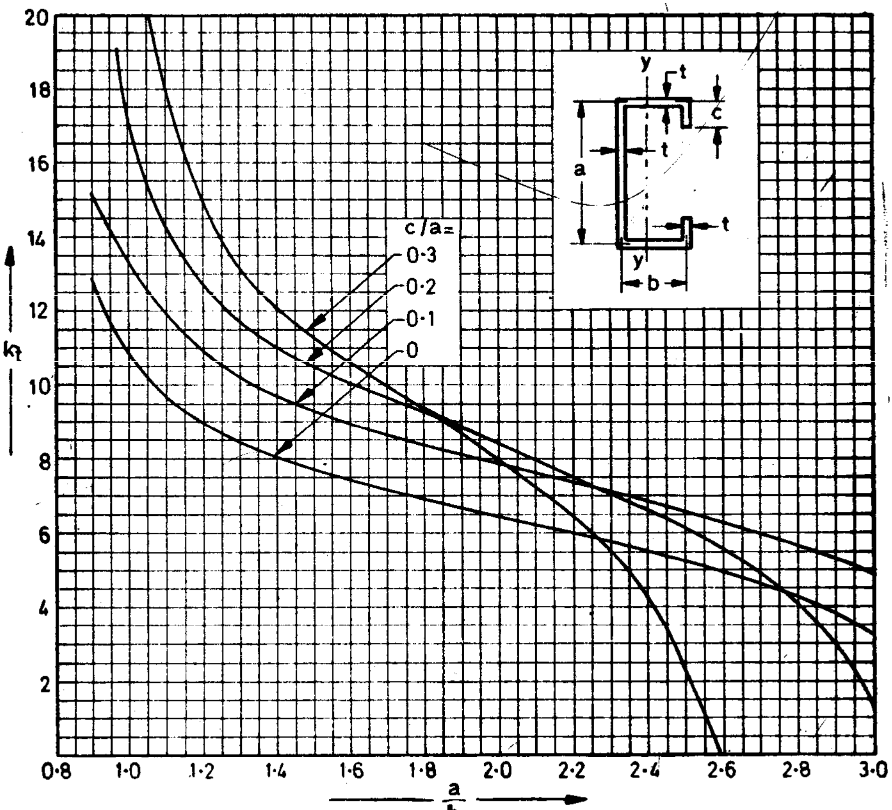


FIG. 4 VALUES OF k_t FOR LIPPED CHANNELS

For other sections, the torsional properties shall be obtained by reference to Appendix H, and the values of λ_t by reference to Appendix J. Use of these appendices may lead to slightly higher permissible stresses for the sections specifically dealt with in Table 8.

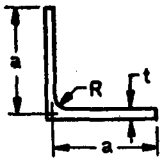
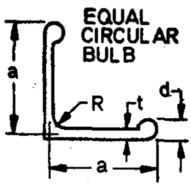
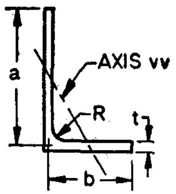
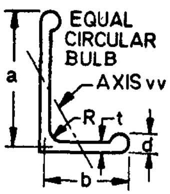
8.2.6 *Battened Struts*

8.2.6.1 *General* — Struts composed of two main components battened shall 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 shall be proportioned to resist a total transverse shear load S equal to 2·5 percent of the total compressive load on the strut, divided equally between the two parallel batten systems.

TABLE 8 VALUES OF λ_t FOR STRUTS

(*Clause* 8.2.5)

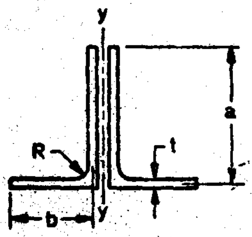
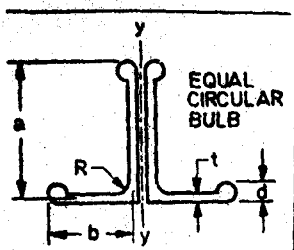
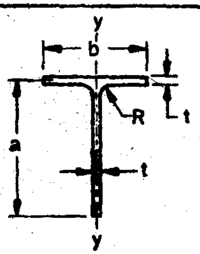
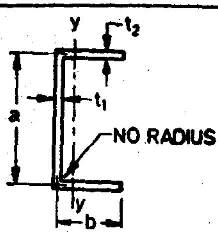
SECTION	LIMITS	VALUE OF λ_t
(1)	(2)	(3)
	$\frac{R}{t} \leqslant 3$	$\frac{5{\cdot}2a}{t} - 1{\cdot}3 \left(\frac{R}{t}\right)^2$
	$\frac{R}{t} \leqslant 3$ $\frac{d}{t} \leqslant 2{\cdot}5$	$\frac{5{\cdot}2a}{t} - 1{\cdot}3 \left(\frac{R}{t}\right)^2 - 2\left(\frac{d}{t} - 1\right)^3 + 1{\cdot}5 \left(\frac{d}{t} - 1\right)\left(\frac{R}{t}\right)$
	$\frac{R}{t} \leqslant 3$ $1 < \frac{a}{b} < 2$	$\sqrt{\lambda_o^2 + \lambda_v^2 \sqrt{\frac{a}{b} - 1}}$ where $\lambda_o = 2{\cdot}6 \left(\frac{a+b}{t}\right) - 1{\cdot}3 \left(\frac{R}{t}\right)^2$ $\lambda_v = \frac{l}{r_v}$
	$\frac{R}{t} \leqslant 3$ $1 < \frac{a}{b} < 2$ $\frac{d}{t} \leqslant 2{\cdot}5$	$\sqrt{\lambda_o^2 + \lambda_v^2 \sqrt{\frac{a}{b} - 1}}$ where $\lambda_o = 2{\cdot}6 \left(\frac{a+b}{t}\right) - 1{\cdot}3 \left(\frac{R}{t}\right)^2 - 2\left(\frac{d}{t} - 1\right)^3 + 1{\cdot}5\left(\frac{d}{t} - 1\right)\left(\frac{R}{t}\right)$ $\lambda_v = \frac{l}{r_v}$

NOTE — l is the effective length.

r_v is the radius of gyration about the axis vv (that is the minimum value of r).

(*Continued*)

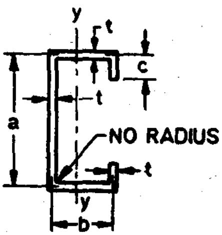
TABLE 8 VALUES OF λ_t FOR STRUTS — *Contd*

SECTION	LIMITS	VALUE OF λ_t
(1)	(2)	(3)
	$R < 3$ $0.5 < \frac{a}{b} < 2$	$\sqrt{\lambda_o^2 + \lambda_y^2\left(\frac{a}{2b}\right)}$ where $\lambda_o = 1.9\left(\frac{a+2b}{t}\right) - 1.3\left(\frac{R}{t}\right)^2$ $\lambda_y = \frac{l}{r_y}$
	$\frac{R}{t} < 3$ $0.5 < \frac{a}{b} < 2$ $\frac{d}{t} < 2.5$	$\sqrt{\lambda_o^2 + \lambda_y^2\left(\frac{a}{2b}\right)}$ where $\lambda_o = 1.9\left(\frac{a+2b}{t}\right) - 1.3\left(\frac{R}{t}\right)^2$ $-2\left(\frac{d}{t} - 1\right)^2 + 1.5\left(\frac{d}{t} - 1\right)\left(\frac{R}{t}\right)$ $\lambda_y = \frac{l}{r_y}$
	$\frac{R}{t} < 2$ $0.5 < \frac{a}{b} < 1$	$\sqrt{\lambda_o^2 + \lambda_y^2\left(\frac{0.8\,a}{b}\right)}$ where $\lambda_o = \left(\frac{3.2\,a + b}{t}\right) - 2\left(\frac{R}{t}\right)^2$ $\lambda_y = \frac{l}{r_y}$
	$R = 0$ $1 < \frac{a}{b} < 3$ $1 < \frac{t_2}{t_1} < 2$	$0.5\left(\frac{k_t b}{t_2} + \lambda_y\right)$ where k_t is obtained from Fig. 3. $\lambda_y = \frac{l}{r_y}$ The presence of small fillets ($R < 2\,t$) has negligible effect on λ_t

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

(Continued)

TABLE 8 VALUES OF λ_t FOR STRUTS — *Contd*

SECTION	LIMITS	VALUE OF λ_t
(1)	(2)	(3)
	$R = 0$ $1 < \frac{a}{b} < 3$ $\frac{c}{a} < 0{\cdot}3$	$0{\cdot}5\left(\frac{k_t b}{t} + \lambda_Y\right)$ where k_t is obtained from Fig. 4 $\lambda_Y = \frac{l}{r_Y}$ The presence of small fillets ($R \nless 2t$) has negligible effect on λ_t
Symmetrical I—Section	None for: plain section, lipped section and bulb section with $\frac{d}{t} \nless 2{\cdot}5$	Torsional buckling may be ignored
Closed hollow section		Torsional buckling may be ignored
Others		See Appendix J

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

Where there is eccentricity of loading applied and moments or lateral loads (including the 2·5 percent transverse shear load S) acting in the plane parallel to the battens, all forces resulting from deformation shall be provided for in the battens and their fastenings.

8.2.6.2 *Spacing* — The spacing between battens shall 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 shall be in pairs placed opposite each other on the two sides in the main components, and shall be spaced uniformly throughout the length of the strut.

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

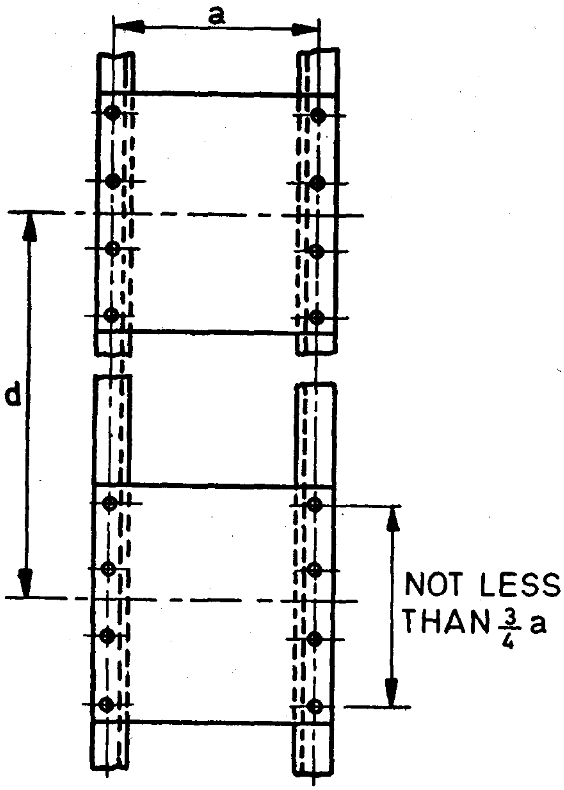


FIG. 5 BATTEN DIMENSIONS AND SPACING

8.2.6.4 *Thickness* — The thickness of a batten plate shall be not less than either $a/36$ or 2·5 mm, whichever is more. 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 shall be not less than either $a/50$ or 2·5 mm, whichever is more, where *a* has the same meaning as in **8.2.6.3**.

8.2.6.5 *Fastening* — Each batten shall be fastened to the main components by at least two rivets or close-fitting bolts, or by welding. Each fastening shall 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* **8.2.6.1**), *d* is the distance between centres of battens (*see* Fig. 5), and a has the same meaning as in **8.2.6.3**.

8.2.7 *Laced Struts*

8.2.7.1 *General* — Struts composed of two main components laced and tied shall 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 shall be provided with tie plates at the ends of the lacing system. If the system is interupted, intermediate tie plates shall be used.

Lacing bars and their fastenings shall be proportioned to resist a total transverse shear load S equal to 2·5 percent of the total compressive load on the strut, divided equally between the two parallel lacing systems.

Where there is eccentricity of loading, applied and moments or lateral loads (including the 2·5 percent transverse shear load S) acting in a plane parallel to the lacing system, all forces resulting from deformation shall 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, shall 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. Typical lacing details and single and double lacing systems with or without tie plates are shown in Fig. 6.

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

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

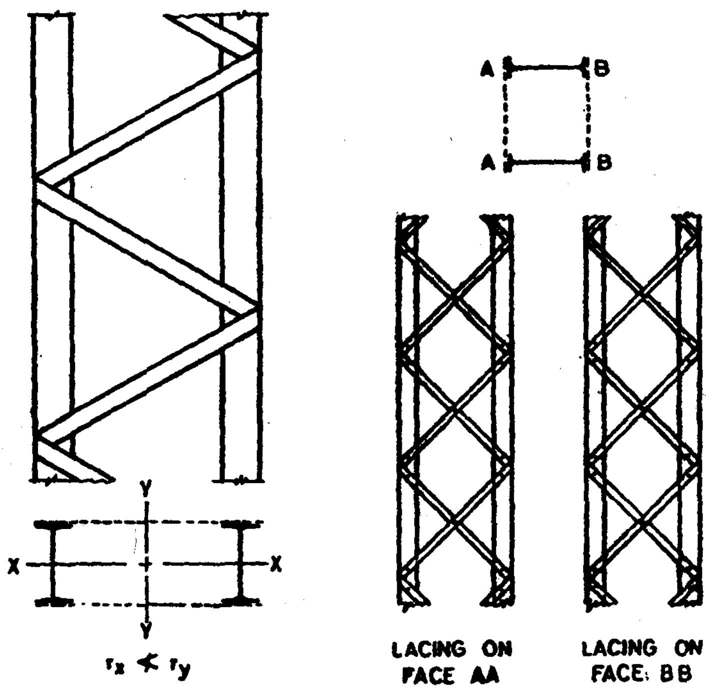
8.2.7.3 *Tie plates* — Tie plates and their fastenings shall be designed as for battens (*see* **8.2.6**). An intermediate tie plate shall have an effective length of not less than $3a/4$, where a has the same meaning as in **8.2.6.3**.

8.2.8 *Welded Struts* — Welded struts in materials in the O and M condition (for example 54300-O, 54300-M) may be designed as though they were unwelded.

With heat-treated materials (for example 64430-WP) and work-hardened materials (for example 53000-H1) the effect of heat affected zones (*see* **9.3.2**) 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 are to be given. Greater economy may be affected by making use of published research* and by testing. The rules are as follows:

a) An empirical graph giving permissible compressive stresses for struts consisting wholly of heat affected zones may be set up for any material, as follows. On the axes of Fig. 1 draw a straight line from a point with ordinate p_{wt} (*see* Table 15) at $\lambda = 8$ to a point on the existing hyperbola with ordinate $\frac{p_{wt}}{3}$ the permissible stress may then be read from the new graph at the appropriate value of λ.

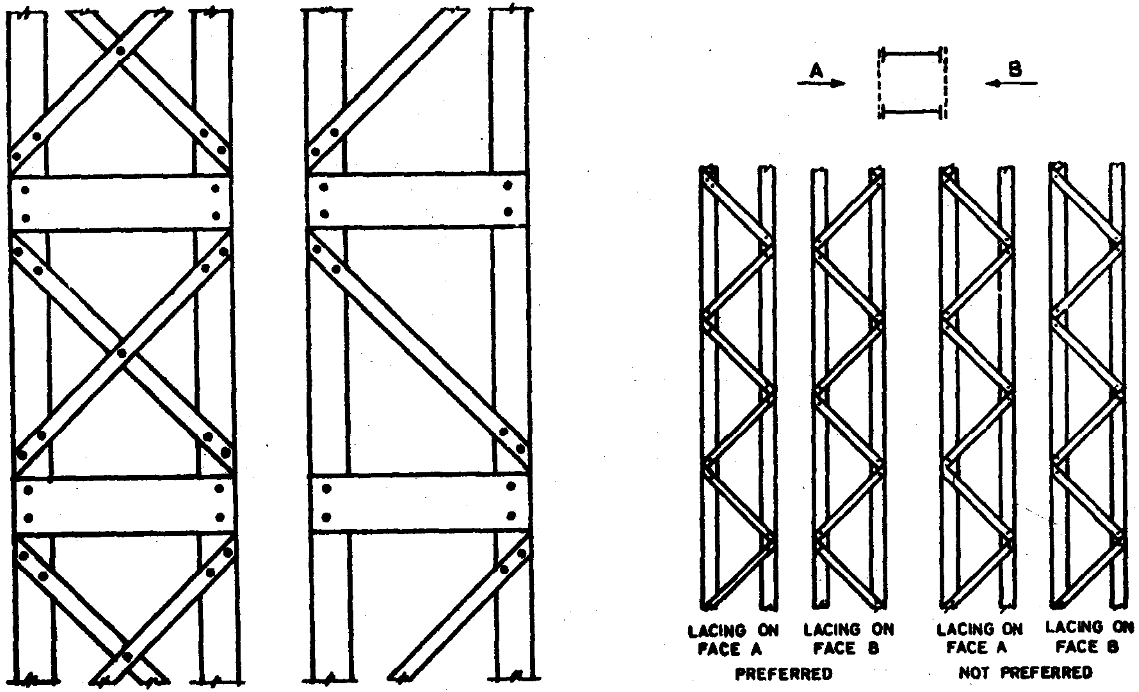
b) For a symmetrical strut with one or more longitudinal welds (for example welds by which a members is built up from plates or sections), and with the heat affected zones disposed symmetrically with respect to the principal axes of the cross section, the permissible stress is equal to $p_c - n\ (p_c - p_{wc})$.



6A Typical Lacing Details for Struts   6B Double Laced System

FIG. 6 TYPICAL LACING SYSTEMS FOR STRUTS — *Contd*

*For example, BRUNGRABER and CLARK. Strength of welded aluminium columns. Trans. Am. Sec. C. E. Vol. 127. Part II. 1962.



6C Double Laced and Single Laced Systems Combined with Cross Members

6D Single Laced System on Opposite Sides of Main Components

FIG. 6 TYPICAL LACING SYSTEMS FOR STRUTS where

p_c = the permissible compressive stress for unwelded material obtained from Fig. 1 or Fig. 2 as appropriate,

p_{wc} = the permissible compressive stress obtained as in (a) above, and

n = the fraction of the cross section consisting of heat affected zones.

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

c) For a strut with one or more transverse welds (for example, butt welds, or welds connecting other members or attachments), the permissible stress is obtained as in (a) above.

d) Notwithstanding (b) and (c) 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.

8.2.9 *Limiting Deflection* — At the caps of columns in single storey buildings the horizontal deflection due to lateral forces should not ordinarily exceed 1/325 of the actual length L of the column. This limit may be exceeded in cases where greater deflections would not impair the strength and efficiency of the structure or lead to damage to finishings.

8.3 Design of Beams

8.3.1 *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 shall 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 shall not be exceeded:

a) Beams carrying plaster finish	span/360
b) Purlin and sheeting rails	
i) under dead load only	span/200
ii) Under worst combination of dead, imposed wind and snow loads	span/100
c) Curtain wall mullions	span/175
d) Members carrying glass direct	$(\text{span in mm})^2/280\,000$ mm

For other members the limit of deflection, unless specified shall be established by the engineer.

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

8.3.2 *Beams in General: Section Properties*

8.3.2.1 *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 shall 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* **8.1.2.1**).

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

8.3.2.2 *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 (for example, by the use of tongue plates), or where the depth of web included in a flange area (*see* **8.3.2.1**) is greater than one-quarter of the overall depth, the above approximations are not permissible, and the web stresses shall be computed with due regard to the distribution of bending stresses.

8.3.2.3 *Flanges and webs with large holes* — Flanges and webs having holes larger than those normally required for bolts or rivets shall be the subject of special analysis, and the provisions of **8.3.2.1** and **8.3.2.2** do not apply.

8.3.2.4 *Use in design* — Beams shall 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 shall, for each flange, be increased in the ratio of its gross area to its effective area.

8.3.3 *Beams in General: Permissible Stresses*

8.3.3.1 *Flanges* — The bending tensile stress in the extreme fibre of a beam, calculated on the effective section (*see* **8.3.2**) shall not exceed the permissible value given in Table 4.

The bending compressive stress, calculated on the effective section (*see* **8.3.2**), shall not exceed the permissible value, either for lateral buckling or local buckling, obtained from Fig. 2.

8.3.3.2 *Webs* — Provided that the ratio d/t does not exceed C_1 in Table 9, the average shear stress, taken as the shear force divided by the effective web area (*see* **8.3.2.2**), shall not exceed the permissible value given in Fig. 7. In using Fig. 7, values of b/d greater than 2 shall be considered as infinite. The requirements of **7.5.3**, **7.5.4** and **8.3.7.3** shall also be met.

If $\frac{d}{t}$ exceeds C_1, intermediate transverse stiffeners are required (*see* **8.3.6.4**) and where the ratio $\frac{d}{t}$ exceeds C_2, longitudinal stiffeners in addition to the intermediate transverse stiffeners shall be provided (*see* **8.3.6.5**).

TABLE 9 VALUES OF C_1 AND C_2 FOR WEBS

(*Clauses* 8.3.3.2, 8.3.6.4 *and* 8.3.6.5)

Alloy		C_1	C_2	Remarks
64430-WP	Sheet	65	120	—
	Plate	67	124	
54300-O	Plate	88	164	—
54300-M	Plate	85	159	
Others		$590/\sqrt{p_q}$	$1\,100/\sqrt{p_q}$	p_q in N/mm²

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

8.3.4 *Beams in General: Lateral Buckling*

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

8.3.4.2 *Beams bent about major axis* — An unrestrained beam, subject to bending about the major axis only, shall be so proportioned that the bending compressive stress in any part between points of support shall

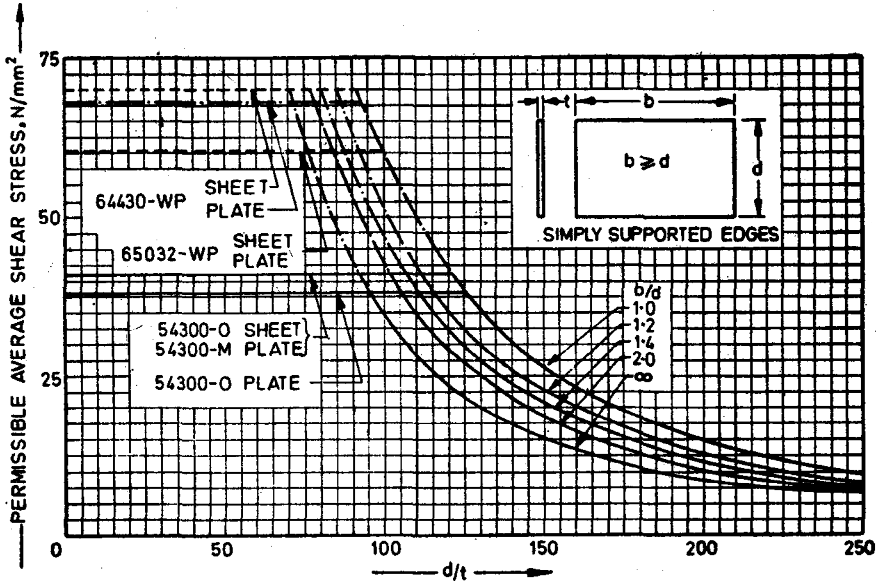


FIG. 7 PERMISSIBLE AVERAGE SHEAR STRESSES IN UNSTIFFENED WEBS AND THIN PLATES

not exceed the permissible stress obtained from Fig. 2 at $\lambda = \lambda_{lat}$, where λ_{lat} for that part is calculated as below:

a) I-sections and channels:

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

where

t_2 = the flange thickness, and

k_{lat} = values obtained from Fig. 8.

b) Rectangular sections, solid or hollow:

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

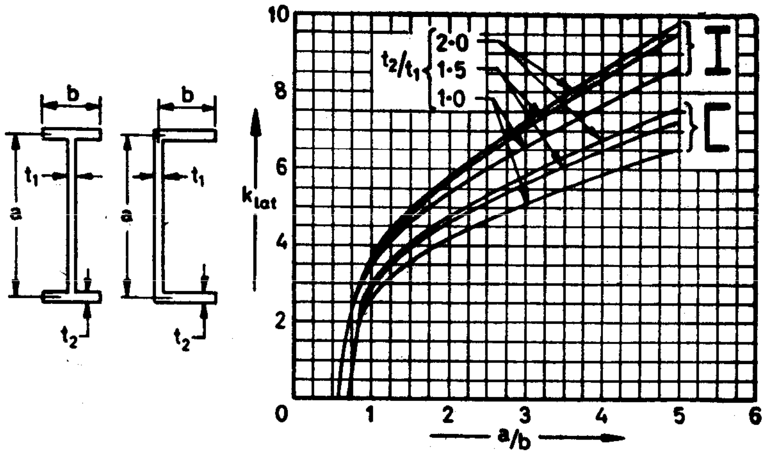
where

b = the width of the section, and

k_{lat} = values obtained from Fig. 9.

c) Other doubly-symmetrical sections:

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



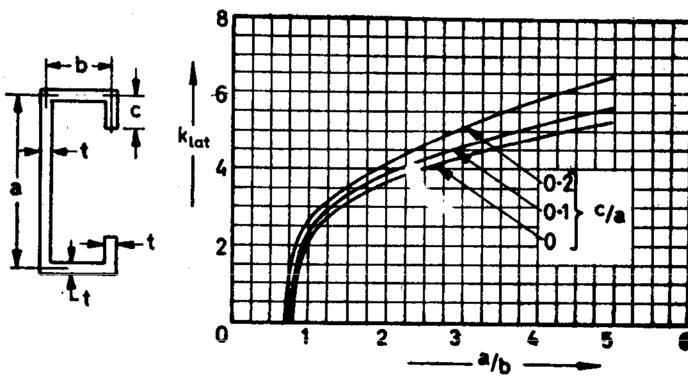


FIG. 8 VALUES OF k_{lat} FOR I-SECTION AND CHANNELS

where

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

J = the torsion factor (*see* Appendix H), and

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

d) Singly-symmetrical sections:

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

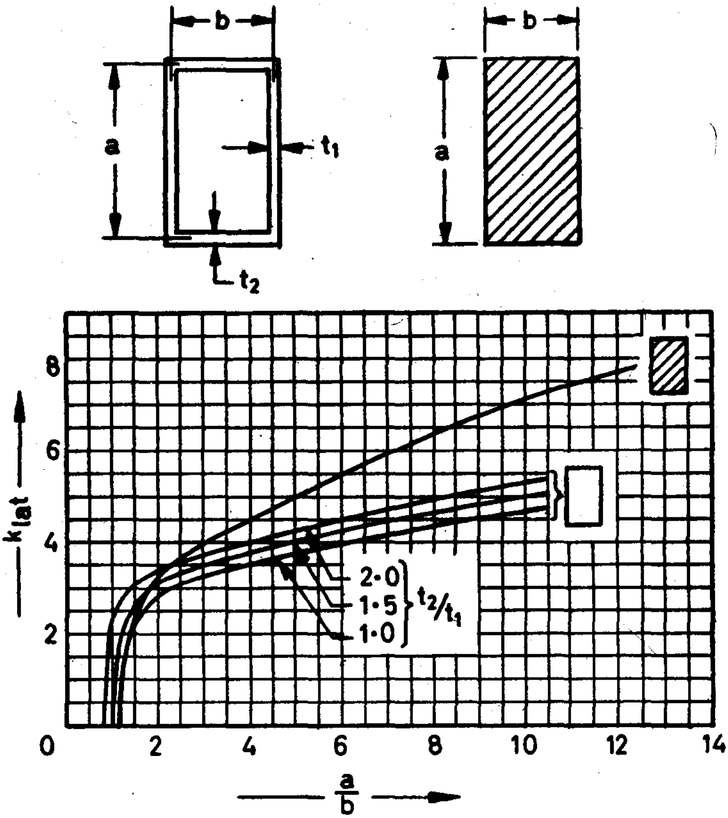


FIG. 9 VALUES OF k_{lat} FOR RECTANGULAR SECTION

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

$$l_l = k_1 k_2 L,$$

where

k_1 = a factor depending on the conditions of restraint at those points (*see* Table 10), and

k_2 = a factor depending on the shape of the bending-moment diagram between those points (*see* Table 11).

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

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

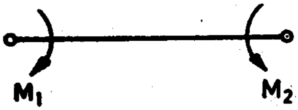
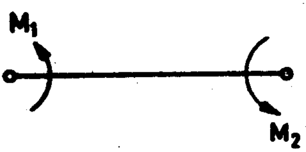
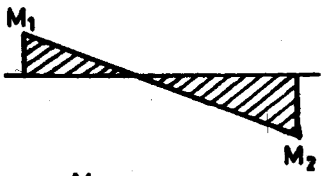
TABLE 10 CONDITION OF RESTRAINT FACTOR k_1

(*Clause* 8.3.4.2)

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

TABLE 11 BENDING-MOMENT SHAPE FACTOR k_2

(*Clause* 8.3.4.2)

TYPE OF LOADING	BENDING MOMENT DIAGRAM BETWEEN POINTS OF LATERAL SUPPORT	k_2
	 $\frac{M_1}{M_2}$ POSITIVE	$\left(0{\cdot}6 + 0{\cdot}4\ \frac{M_1}{M_2}\right)$ or 0·4, whichever is greater
	 $\frac{M_1}{M_2}$ NEGATIVE	M_2 is numerically greater than, or equal to, M_1

* BLEICH (F). Buckling strength of metal structures. McGraw-Hill, New York 1952.

8.3.4.3 *Beams bent about both axes* — An unrestrained beam subject to bending about both axes shall be proportioned for major axis bending alone in accordance with **8.3.4.2** and also that:

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

where

f_x = the extreme fibre compressive stress due to major-axis bending,

f_y = the extreme fibre stress (tensile or compressive) due to minor-axis bending,

p_{bc} = the permissible bending compressive stress obtained from **8.3.4.2**, and

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

In addition, the tensile stress and compressive stress due to major axis and minor axis bending combined shall not exceed p_{bt} and p_{bc} respectively.

8.3.5 *Beams in General: With End Loads* — A beam in which bending is combined with axial tension or compression shall be designed in accordance with **7.5.1** or **7.5.2** respectively.

8.3.6 *Built-up Beams: Construction Details*

8.3.6.1 *Flange* — In any built-up beam, each flange (*see* **8.3.2.1**) shall 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 shall form as large a part (preferably not less than one-third) of the flange area as practicable, and the number of flange plates shall be kept to a minimum. Flange plates should preferably all be of the same thickness, and one of the top flange plates shall extend over the full length of the beam unless the top of the web is finished flush with the flange angles. Each flange plate shall extend beyond its theoretical cut-off points, and shall 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 end of such a plate shall be butt-welded to the lighter flange plate (*see* Table 30) to give a continuous flange. The heavier plate shall extend beyond its theoretical cut-off points and shall 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 shall not be less than that of the part spliced, and its centroid shall be as close as possible to that of the part spliced. Enough bolts or rivets shall be used on each side of the splice to develop the load on the part spliced. In a welded beam, flange splices shall be made with butt welds.

8.3.6.2 *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 shall be finished either flush with or above the flange angles.

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

8.3.6.3 *Bearing stiffeners* — Bearing stiffeners shall be provided at all points of concentrated load or reaction, including points of support, where the concentrated load or reaction exceeds $p_c t b$.

where

p_c = the permissible compressive stress obtained from Fig. 1 at $\lambda = 1{\cdot}73\ d/t$;

t = the thickness of the web; and

b = 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 shall not be taken as greater than half the depth of the beam; and

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

Bearing stiffeners shall where possible, be symmetrical about the web and, at points of support, shall project as nearly as practicable to the outer edges of the flanges. Each stiffener assembly shall be designed as a strut to carry the three-fourth of the 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 shall be taken about the axis parallel to the web of the beam, and the permissible stress shall be that for a strut of effective length equal to 0·7 times the length of the stiffener (*see* **8.2.3**; note that torsional buckling need not be considered).

The outstanding leg of each stiffener shall 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 shall 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 shall not be less than:

$$\frac{d_0^3 t_0 R}{250\ W}$$

where

d_0 = the overall depth of the beam,

t_0 = the maximum thickness of the compression flange,

R = the reaction at the bearing, and

W = the total load on the beam.

In addition, either the beam shall be securely bolted down at the bearings or the width of the seating under the stiffener shall not be less than $d_0/3{\cdot}5$.

The ends of bearing stiffeners shall 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 shall not be joggled and shall be solidly packed throughout.

8.3.6.4 *Transverse stiffeners* — Intermediate transverse stiffeners shall be provided throughout the length of a beam where the ratio d/t exceeds the value C_1 in Table 9.

where

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

t = 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 (*see also* **8.3.6.5**), or may consist of pairs of stiffeners arranged one on each side of the web. They shall extend substantially from flange to flange but need not be connected to either flange.

Transverse stiffeners shall 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:

$$1{\cdot}3\ d^3 t^3/b^2$$

where d and t have the meanings given above, and

b = the spacing of the stiffeners (with stiffeners on one side only, b shall be taken to the lines of attachment of them with stiffeners on both sides, b may be taken as the clear distance between them provided that they are at least a 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 **8.3.3** and **8.3.7** 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.

8.3.6.5 *Longitudinal stiffeners* — Where the ratio d/t exceeds the value C_2 in Table 9, the symbols d and t having the same meanings as in **8.3.6.4** a longitudinal stiffener shall be provided in addition to intermediate transverse stiffeners. Figure 10 gives, for various $f_{q \cdot av}/f_1$ and b/d ratios, value of the ratio b/d such that the panels above and below the longitudinal stiffeners are of equal strength.

where

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

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

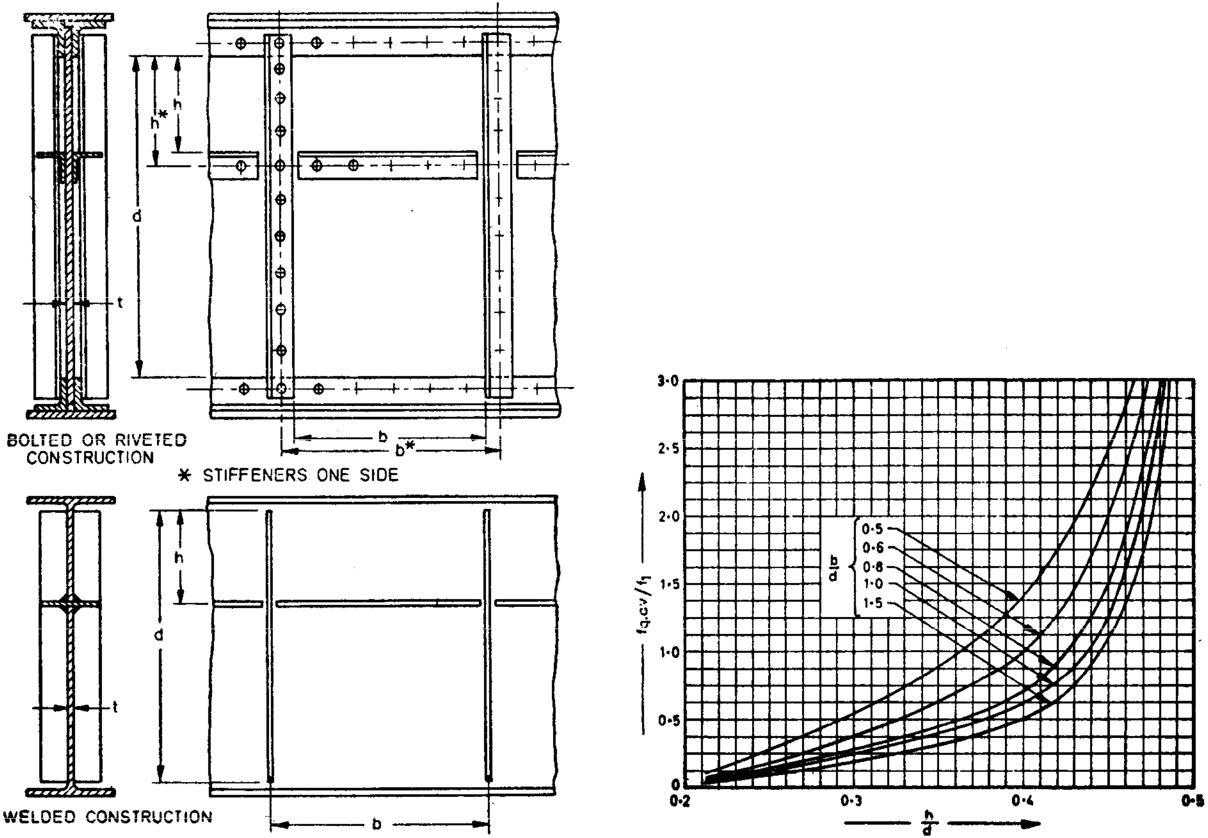
b = the transverse stiffener spacing (*see* **8.3.6.4**), and

h = the distance from compression flange (root fillet or toe 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 shall extend fully between intermediate transverse stiffeners, but may be interrupted at each of them.

Longitudinal stiffeners shall 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.

8.3.6.6 *Thickness of transverse and longitudinal stiffeners* — The outstanding leg of a plate stiffener or a web-attached angle stiffener shall 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* **8.4.1**).



NOTE — Symbols are defined in **8.3.6.**

FIG. 10 OPTIMUM SPACING OF LONGITUDINAL STIFFENERS

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

$$13{\cdot}5\ t_s^2/t$$

where

t_s = the thickness of the attached leg of the stiffener, and

t = the thickness of the web.

8.3.6.7 *Connection of transverse and longitudinal stiffeners* — A transverse or longitudinal stiffener, not subject to external loads, shall 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:

$$123\ t^2/s\ N/mm$$

where

t = the thickness of the web in mm, and

s = the unsupported width of the outstanding leg of the stiffener in mm.

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

8.3.7 *Built-Up Beams: Permissible Stresses*

8.3.7.1 *Section properties* — The effective areas of flanges and webs, and the basis for determining flange stresses, are given in **8.3.2**.

8.3.7.2 *Flanges* — Permissible stresses for flanges are given in **8.3.3.1**.

8.3.7.3 *Unstiffened webs* ($d/t \leqslant C_1$ *in Table 9*).

a) *In shear* — Permissible average shear stresses for unstiffened webs are dealt with in **8.3.3.2**.

b) *In pure bending* — The bending compressive stress shall not exceed the permissible value obtained from the curve $h/d=0$ in Fig. 11, where h and d have the meanings given in **8.3.6.5** and **8.3.6.4**.

c) *In combined bending and axial compression* — The total compressive stress due to combined bending and axial compression shall exceed neither the permissible compressive stress obtained from Fig. 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 Fig. 12, and d and t have the meanings given in **8.3.6.4**.

d) *In combined bending, axial compression and shear* — The following expression shall be satisfied:

$$(f_l/p_l)^n + (f_{q.av}/p_{q.av})^2 \leqslant 1$$

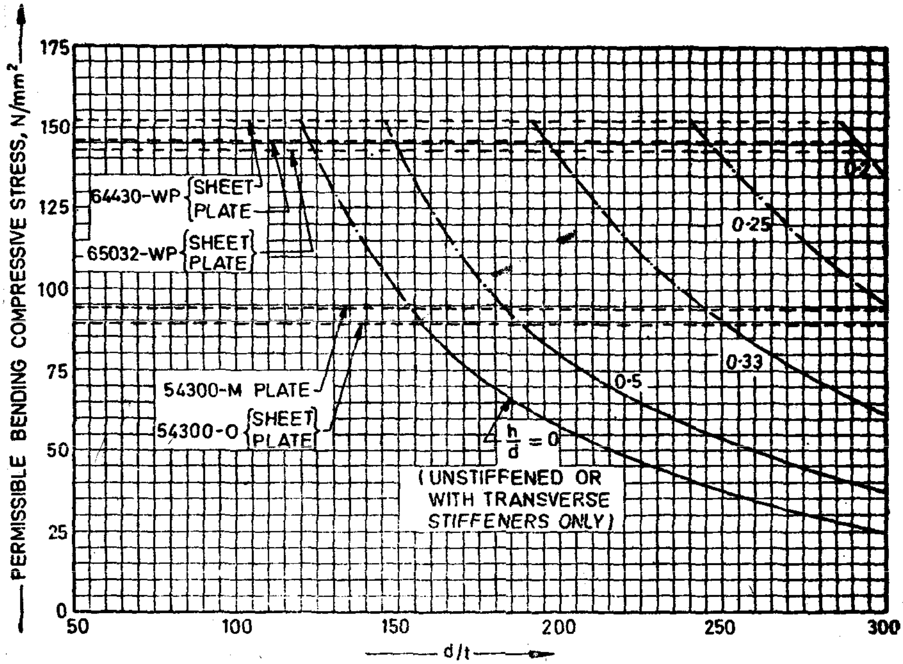


FIG. 11 PERMISSIBLE BENDING COMPRESSIVE STRESSES FOR WEBS IN PURE BENDING

where

f_l = the maximum total compressive stress due to combined bending and axial compression;

p_l = the permissible total compressive stress obtained from (c) above;

$f_{q.av}$ = the average shear stress;

$p_{q.av}$ = the permissible average shear stress obtained from (a) above; and

n = an exponent, dependent on the distribution of total longitudinal stress, as given in Fig. 13, where the above equation with the left-hand side equal to unity is plotted.

8.3.7.4 *Webs with transverse stiffeners* ($C_1 < d/t \leqslant C_2$ *in Table 9*) — The permissible stresses given in (a) to (d) below are applicable provided that the stiffeners satisfy the conditions of **8.3.6.4**, and that I_t/bt^3 is not less than 0·000 35, where I_t is the second moment of the gross area of the compression

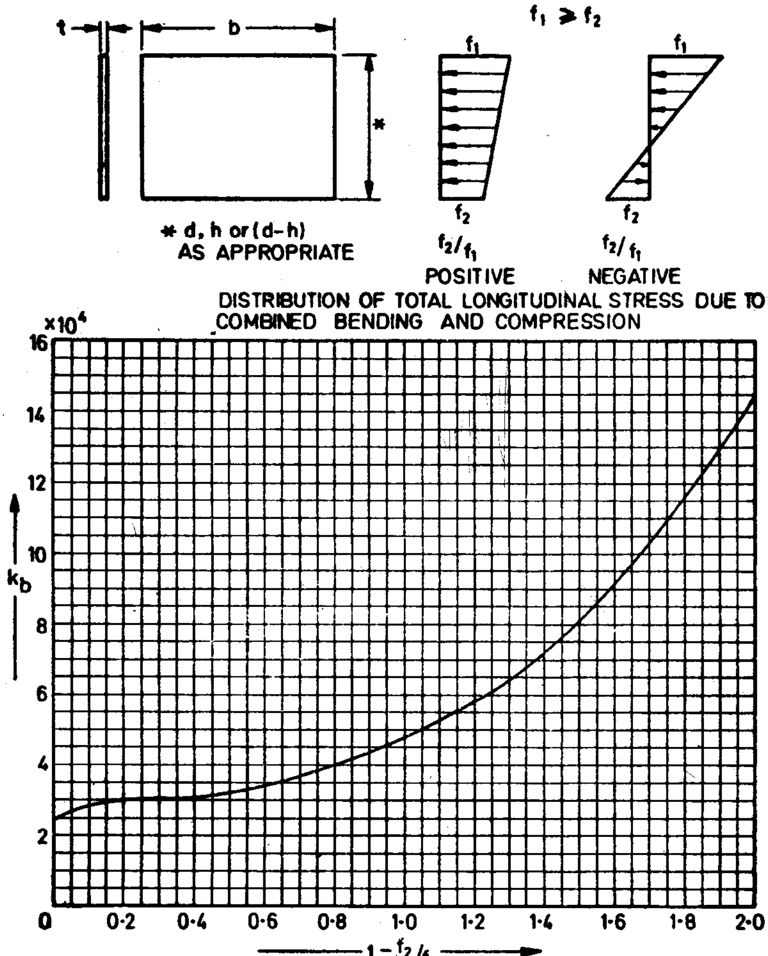
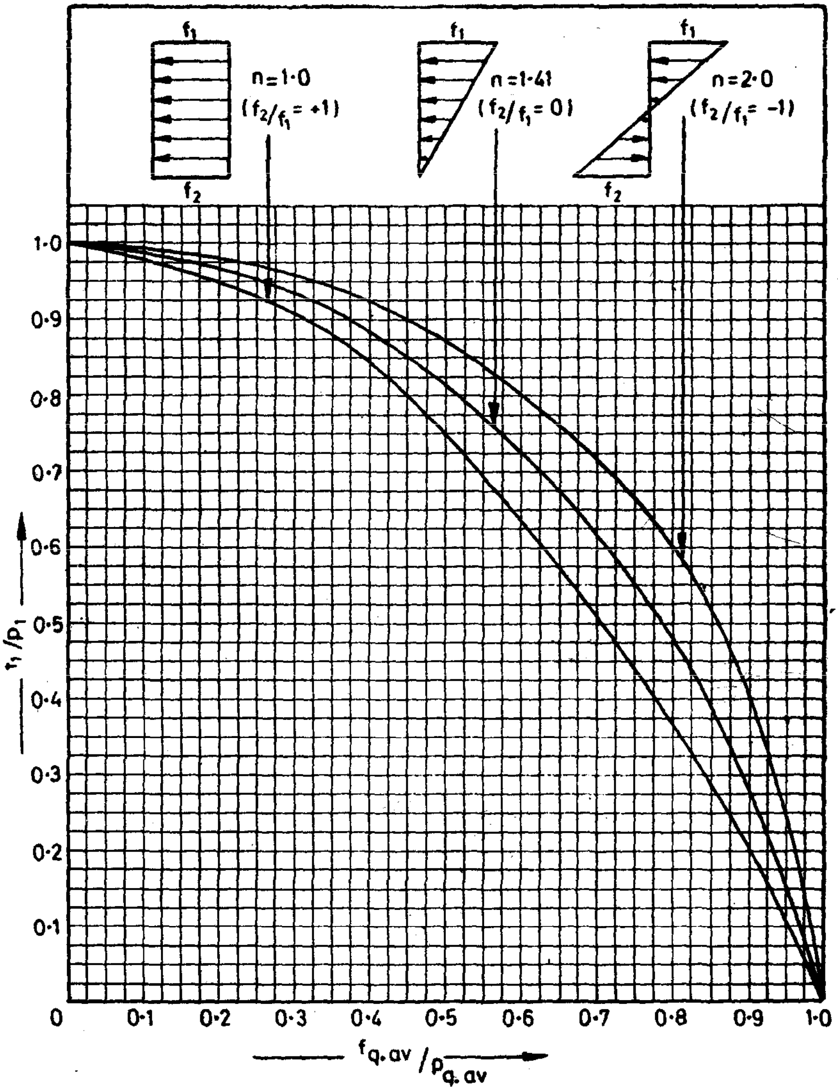


FIG. 12 BUCKLING COEFFICIENT k_b FOR COMBINED BENDING AND AXIAL COMPRESSION

flange (*see* **8.3.2.1**) about its axis normal to the web, and *b* and *t* have the meanings given in **8.3.6.4**.

a) *In shear* — Permissible average shear stresses are given in Fig. 13 for various stiffener spacings and *d*/*t* ratios, where *d* and *t* have the meaning given in **8.3.6.4**.

b) *In pure bending* — Permissible stresses are obtained as in **8.3.7.3** (b).



NOTE — Symbols are defined in **8.3.7.3** and Fig. 12.

FIG. 13 LIMITING RATIOS OF COMPRESSIVE AND SHEAR STRESSES

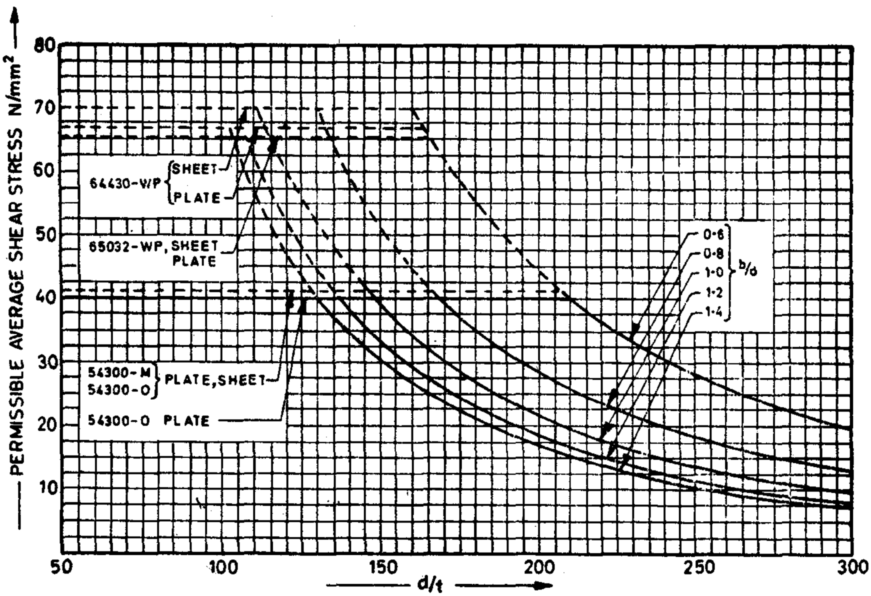
c) *In combined bending and axial compression* — Permissible stresses are obtained as in **8.3.7.3**(c).

d) *In combined bending, axial compression and shear* — The requirements of **8.3.7.3**(d), but with $p_{q \cdot av}$ as obtained from **8.3.7.4**(a) shall be satisfied.

8.3.7.5 *Webs with longitudinal and transverse stiffeners ($d/t > C_2$ in Table 9)* — The permissible stresses given in (a) to (d) below are applicable provided that the stiffeners satisfy the conditions of **8.3.6.4** and **8.3.6.5**, and that I_t/bt^3 is not less than 0·000 35, where I_t, b and t have the meanings given in **8.3.7.4**:

a) *In shear* — The average shear stress in any panel shall not exceed the permissible value obtained from Fig. 14 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 **8.3.6.4**, and h has the meaning given in **8.3.6.5**.

b) *In pure bending* — The bending compressive stress in any panel shall not exceed the permissible value obtained, by interpolation if necessary, from Fig. 11 at the appropriate h/d ratio, where h and d have the meanings given in **8.3.6.5** and **8.3.6.4** respectively.



NOTE — Symbols are defined in **8.3.6**.

FIG. 14 PERMISSIBLE AVERAGE SHEAR STRESSES IN STIFFENED WEBS

c) *In combined bending and axial compression* — The total compressive stress in any panel due to combined bending and axial compression shall exceed neither the permissible value obtained from Fig. 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 **8.3.7.3**.

d) *In combined bending, axial compression and shear* — The requirements of **8.3.7.3**(d), but applying to any panel and with $p_{q \cdot av}$ and p_1 obtained respectively from (a) and (b) of this clause shall be satisfied.

8.3.7.6 *Webs with torsionally strong stiffeners* — The requirements of **8.3.7.4** and **8.3.7.5** 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 L).

8.4 Thin Plates, Webs and Flanges

8.4.1 *Local Buckling in Compression*

8.4.1.1 *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 **8.2.5**.

8.4.1.2 *Unreinforced webs and flanges* — The permissible stresses in local buckling for unreinforced webs and flanges shall be obtained from Fig. 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 12), and b and t are the width and thickness respectively of the element (*see* Table 12).

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

8.4.1.3 *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 shall be obtained from Fig. 2 at $\lambda = mb/t$. The value of mb/t to be used is the largest of those obtained by:

a) Calculation for the flange as a web element (*see* **8.4.1.2**) where $m = 1{\cdot}6$;

b) Calculation for the lip as a flange element (*see* **8.4.1.2**) where $m = 5{\cdot}1$;

c) Calculation for the flange-lip combination where $m = 5{\cdot}1\ (1 - c^2/80\ t^2)$, c and t being the width and thickness respectively of the lip (*see* Table 12).

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

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

a) Calculation for the flange as a web element (*see* **8.4.1.2**) where $m = 1{\cdot}6$, and the width $b = b_c + t/2$ (*see* Table 12);

b) Calculation for the flange-bulb combination, where $m = 5{\cdot}1\ (1 - d^2/256\ t^2)$, d and t being the bulb diameter and flange thickness respectively (*see* Table 12).

8.4.1.5 *Welded thin-walled members* — Welded thin-walled members in materials in the O and M condition (for example 54300-O, 54300-M) may be designed as though they were unwelded.

With heat-treated materials (for example 64430-WP) and work-hardened materials (for example 53000-H1) the effect of heat affected zones (*see* **9.3.2**) 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 **8.2.8**(a).

8.4.1.6 *Very thin plates* —Where λ as obtained from **8.4.1.2** to **8.4.1.4** 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.

$$1 + \left[\lambda/\lambda_s - 1\right]\left[1 - \frac{l}{r\lambda}\right]$$

where

λ_s = the slenderness ratio corresponding to the junction of straight line and hyperbola in Fig. 2 (*see* Table 4), and

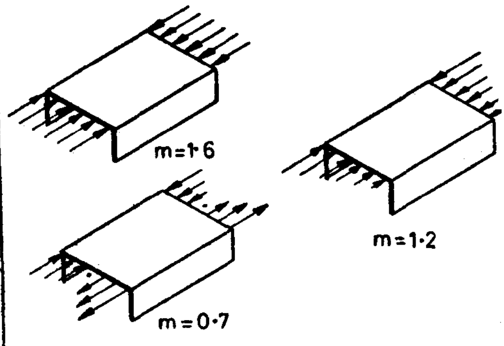
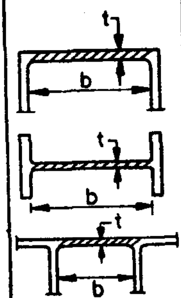
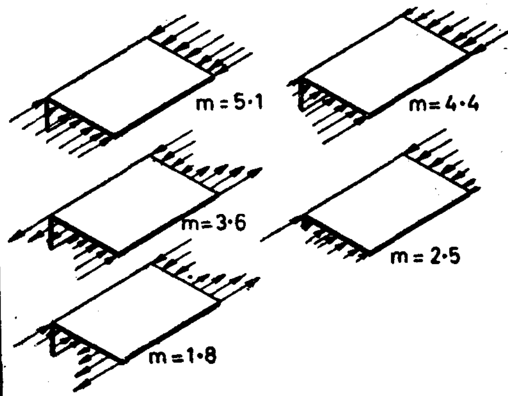
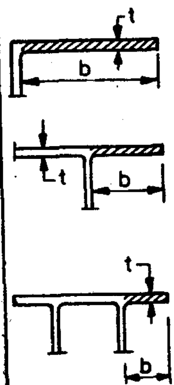
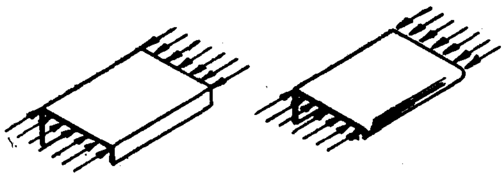
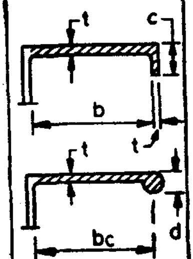
l/r = the effective slenderness ratio of the entire cross section as a strut in ordinary column buckling (*see* **8.2.3**).

8.4.2 *Shear Buckling* —For a thin rectangular panel simply supported on all four edges the permissible average shear stress shall be obtained from Fig. 7. For webs of built-up beams *see* **8.3.7.4**.

8.4.3 *Buckling Due to Bending, Axial Compression and Shear* — For thin plates in combined bending, axial compression and shear (*see* **8.3.7.3**).

TABLE 12 LOCAL BUCKLING COEFFICIENT, m

(*Clause* 8.4.1)

BOTH EDGES SUPPORTED (e.g. a web)		
ONE EDGE SUPPORTED; ONE EDGE FREE (e.g. a Flange)		
ONE EDGE SUPPORTED; ONE EDGE WITH LIP OR BULB	 for m see 8.4.1.3 / for m see 8.4.1.4.	

9. JOINTS

9.1 General —To avoid eccentricity, members meeting at a joint shall, 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 shall be designed to resist adequately the bending moments arising therefrom.

Joints of a type liable to produce indeterminate distributions of stress shall 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 number of one type of fastening (bolting, riveting, welding or other) shall be provided to resist the forces.

9.2 Bolted and Riveted Joints

9.2.1 *Permissible Stresses* — Permissible stresses in shear and in tension for close-fitting bolts (*see* **9.2.2**) and solid rivets of certain materials are given in Table 13. Values for aluminium-alloys not tabulated may be established by the procedures given in Appendix F.

The use of cold-driven aluminium rivets in tension is not recommended. The use of 24345-WP bolts in tension is not permitted.

The permissible stress in shear for a bolt in a clearance hole (*see* **9.2.2**) 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 secondary alloys are given in Table 4 and Table 25 respectively. 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 F. If the edge distance on the bearing side of a bolt or rivet is less than the appropriate limit given in **9.2.2**, the permissible bearing stress shall be reduced by multiplying it by the edge distance and then dividing by the appropriate limit.

With bolts, the shear and bearing areas shall 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 14.

9.2.2 *Details*

a) *Diameter* —The diameter of a bolt or solid rivet in tension should generally be not less than 12 mm and shall not be less than 10 mm. The diameter of a bolt or solid rivet in shear should generally be not less than 8 mm and shall not be less than 6 mm.

TABLE 13 PERMISSIBLE STRESSES FOR BOLTS AND RIVETS IN N/mm² (kgf/mm²)

(*Clause* 9.2.1)

Item	Material	Process	Diameter* mm	Shear	Tension
Bolts†	64430-WP (H30-WP)	—	Up to 6·3 mm	62 (6·3)	64 (6·5)
			6·3 mm or more	69 (7·0)	68 (6·9)
	Steel	—	Up to 20 mm	98 (10·0)	77 (7·8)
			20 mm to 38 mm (Both inclusive)		93 (9·5)
Rivets†	64430-W (H30-W)	Cold driven	Any	62 (6·3)	Not recommended
	53000-O (N5-O)	Cold driven		54 (5·5)	
		Hot driven		49 (5·0)	‡
	Steel	Power driven (shop)		100 (10·2)	77 (7·8)
		Power driven (field)		93 (9·5)	62 (6·3)

*Permissible diameters are given in **9.2.2**.

†Close fitting bolts and solid rivets for bolts in clearance holes (*see* **9.2.1**).

‡Information not available. Permissible stress shall be obtained in accordance with Appendix F.

TABLE 14 HOLE CLEARANCES FOR BOLTS AND RIVETS

(*Clauses* 9.2.1 *and* 9.2.2)

ITEM	TYPE	MATERIAL	DIAMETER mm	MAXIMUM CLEARANCE ON DIAMETER mm
Bolts	Close-fitting	—	Any	0·13*
	Not close-fitting		Up to, but excluding 12	0·4*
			12 or more	0·8*
Rivets	Solid	Aluminium	Up to, but excluding 12	0·4
			12 or more	0·8
		Steel or corrosion-resisting steel	Up to, but excluding 12	0·8
			12 or more	1·6
	Tubular	As recommended by manufacturer		

*From measurements of actual bolt and hole diameters; the clearance shall 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 0·13 mm except where the hole is deep and the spraying consequently non-uniform.

b) *Minimum spacing* — The spacing between centres of bolts and rivets shall be not less than two and a half times the bolt or rivet diameter.

c) *Maximum spacing* — In tension members the spacing of adjacent bolts or rivets on a line in the direction of stress shall exceed neither 16 t, where t is the thickness of the thinnest outside ply, nor 200 mm; in compression or shear members it shall exceed neither 8 t nor 200 mm. In addition, the spacing of adjacent bolts or rivets on a line adjacent and parallel to an edge of an outside ply shall exceed neither 8 t nor 100 mm. Where bolts and rivets are staggered on adjacent lines and the lines are not more than 75 mm apart the above limits may be increased by 50 percent.

In any event the spacing of adjacent bolts or rivets, whether staggered or not, shall exceed neither 32 t nor 300 mm in tension members and neither 20 t nor 300 mm in compression and shear members.

d) *Edge distance* — With extruded, rolled or machined edges, the edge distance (measured from the centre of the bolt or rivet) shall be not less than one and a half times the bolt or rivet diameter. If, on the bearing side, it is less than twice the diameter the permissible bearing stress shall be reduced as in **9.2.1**.

With sheared edges, the above limits shall be increased by 3 mm.

e) *Hole clearance* — The hole clearance shall be in accordance with Table 14. Bolts that transmit fluctuating loads, other than those caused by wind, shall be close-fitting.

f) *Washers and locking devices* — Washers shall be used in accordance with **13.1**.

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

9.2.3 *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 of same type and size as, and similarly loaded to, those in the actual structure.

9.2.4 *Packing* — The number of bolts or rivets carrying shear through a packing shall be increased above that required by normal calculation by 2 percent for each 1·5 mm of the total thickness of the packing beyond 6·0 mm. For double-shear joints packed on both sides, the number of additional bolts or rivets shall be determined from the thickness of the thicker packing. The additional bolts or rivets may be placed in extensions of the packing.

9.2.5 *Countersinking* — One half of the depth of any countersinking of a bolt or rivet shall 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 shall be taken as two-thirds of that of a plain one of the same diameter. The depth of countersinking shall not exceed the thickness of the countersunk part less 4 mm.

9.2.6 *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 shall be increased above that required by normal calculation by 1 percent for each additional 1·5 mm of grip. The total grip shall not exceed five times the diameter.

9.3 Welded Joints

9.3.1 *Exchange of Information* — Drawings and specifications shall be provided, giving the following information about every weld:

a) Parent and filler material;

b) Dimensions of weld;

c) Edge preparation, welding position;

d) Welding process; and

e) Any special requirements, such as smoothness of weld profile, welder's test, precautions against excessive temperature and special quality control (as required, for example, in **10.4**).

9.3.2 *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 (for example 54300-O and 54300-M) will, after welding, still have tensile properties close to or equal to the specified ones.

Aluminium in other than the annealed condition (for example 64430-WP, 63400-WP, and 54300 in a temper harder than 54300-M), shall, irrespective of its thickness, be assumed in design to have heat affected zones extending over a distance of 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 heat affected zone extends for less than 25 mm, an appropriate smaller distance may be assumed.

9.3.3 *Permissible Stresses* — Permissible stresses for welded joints, and for cross sections consisting entirely of heat affected zones, in the recommended combinations of parent and filler material (*see* Table 3) are given in Table 15.

Permissible stresses for other combinations of parent and filler material may be established by the procedure given in Appendix F.

The permissible stress in compression may be taken as equal to that in tension, except where buckling may occur; in such cases design shall be in accordance with **8.2.8** and **8.4.1.**

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 minus 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:

a) 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

b) 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 minus, 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 shall be ascertained, in tension or in shear as may be appropriate, by taking into account the effect of heat affected zones. For tension the procedure in **8.1.2.1**(b) shall be followed. For shear the same procedure, but using the permissible shear stresses p_q (*see* Tables 4 and 15) shall be followed.

Reference may be made to IS : 812-1957* for definitions of terms used above.

TABLE 15 PERMISSIBLE STRESSES FOR WELDED JOINTS AND HEAT AFFECTED ZONES

(*Clause* 9.3.3)

Parent Metal	Stresses in Butt Welded Joints and Heat Affected Zones in		Stresses in Fillet Welded Joints* (Weld Metal)	
	Tension p_{wt} N/mm² (kgf/mm²)	Shear p_{wq} N/mm² (kgf/mm²)	Transverse N/mm² (kgf/mm²)	Longitudinal N/mm² (kgf/mm²)
64430 (H 30)	51 (5·2)	31 (3·1)	54 (5·5)	31 (3·1)
65032 (H 20)	51 (5·2)	31 (3·1)	54 (5·5)	31 (3·1)
63400 (H 9)	31 (3·1)	19 (1·9)	54 (5·5)	31 (3·1)
54300 (N 8)	82 (8·3)	48 (4·9)	73 (7·4)	46 (4·7)
53000 (N 5)	62 (6·3)	37 (3·8)	65 (6·6)	36 (3·7)

*Values apply to the effective throat area of weld metal, filler wire shall be in accordance with Table 3.

*Glossary of terms relating to welding and cutting of metals.

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

a) *Intermittent butt welds* — Intermittent butt welds shall not be used.

b) *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 alternate sides of the part, shall 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 shall not exceed 300 mm.

c) *Longitudinal fillet welds* — If longitudinal fillet welds along the edges are used in an end connection, the length of each shall be not less than the distance between the welded edges.

d) *Edge preparations* — Appendix P gives guidance on the choice of edge preparation for welded joints.

9.4 Other Joints — A joint made by means other than those dealt with in **9.2** to **9.3** may be used provided that its load-carrying capacity can be demonstrated to be satisfactory and is approved by the engineer.

10. FATIGUE

10.1 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. Discontinuties such as bolt or rivet holes, welds and other local or general changes in geometrical form set up stress concentrations. Details shall be worked out to avoid, as far as possible, stress concentrations which may give rise to excessive reduction of the fatigue strength of members or connections. Guidance on the design of welded joints is given in Appendix N.

10.2 Loads and Stresses — When designing against fatigue failure, stresses due to all combinations of loads (*see* Section II), and secondary stresses such as result from eccentricity of connections and loading shall be considered. Members subject to wind loading may be liable to fluctuating stress and, therefore, shall 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 shall be estimated as accurately as possible. The accumulation of all these stress cycles shall be used in design against fatigue failure (*see* **10.3.3**).

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 lower-cycle fatigue, and expert advice should be sought.

The stresses to be considered in fatigue are principal stresses; for example in the design of webs and web-to-flange joints in built-up beams the combined effect of shear and bending shall be considered, and in butt joints the effect of any eccentricity shall be included*.

The terms used above to describe fluctuating loads are defined as follows (*see* Fig. 15):

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.

10.3 Permissible Stresses

10.3.1 *General* — The permissible stresses, to which no additional safety factor need be applied, for 9 classes of member (*see* **10.4**) are given in Fig. 16 to 24. 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 64430, 54300, 65032, 24345, 52000 and 53000; they do not apply to 63400, as there are no experimental data available.

For welded members (all other classes), the stresses apply to the above alloys except 24345 and also to 63400.

*An approximate method allowing for eccentricity in the thickness direction, whether due to misalignment, eccentricity or variation of thickness (*see* Table 30) is to multiply the nominal stress by ($1 + 3e/t$), where e is the distance between centres of thickness of the two abutting member if one of the members is tapered, the centre of the untapered thickness shall be used; and t is the thickness of the thinner member.

With connections which are supported laterally (for example the flange of a beam which are supported by the web (*see* Table 30), eccentriticity may be neglected.

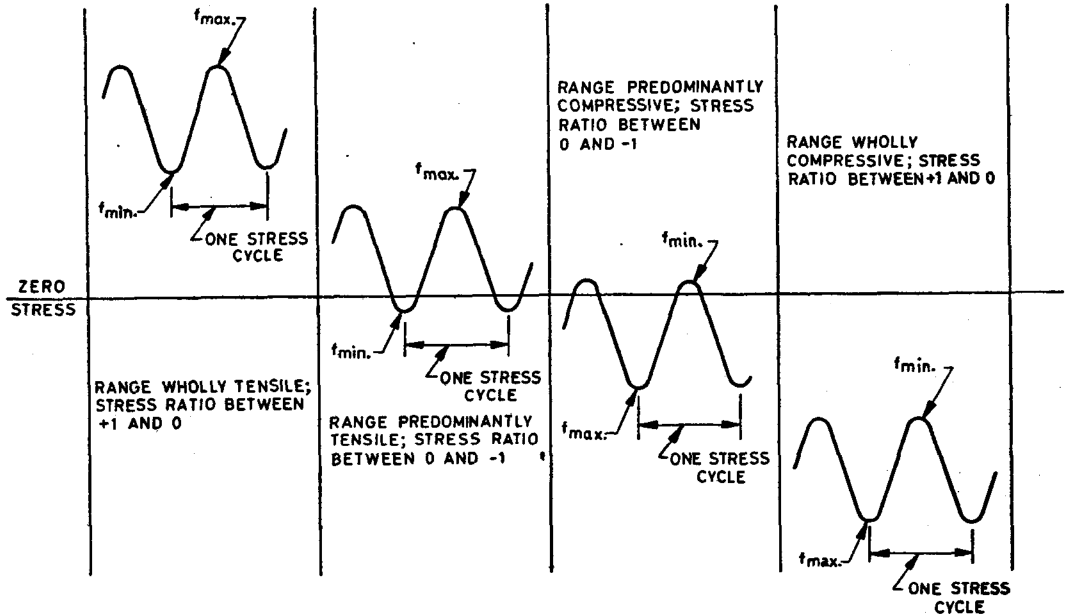


FIG. 15 MAXIMUM AND MINIMUM STRESSES AND STRESS CYCLE

In the sets of curves for maximum tensile stress (Fig. 16A to 24A) the parts of the curves corresponding to values of the stress ratio in excess of 0·5 are shown in broken lines. The precise values of f_{Max} in this range may be calculated from:

$$f_{Max} = f_{0\cdot5}/2\ (1 - f_{Min}/f_{Max}),$$

where

$f_{0\cdot5}$ = the maximum stress corresponding to the stress ratio 0·5,

f_{Max} = the maximum stress, and

f_{Min}/f_{Max} = the stress ratio.

Interpolation between adjacent curves shall 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 stress adopted in Fig. 16 to 24 may not be the most convenient for some design procedures. The information is, therefore repeated, in Appendix Q in tabular form.

10.3.2 *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.

10.3.3 *Non-uniform Load Fluctuations* — In the general case of members subjected to a stress spectrum, namely to number of cycles $n_1, n_2 \ldots\ldots n_n$, of different maximum stress at different stress ratios, the following design method shall be used:

a) All cycles with a maximum stress equal to or lower than the permissible stress given for members of Class 9 in Fig. 24 for 10^8 cycles and for the relevant stress ratio may be ignored.

b) 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 (a) above shall be divided into at least five groups defined by maximum stresses equally spaced between the algebraically smallest and largest.

c) For the above groups, the corresponding permissible numbers of cycles $N_1, N_2, \ldots\ldots\ldots, N_n$, shall be determined, if necessary by logarithmic interpolation, from the figure appropriate to the class of member (*see* **10.4**). 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 shall 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.

d) The member shall then be designed so that :

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

10.4 Classification of Structural Members

10.4.1 *Classes* — The 9 classes of members, in descending order of fatigue strength, are:

Class 1 — Members consisting of plain wrought material with edges as extruded or carefully machined or filled 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* **14.7**). To qualify for Class 2, this type of member shall comply with **10.4.2**.

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 (for example, 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 shall comply with **10.4.3**.

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 3·0 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 shall comply with **10.4.4**.

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 shall comply with **10.4.5**.

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 shall comply with **10.4.5**.

ii) Members with transverse butt welds made from both sides, but with the height of the reinforcement above the parent metal greater than that permitted in (ii) of Class 3. To qualify for Class 4, this type of member shall comply with **10.4.4.**

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 shall comply with **10.4.4.**

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 members shall comply with **10.4.4.**

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 shall comply with **10.4.6.**

Class 7

i) Members with continuous longitudinal fillet welds with interruptions which have not been repaired in accordance with **10.4.5.**

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 shall comply with **10.4.6.**

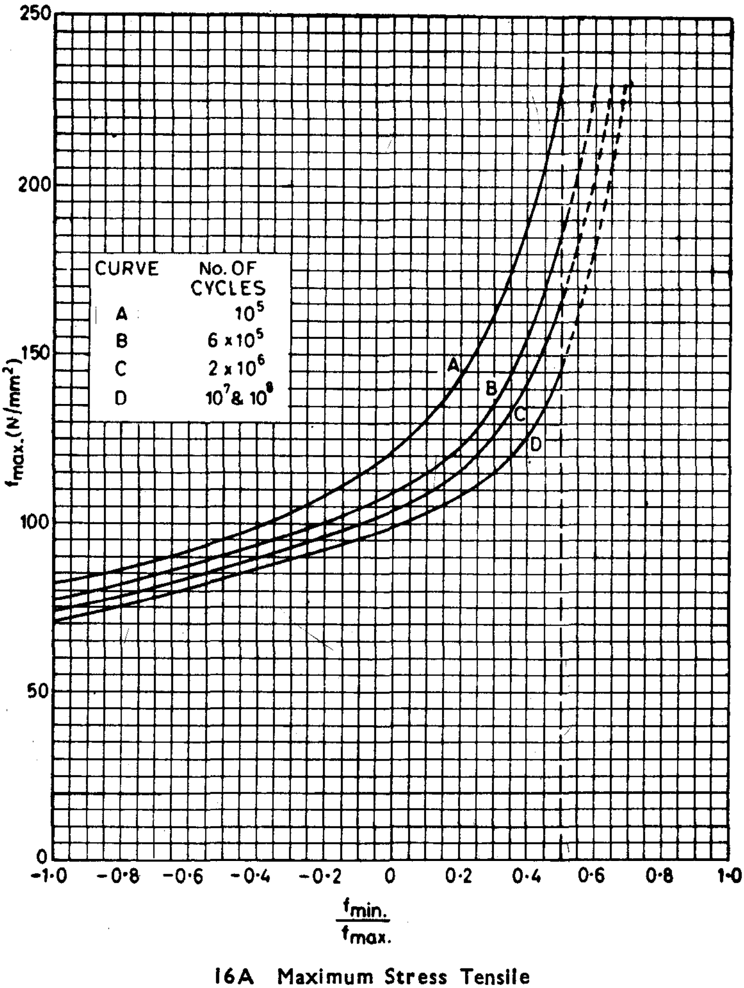
Class 8—Members with discontinuous longitudinal non-load-carrying fillet or butt welds; this class includes beams with intermittent web-to-flange welds.

Class 9—Members with discontinuous longitudinal load-carrying fillet or butt welds. To qualify for Class 9, this type of member shall comply with **10.4.6.**

10.4.2 *Dressed Butt Welds* — Butt welds for members described in Class 2 shall be dressed flush by machining in the direction of the applied stress; the members shall have edges as extruded or carefully machined or filled in the direction of the stress.

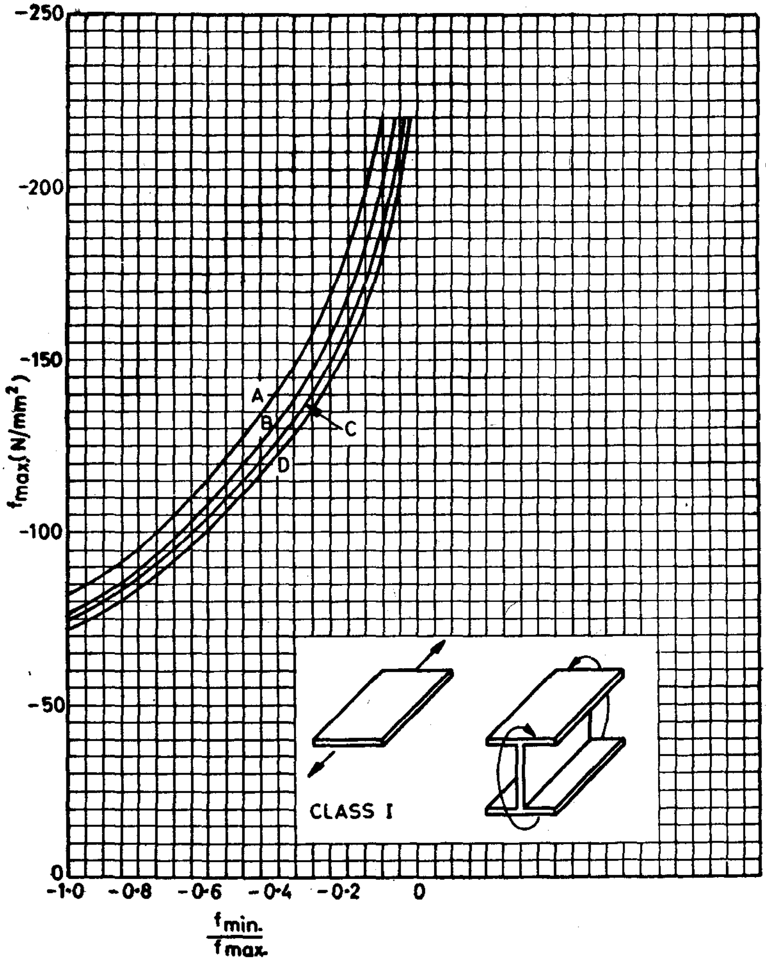
10.4.3 *Bolts and Rivets* — Bolts or rivets for members described in (i) of Class 3 shall be proportioned to develop the full static strength of the member; bolts shall be secured against working loose [*see* **9.2.2**(f)].

10.4.4 *Butt 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,



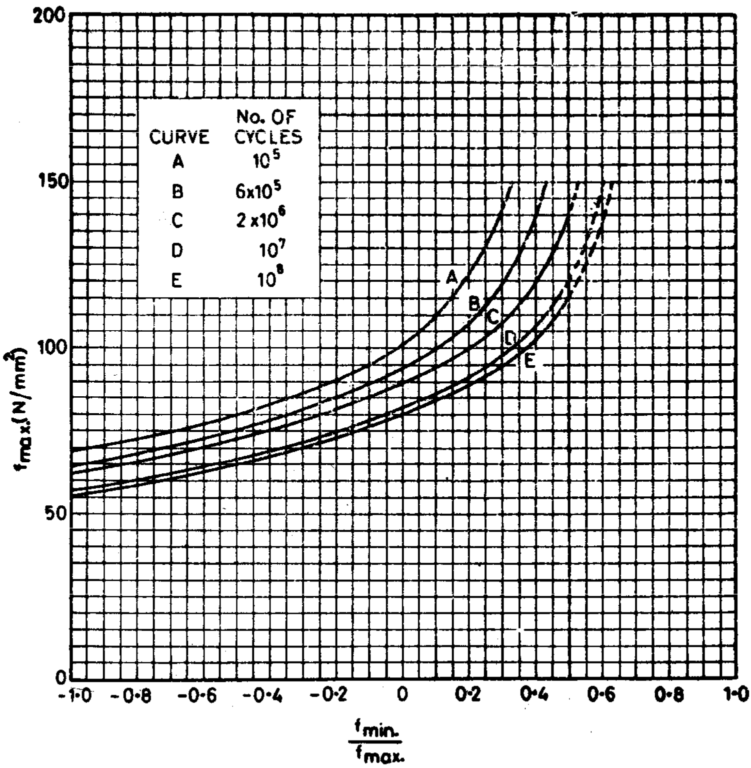
16A Maximum Stress Tensile

FIG. 16 CURVES RELATING MAXIMUM STRESS, STRESS RATIO AND NUMBER OF CYCLES FOR CLASS 1 MEMBERS — *Contd*



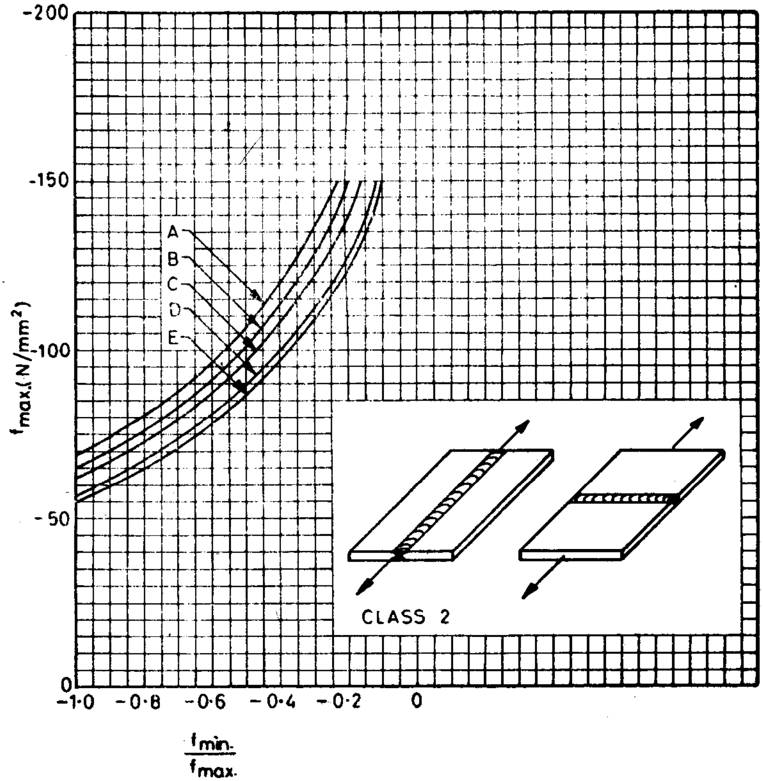
16B Maximum Stress Compressive

FIG. 16 CURVES RELATING MAXIMUM STRESS, STRESS RATIO AND NUMBER OF CYCLES FOR CLASS 1 MEMBERS



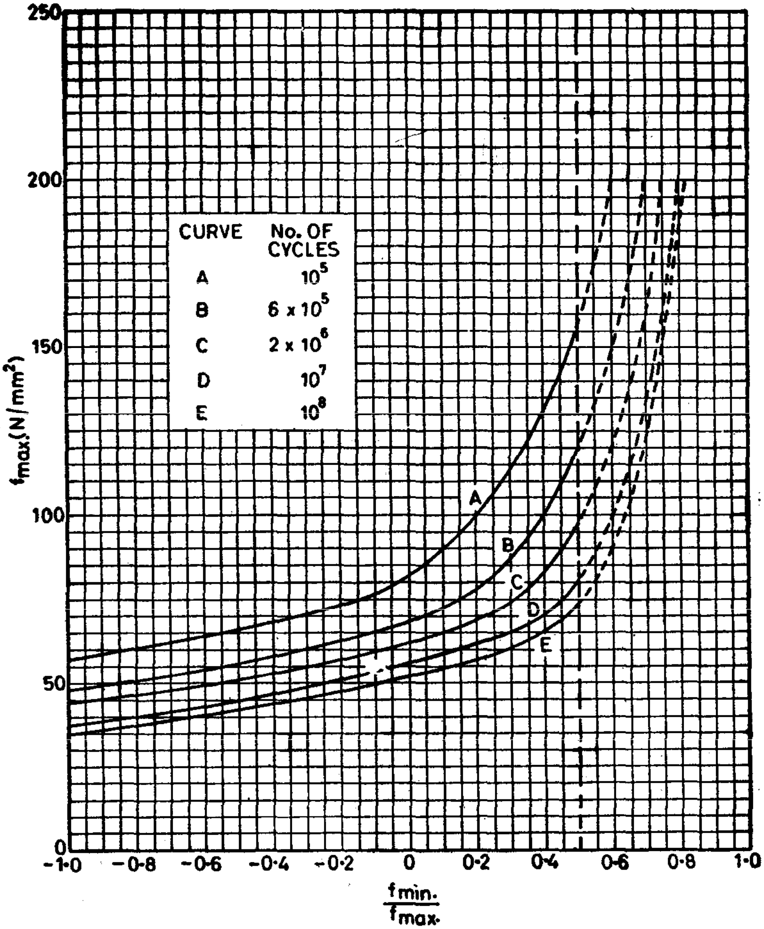
17A Maximum Stress Tensile

FIG. 17 CURVES RELATING MAXIMUM STRESS, STRESS RATIO AND NUMBER OF CYCLES FOR CLASS 2 MEMBERS — *Contd*



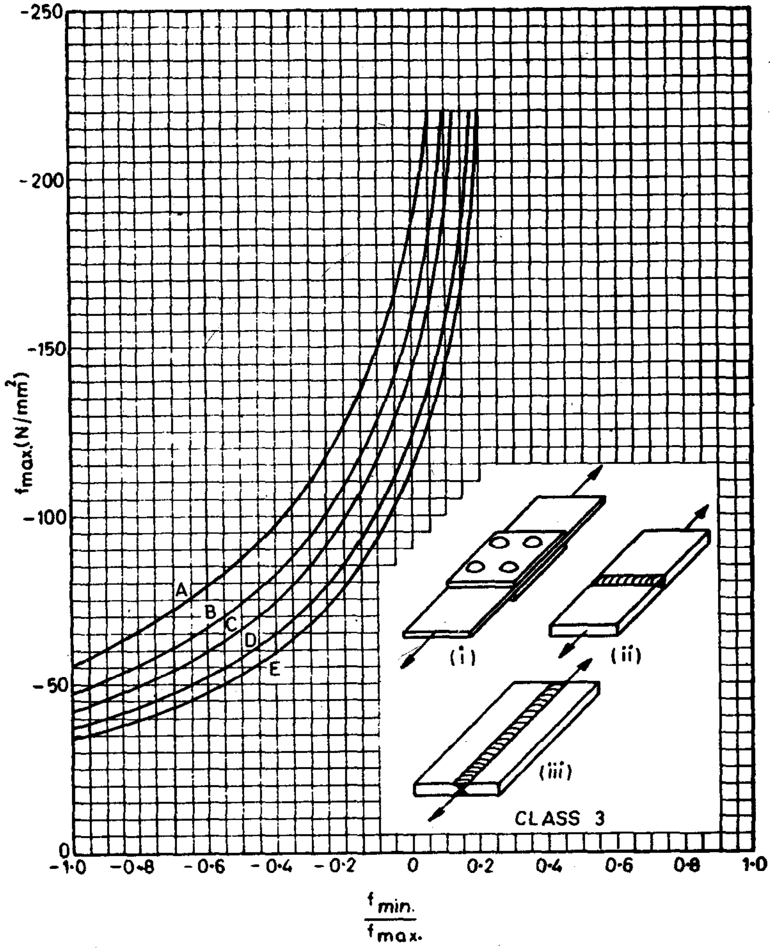
17B Maximum Stress Compressive

FIG. 17 CURVES RELATING MAXIMUM STRESS, STRESS RATIO AND NUMBER OF CYCLES FOR CLASS 2 MEMBERS



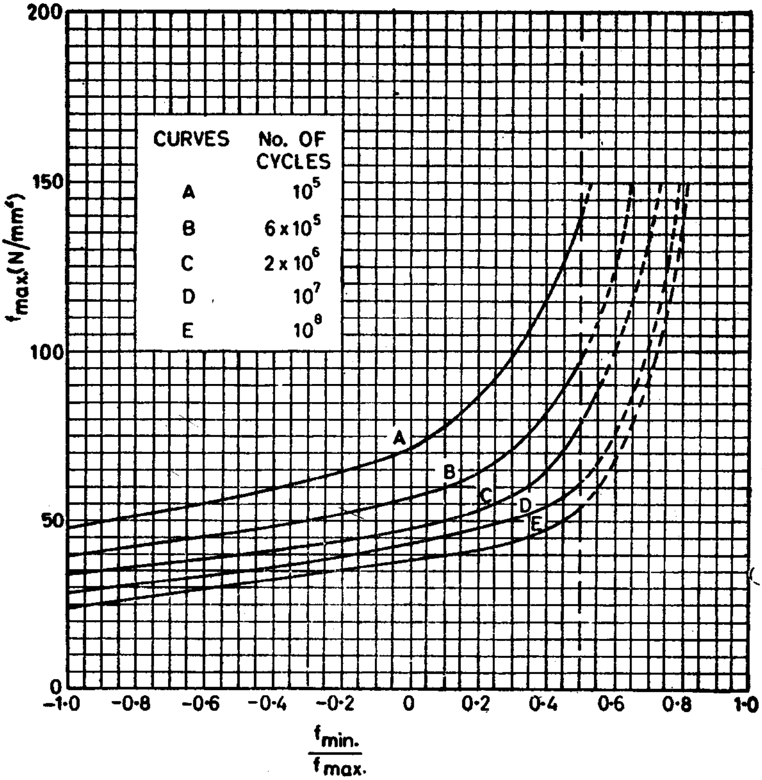
18A Maximum Stress Tensile

FIG. 18 CURVES RELATING MAXIMUM STRESS, STRESS RATIO AND NUMBER OF CYCLES FOR CLASS 3 MEMBERS — *Contd*



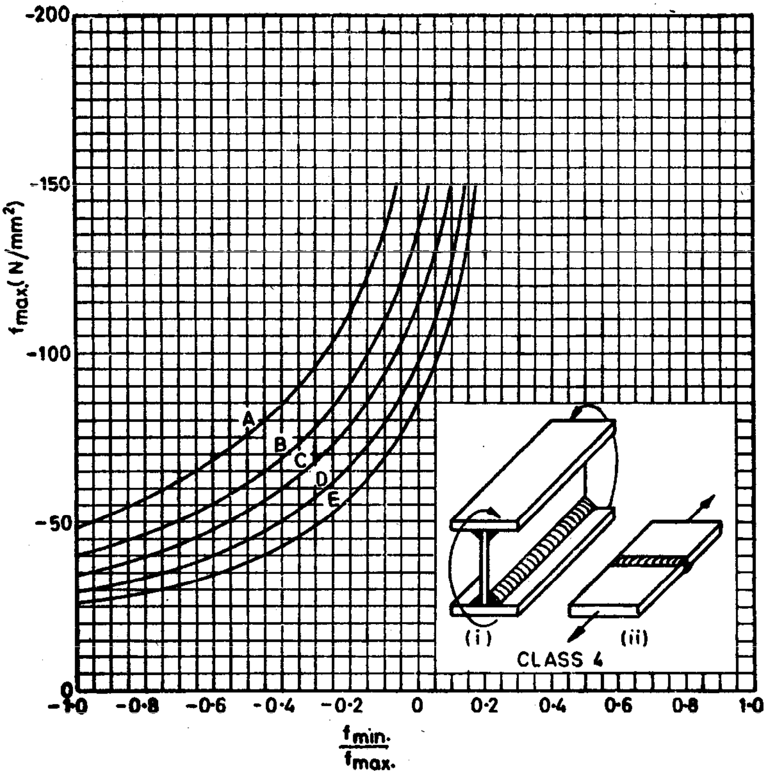
18B Maximum Stress Compressive

FIG. 18 CURVES RELATING MAXIMUM STRESS, STRESS RATIO AND NUMBER OF CYCLES FOR CLASS 3 MEMBERS



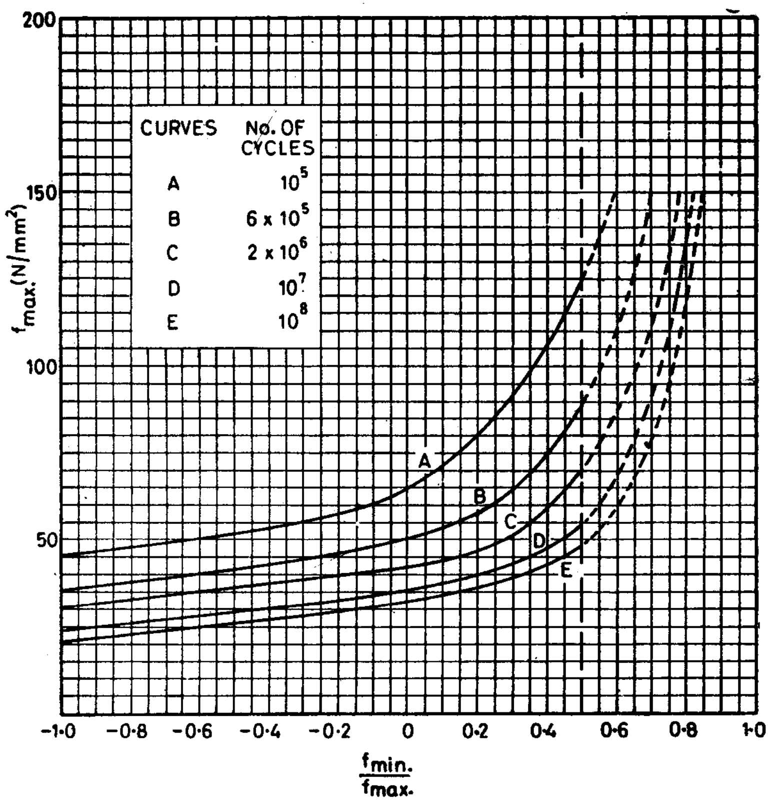
19A Maximum Stress Tensile

FIG. 19 CURVES RELATING MAXIMUM STRESS, STRESS RATIO AND NUMBER OF CYCLES FOR CLASS 4 MEMBERS — *Contd*



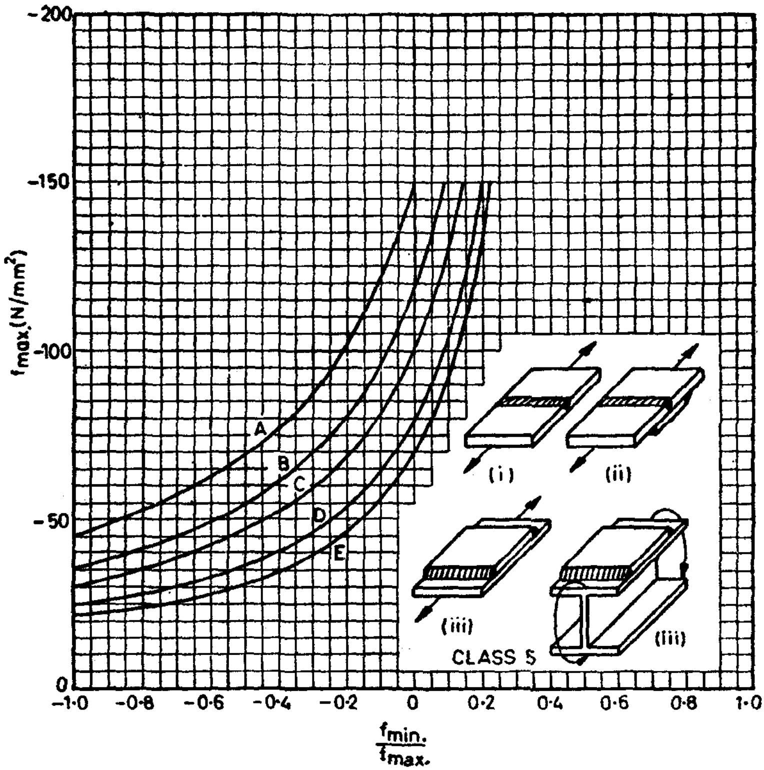
19B Maximum Stress Compressive

FIG. 19 CURVES RELATING MAXIMUM STRESS, STRESS RATIO AND NUMBER OF CYCLES FOR CLASS 4 MEMBERS



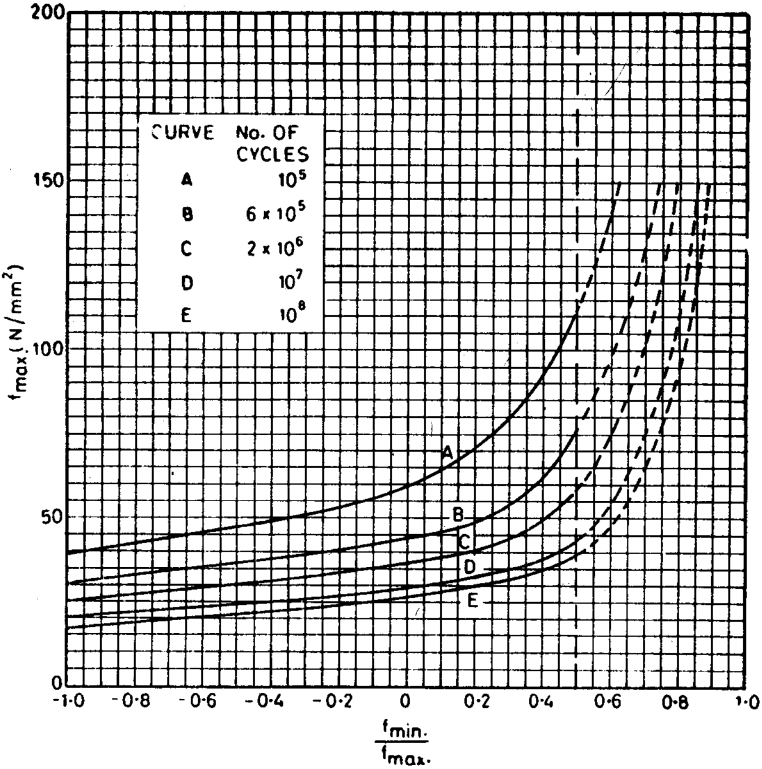
20A Maximum Stress Tensile

FIG. 20 CURVES RELATING MAXIMUM STRESS, STRESS RATIO AND NUMBER OF CYCLES FOR CLASS 5 MEMBERS — *Contd*



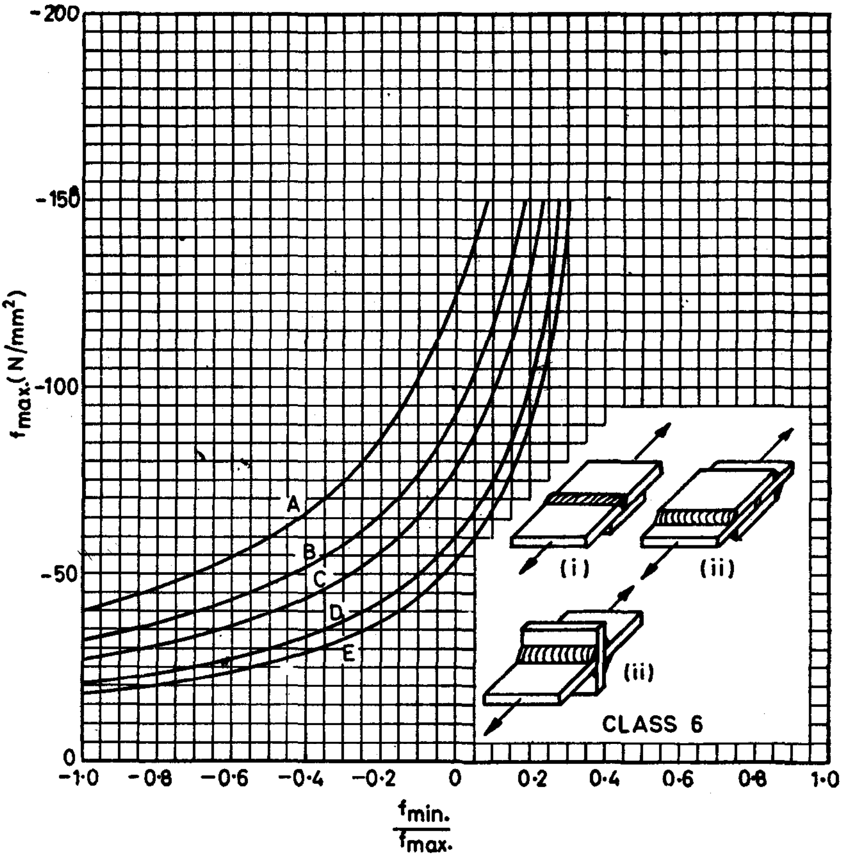
20B Maximum Stress Compressive

Fig. 20 Curves Relating Maximum Stress, Stress Ratio and Number of Cycles for Class 5 Members



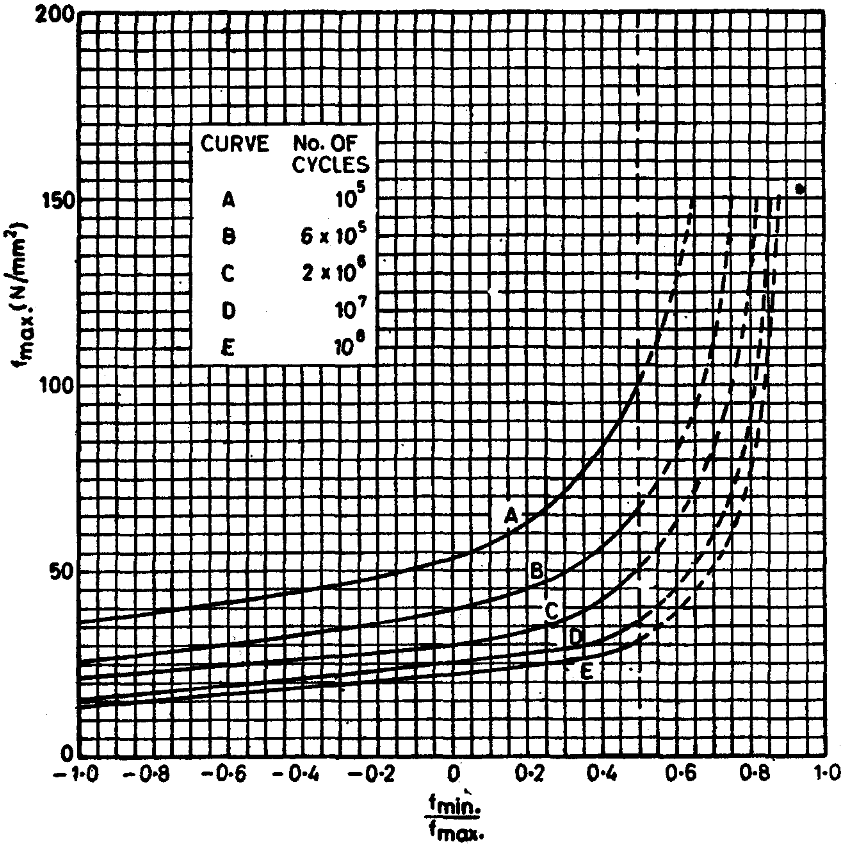
21A Maximum Stress Tensile

FIG. 21 CURVES RELATING MAXIMUM STRESS, STRESS RATIO AND NUMBER OF CYCLES FOR CLASS 6 MEMBERS — *Contd*



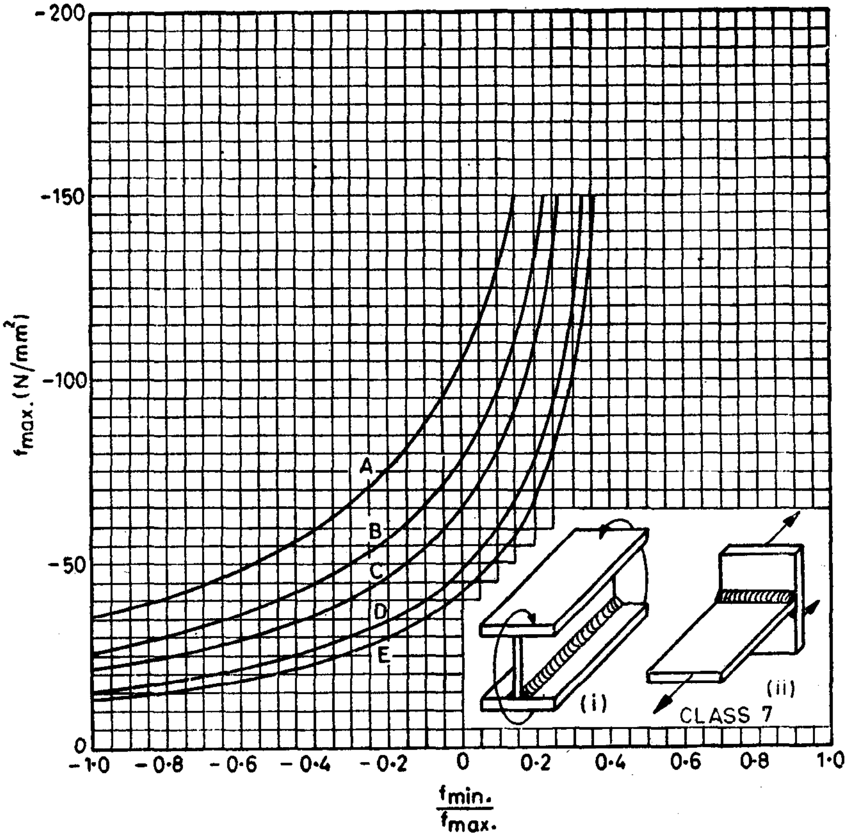
21B Maximum Stress Compressive

Fig. 21 Curves Relating Maximum Stress, Stress Ratio and Number of Cycles for Class 6 Members



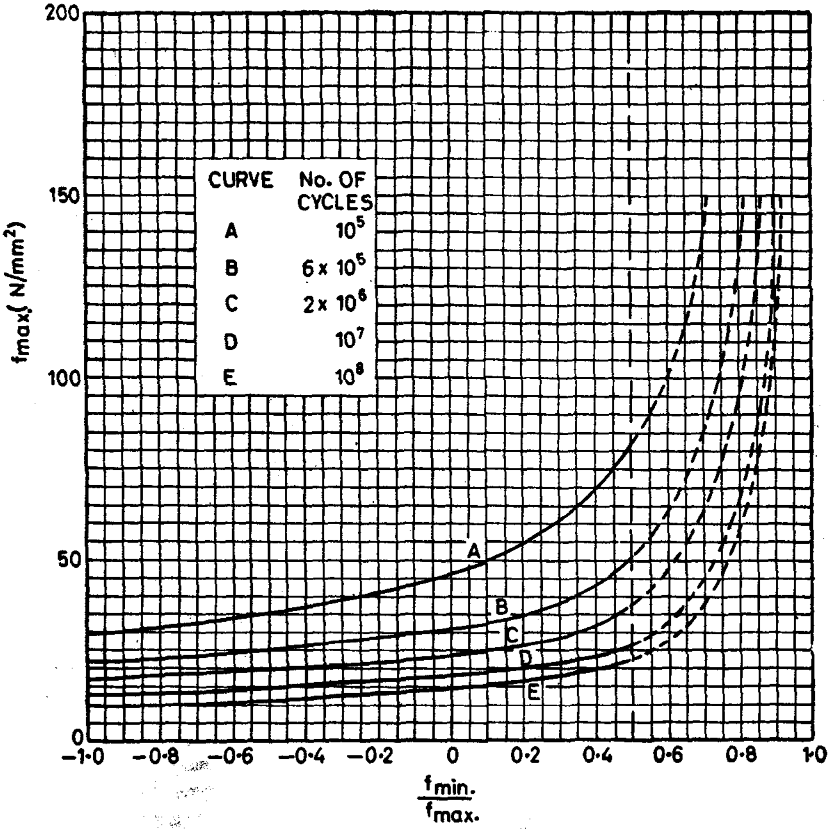
22A Maximum Stress Tensile

FIG. 22 CURVES RELATING MAXIMUM STRESS, STRESS RATIO AND NUMBER OF CYCLES FOR CLASS 7 MEMBERS — *Contd*



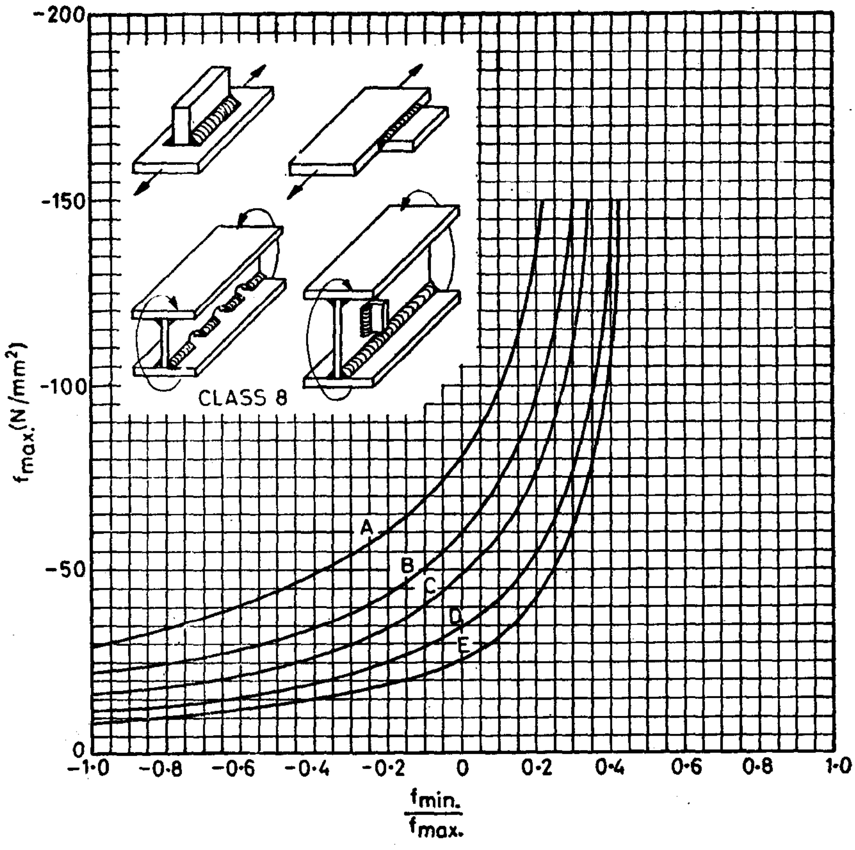
22B Maximum Stress Compressive

FIG. 22 CURVES RELATING MAXIMUM STRESS, STRESS RATIO AND NUMBER OF CYCLES FOR CLASS 7 MEMBERS



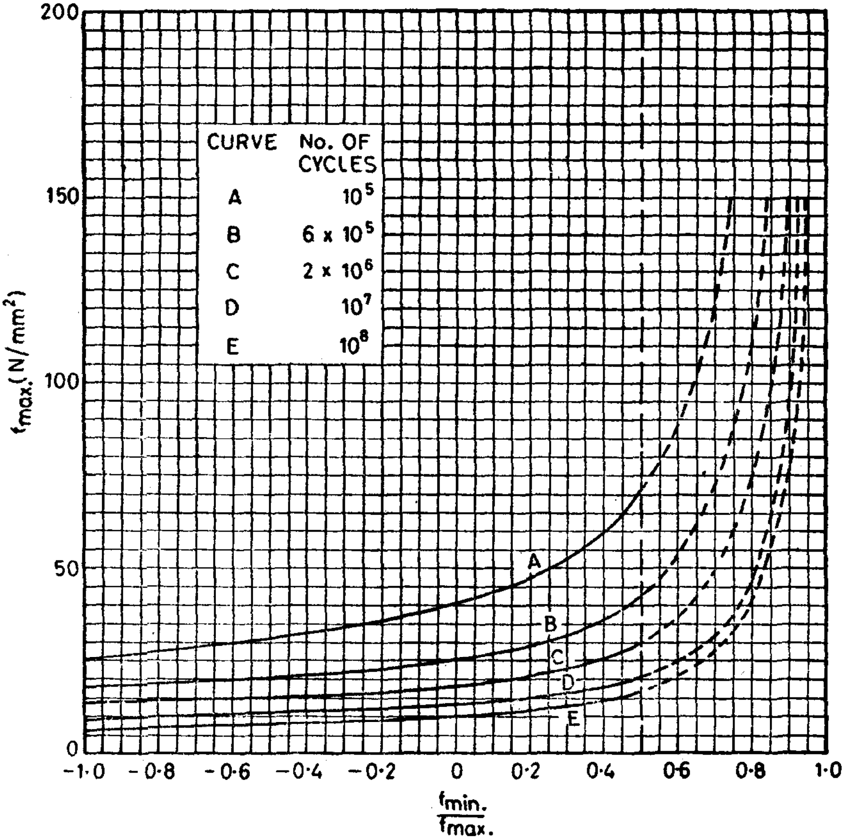
23A Maximum Stress Tensile

FIG. 23 CURVES RELATING MAXIMUM STRESS, STRESS RATIO AND NUMBER OF CYCLES FOR CLASS 8 MEMBERS — *Contd*



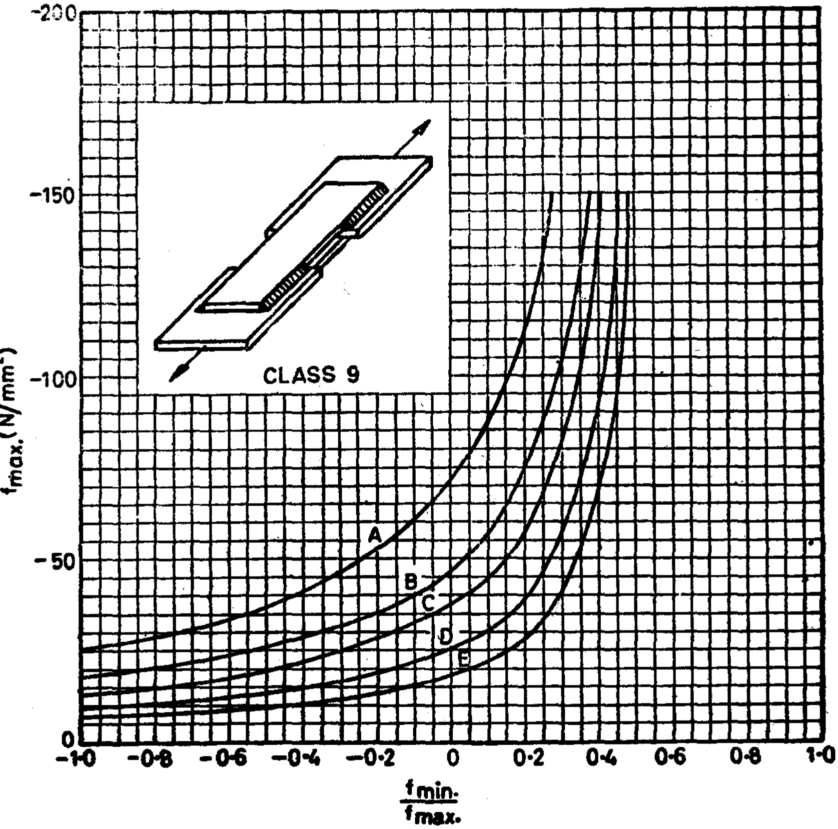
23B Maximum Stress Compressive

FIG. 23 CURVES RELATING MAXIMUM STRESS, STRESS RATIO AND NUMBER OF CYCLES FOR CLASS 8 MEMBERS



24A Maximum Stress Tensile

FIG. 24 CURVES RELATING MAXIMUM STRESS, STRESS RATIO AND NUMBER OF CYCLES FOR CLASS 9 MEMBERS — *Contd*



24B Maximum Stress Compressive

FIG. 24 CURVES RELATING MAXIMUM STRESS, STRESS RATIO AND NUMBER OF CYCLES FOR CLASS 9 MEMBERS

or (i) of Class 6, if the materials on the two sides of the joint differ in thickness by more than 3·0 mm or one-fifth of the thickness of the thinner material, whichever is smaller, the thicker material shall be tapered down to the thickness of the thinner material with a slope of about 1 in 5 (*see* Appendix N). Differences in width shall be treated similarly. The effect of misalignment on permissible stresses is dealt with in **10.2**.

10.4.5 *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 shall be chipped or machined back in the form of a taper over a length of at least eight times its width, and the weld shall 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 shall be machined or filled smooth.

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

10.4.6 *Load-Carrying Fillet Welds* — Welds for members described in (ii) of Class 6, (ii) of Class 7, or Class 9, shall 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 shall be designed so that secondary bending stresses are not introduced [for example single-lap joints would not be used except in special circumstances (*see* Table 30)].

SECTION IV TESTING

11. TESTING REQUIREMENTS AND PROCEDURE

11.1 General — A structure designed in accordance with Section III is acceptable without testing. A structure or part of a structure not so designed shall comply with either the static acceptance test described in **11.2** or the fatigue acceptance test described in **11.3** except that those tests need not apply where an alternative test is required by an appropriate specification. The choice of test shall be agreed with the engineer. An acceptance test is appropriate where:

a) the structure is not amendable to calculation or calculation is deemed impracticable,

b) design methods other than those specifically referred to in Section III are used, or

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

11.2 Static Acceptance Test*

11.2.1 *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* **10**). 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 shall be taken of any readily excited natural vibration and, if the damping characteristics are poor, arrangements shall be made to prevent or minimize such vibration in the actual structure.

11.2.2 *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 shall be carefully estimated and then multiplied by 1·1 (or by 0·9 if it acts in opposition to the live load) and applied as dead load additional to that of the incomplete structure. Any such additional dead load shall 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 shall be augmented by the appropriate impact effect.

Prior to the actual test or tests, preliminary settling-down of the structure shall 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 shall be removed again before the testing begins, but any additional dead load shall 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, produces the severest effects, shall in turn be applied to the structure in at least five approximately equal increments. They shall in each case be positioned so as to reproduce the actual live loads as realistically as possible.

11.2.3 *Duration of Loading* — The preliminary settling-down live loads shall remain in place for at least 15 minutes.

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*Attention is drawn to 'Report of a Committee on the Testing of Structures' published by the Institution of Structural Engineers in September 1964.

In the actual test, each increment of test live load shall 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 shall remain in place for at least 15 minutes before the measurements and inspection required for acceptance are made.

11.2.4 *Acceptance* — The criterion for acceptance is that the structure shall sustain the test loads without excessive deformation and without the development of deleterious defect. Beam deflections shall not exceed the values given in **8.3.1** modified appropriately to allow for the difference between the working load and the test load.

Load-deflection curves shall be plotted throughout the incremental loading or loadings, and shall be examined for signs of instability. If doubt arises from the examination, the engineer may require that the test be repeated. The engineer shall 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 shall be at least 95 percent. Failing this, the structure will be acceptable if, on repetition of the test, recovery is at least 95 percent of the deformation occurring during the repetition.

11.3 Fatigue Acceptance Test

11.3.1 *Application* — The fatigue acceptance test applies to structures or parts of structures that are subject to fluctuating loads of such magnitude and frequencies as to render fatigue failure a reasonable possibility (*see* **10**). The test is intended to show whether the structure is capable of carrying the design loads during its service life.

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

11.3.2 *Loading* — The structure shall 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 shall be represented in test by an estimated equivalent sequence of loads which shall be agreed with the engineer. The test programme shall be arranged to include at least 30 repetitions of the agreed sequence before failure.

Alternatively, the test load shall be the maximum service load, and the number of repetitions shall 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 (Fig. 24) for the appropriate values of the stress ratio and the number of cycles.

11.3.3 *Acceptance* — The criterion for acceptance will depend on whether the structure is classified as a safe-life structure (*see* **11.3.3.1**) or a fail-safe structure (*see* **11.3.3.2**).

11.3.3.1 *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 shall be done under repeated loadings as defined in **11.3.2** until failure results. The geometric mean life obtained from the effective number of specimens in these tests shall 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 shall 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.

11.3.3.2 *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 shall be done under repeated loadings as defined in **11.3.2** and shall continue until a fatigue crack is detected by the same technique as will be employed in service. The crack shall 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 shall not be affected by its presence.

A fail-safe design may, in addition, be required to have a specified minimum life which shall be established by tests as for safe life. The tests shall 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.

SECTION V FABRICATION AND ERECTION

12. GENERAL

12.1 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 easier machinability of aluminium. Aluminium lends itself to high standards of workmanship.

During erection the structure shall 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.

12.2 Handling — Care shall be taken in handling to prevent scratching or nicking of the aluminium. When required, pieces of wood or other soft material shall be inserted between the aluminium and contacting objects.

12.3 Storage and Transport — If aluminium is stored in damp conditions where condensation can take place, superficial corrosion may cause staining. When temperature and moisture condition are such that condensation may occur, heated and ventilated storage space be provided, if such condensation stain would be objectionable.

Where appearance is important, aluminium shall be stored in dry places, clear of the ground; contact with other metals and with materials such as cement and damp timber shall be avoided. Care shall 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 shall be packed so as to avoid mechanical damage, abrasion and, where appearance is important, surface corrosion and staining. For export shipment, aluminium shall be packed in moisture-proof parcels, which may be of heavy bitumen paper adequately crated to prevent damage to the waterproofing. Sheets or other items inside the parcels may be separated by interleaving with paper or cardboard spacers.

12.4 Layout — Layout techniques are similar to those for steel work except that where subsequent welding is involved paint, chalk, graphite and other contaminants shall not be used. Fine scribing lines be permissible except on critically stressed areas of thin material.

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

12.5 Straightening — All material shall be straight, unless required to be of curvilinear form. Straightening shall be done by a process and in a manner so as not to cause any injury and shall be free from twist, sharp kinks or bends.

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

Shearing should normally be limited to material 6·0 mm thick or less. Arc cutting may be used on all thicknesses and to the satisfaction of engineer and shall have no deleterious effect on the material. Flame-cutting shall 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.

12.7 Drilling, Punching and Reaming — Holes shall 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 shall unless otherwise specified by the engineer, be of the sizes given in Table 14. Holes for close-fitting bolts shall 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 shall be subsequently separated to remove burrs.

12.8 Bending and Forming — Aluminium alloys are available in a wide range of tempers and formability. Where forming or bending is necessary, the enginner shall 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 shall be done only under competent metallurgical direction and supervision.

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

12.9 Finishing — Planing and finishing of sheared edges of plates or shapes shall normally be done for plate thicknesses 12 mm and above, unless specifically called for on the drawing for lower thicknesses too. Edges of material cut by gas tungsten arc need not be dressed of the edges due to be welded, otherwise a minimum of 3 mm shall be removed.

13. BOLTING AND RIVETING

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

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

Nuts shall be properly, but not excessively, tightened. Locking devices shall be used as required (*see* **9.2**).

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

13.2 Riveting — Riveted joints shall be tightly drawn together before and during riveting. Care shall be taken to avoid contaminating rivet holes with paint or other protective material, prior to riveting (*see* **21.1**).

Rivets shall be driven so as to fill the holes, including any counter-sinkings, completely. Head shall be concentric with their shanks and in close contact with the riveted surfaces.

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

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

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

14. WELDING

14.1 General — Care shall be taken not to strike the arc on parts of the work other than the prepared fusion faces. Run-on and run-off plates shall be used where appropriate (*see* **7.3.3**).

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

Care shall be taken to ensure that the welding of attachments to strength members does not impair their performance (*see* Appendix N).

14.1.1 Welding provisions not covered in this code shall conform to those given in IS : 2812-1964*

14.2 Materials — The choice of structural aluminium alloys for welding is dealt with in **4.3**. Filler rods and wires shall be selected in accordance with **4.3.6**. Care shall be taken to store filler rods and wires in a dry and clean place so that they remain smooth, bright and free from surface corrosion.

The engineer shall 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 64430, 63400, 65032 and 52000, 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.

14.3 Processes — Strength members shall 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* **14.6** and **14.5**), TIG welding shall be made in accordance with the recommendations given in IS : 2812-1964*.

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

14.4 Edge Preparation, Cleaning and Setting Up — Suggested edge preparations are given in Appendix P.

Surfaces to be welded shall be smooth, and immediately prior to assembly and welding shall 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 shall be removed prior to scratch brushing. The interval between cleaning and welding should be as short as possible and shall not exceed 6 hours. If accidental contamination with dirt or moisture occurs after cleaning and prior to welding, the joint shall be recleaned. TIG filler wires shall be degreased and cleaned with dry steel wool before use; both TIG and MIG wires shall be kept free from contamination before and during use.

Assembly shall be by jigging or tack-welding or both. Jigs and fixtures, including backing bars, shall be clean and dry and made from materials

*Recommendations for manual tungsten inert-gas arc-welding of aluminium and aluminium alloys.

unlikely to contaminate the weld. Tack welds shall 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 may be preferred to positional welding.

14.5 Procedure and Approval — For strength joints the precise course of action to be followed shall be documented as a welding procedure which shall contain the information listed in Table 16. The welding procedure shall be proved by adequate tests and shall receive the approval of the engineer before it is used in actual fabrication. Any significant alteration in a procedure shall be similarly approved. Approval test shall be specified by the engineer, bearing in mind the service conditions of the structure, and the specimens shall be representative of the size and type of joint to be fabricated. Mechanical tests shall be in accordance with IS : 7273-1974* and in the case of butt welds, the results shall meet the requirements of Table 17. For fillet welds, fracture tests shall be employed to see that complete root penetration has been achieved. All welds shall be defined in accordance with **9.3.1** and shall meet the requirements of **14.7**. Procedures need not be reapproved if the fabricator satisfies the engineer that similar procedures have been previously approved.

14.6 Approval of Welders — Every welder employed on a structure or assembly shall 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 shall be made separately for each procedure, as specified in **14.5**. Approval will be granted if the appearance and mechanical performance of the joints meet the design requirements (*see* **9.3**).

14.7 Quality Control — The main requirements for control of weld quality are procedure approval (*see* **14.5**) and welder approval (*see* **14.6**).

In addition, welds of strength member shall be examined by the engineer. They shall 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, shall 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, shall be employed if specified in the design requirements (*see* **9.3.1** *and* **10.4.1** Class 2).

*Method of testing fusion welded joints in aluminium and aluminium alloys.

TABLE 16 INFORMATION FOR WELDING PROCEDURE

(*Clause* 14.5)

SL No.	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	

TABLE 17 MECHANICAL TEST REQUIREMENTS FOR BUTT-WELD PROCEDURE AND WELDER APPROVAL

(*Clause* 14.5)

ALLOY	TENSILE STRENGTH* N/mm²	MAXIMUM BEND RADIUS†
(1)	(2)	(3)
64430	193	‡
65032	193	‡
63400	116	‡
54300	263	3t
53000	216	2t
52000	185	

*Transverse to weld and irrespective of temper before welding.

†Controlled side bend test: the specimen thickness *t* is normally 9·5.

‡Not applicable.

15. INSPECTION

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

15.2 Should any structure or part of a structure be found not to comply with any of the provisions of this standard, it shall be liable to rejection. No structure or part of the structure, once rejected shall be resubmitted for test, except in cases where the purchaser or his authorized representative considers the defect as rectifiable.

15.3 Defects which may appear during fabrication shall be made good with the consent of and according to the procedure laid down by the inspector.

15.4 All gauges and templates necessary to satisfy the inspector shall be supplied by the manufacturer. The inspector may, at his direction, check the test results obtained at the manufacturer's works by independent tests at the National Test House or elsewhere, and should the material so tested be found to be unsatisfactory, the costs of such tests shall be borne by the manufacturer, and if satisfactory, the costs shall be borne by the purchaser.

16. TOLERANCES IN FABRICATION

16.1 Finished members shall be true to line and free from twists, bends, and open joints.

16.2 Compression members may have a lateral variation not greater than 1/480 of the axial length between points which are to be laterally supported.

16.3 A variation of 1 mm is permissible in the overall length of members with both ends machined.

16.4 Members without machined ends which are to be framed to other parts of the structure may have a variation from the detailed length hole to hole not greater than 0·5 mm for members 10 m or less in length, and not greater than 3 mm for members over 10 m in length. The distance between holes within a single group of fasteners shall have a variation from detailed dimensions not exceeding 1 mm.

17. HEATING

17.1 Forming of aluminium shall generally be carried out cold. Where heating is necessary, aluminium may be heated to 150°C for a period not exceeding 30 minutes. Such heating shall be done only when proper temperature controls and supervision are provided to ensure that the limitations on temperature and time are carefully observed.

SECTION VI PROTECTION

18. PROTECTION FROM ENVIRONMENT

18.1 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 (within 0·5 km of the sea coast) 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 then temperate ones, although certain alloys (*see* **7.6.2**) 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 seaspray or of splashing from salt-treated roads. The drainage of water from copper or copper-alloy roofs onto aluminium causes corrosion and shall be prevented. Similarly, the presence of copper in paints and in abrasive agents for precleaning shall be avoided.

Aluminium surfaces, though not usually in structural work, can be given decorative finishes other than the full protective treatment as specified in **19**. Such treatments, which include anodizing (*see* IS : 1868-1968* and IS : 6057-1970†) and certain chemical colouring processes, are not substitutes for painting. Anodized surfaces shall be maintained clean (abrasive shall not be used) to avoid unsightly, pitting in aggressive environments.

18.2 Protective Treatment — Structures shall ordinarily be protected in accordance with Table 18. 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, 12 months' service, and the need for protection re-assessed, this is particularly advisable with material less than 6 mm thick.

*Specification for anodic coatings on aluminium (*first revision*).

†Specification for hard anodic coatings on aluminium.

TABLE 18 GENERAL PROTECTION OF ALUMINIUM STRUCTURES

(*Clause* 18.2)

DURABILITY RATING*	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*†	*P*	*P*†	*N*
C	None	*P*	*P*	*N*	*N*	*N*

P = Protection

N = Not recommended

**See* 4.2.2.

†Material over 3·15 mm thick, normally does not need protection.

If an alloy not listed in Table 1 or Table 24 is used, its durability rating shall be established by the engineer (*see* **4.2.2**).

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

19. PAINTING

19.1 Painting preceded by appropriate pre-treatment as specified in IS : 2524 (Part I)-1968* shall be done in accordance with the provisions of IS : 2524 (Part II)-1968†.

20. METAL SPRAYING

20.1 Surface Preparation — Surfaces to be metal-sprayed shall be thoroughly cleaned [*see* IS : 2524 (Part I)-1968]* 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 shall be free from grease, moisture and other foreign matter immediately before spraying.

20.2 Spray Metal — The metal for spraying shall be aluminium of commercial purity [normally 19500 (1B) of IS : 739-1966‡] except with non-standard alloys where the advice of manufacturer shall be sought.

*Code of practice for painting of non-ferrous metals in buildings, Part I Pretreatment.

†Code of practice for painting of non-ferrous metals in buildings, Part II Painting.

‡Specification for wrought aluminium and aluminium alloys, wire (for general engineering purposes) (*revised*).

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

The spray metal shall be applied by a process approved by the engineer. The thickness of the sprayed coating shall be not less than 0·1 mm or, where protective painting is to be applied over it, not less than 0·05 mm; the coating in either case shall be complete and undamaged.

21. METAL-TO-METAL CONTACT SURFACES, AND BOLTED AND RIVETED JOINTS

21.1 General — To provide protection, one of the five procedures given below shall be followed for contact surfaces and bolted and riveted joints, in accordance with **21.2** to **21.6**:

Procedure 1 — The heads of steel bolts and rivets may for appearance be over-painted with a priming coat 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), shall, before assembly be cleaned, pre-treated and receive one priming coat extending beyond the contact area. The surfaces shall 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, shall 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 shall 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 shall be afforded by an elastomeric jointing compound (preferably of the polysulphide type) applied on to 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 shall 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 or the joints, shall unless they are already metal-sprayed or galvanized, be metal sprayed preferably with aluminium (*see* **20**) 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 shall 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 shall (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.

21.2 Aluminium to Aluminium — Contact surfaces and joints of aluminium to aluminium shall be protected in accordance with Table 19, in which the numbers refer to the procedures of **21.1**. 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 shall not be used for joints subject to sea-water immersion.

TABLE 19 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		
(1)	(2)	(3)	(4)	(5)	(6)	(7)
A	1(1)	1(1)	1(2)	2(4)*	2(3)	3(5)
B	1(1)	1(1)	1(2)	2(4)*	2(4)*	*N*(*N*)
C	1(1)	2(2)	1(2)	*N*(*N*)	*N*(*N*)	*N*(*N*)

*(3) for bolts of corrosion-resisting steel.

N = Not recommended.

Bracketed references apply with ferrous bolts or rivets.

21.3 Aluminium to Zinc or Galvanized Steel — Contact surfaces and joints of aluminium to zinc or galvanized steel shall be protected in accordance with Table 20, in which the numbers refer to the procedures in **21.1**.

Joints shall be made with galvanized steel bolts.

TABLE 20 PROTECTION AT JOINTS OF ALUMINIUM TO ZINC OR GALVANIZED STEEL

(*Clause* 21.3)

Durability Rating	Procedures According to Environment					
	Dry Unpolluted	Mild	Industrial and Industrial Marine		Marine (Non-industrial)	Sea-Water Immersion
			Moderate	Severe		
(1)	(2)	(3)	(4)	(5)	(6)	(7)
A	1	1	2	4	3	5
B	1	1	2	4	4	*N*
C	1	2	2	*N*	*N*	*N*

N = Not recommended.

21.4 Aluminium to Steel, Cast Iron on Lead — Contact surfaces and joints of aluminium to steel, cast iron or lead shall be protected in accordance with Table 21 in which the numbers refer to the procedures in **21.1**.

Corrosion-resisting steel bolts shall 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, shall be used.

TABLE 21 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		
(1)	(2)	(3)	(4)	(5)	(6)	(7)
A	1	2	2	4	4	5
B	1	2	2	4	4	*N*
C	1	2	3	*N*	*N*	*N*

N = Not recommended.

21.5 Aluminium to Corrosion-Resisting Steel — Contact surfaces and joints of aluminium to corrosion-resisting steel shall be protected in accordance with Table 22, in which the numbers refer to the procedure in **21.1**.

TABLE 22 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		
(1)	(2)	(3)	(4)	(5)	(6)	(7)
A	1	1	2	3	3	5
B	1	1	2	3	3	*N*
C	1	2	3	*N*	*N*	*N*

N = Not recommended.

21.6 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 shall be of durability rating A or B, and the bolts or rivets shall be of copper or copper alloy. In mild environments protection shall be by Procedure 3 of **21.1**, and in all other environments by Procedure 5.

22. WELDED JOINTS

22.1 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, shall, 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.

23. GLUED JOINTS

23.1 The advice of the manufacturer of the adhesive used in a glued joint shall, 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 shall be in accordance with **18** and **19**.

24. CONTACT BETWEEN ALUMINIUM AND NON-METALLIC MATERIALS

24.1 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 shall be of durability rating A or B. In a mild environment the surfaces shall be protected with at least two coats of bituminous paint or hot bitumen as specified in IS : 2524 (Part I)-1968* and IS : 2524 (Part II)-1968†. In an industrial or marine environment they shall be painted with at least three coats; the surface of the contacting material should preferably be similarly painted. Submerged contact is not recommended.

24.2 Embedment in Concrete — Aluminium set in concrete shall be of durability rating A or B. In a mild environment the surfaces before embedment shall be protected with at least two coats of bituminous paint or hot bitumen, the coats to extend at least 75 mm above the concrete surface after embedment.

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

24.3 Contact with Timber — Aluminium surfaces in contact with timber, unless the timber is fully seasoned and the environment dry and unpolluted, shall in a mild environment be painted with at least one coat of paint in accordance with **19.** In an industrial, damp or marine environment the aluminium shall be of durability rating A or B and shall be painted with two coats of bituminous paint or hot bitumen; the timber also should, where practicable, be primed and painted in accordance with good practice.

Timber in contact with aluminium shall 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.

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

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*Code of practice for painting of non-ferrous metals in buildings, Part I Pretreatment.

†Code of practice for painting of non-ferrous metals in buildings, Part II Painting.

24.5 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 shall obtain competent advice on the degree of corrosion to be expected; oxygen content, *p*H 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 or of an appropriate number of coats of bituminous paint or hot bitumen. Where abrasion from suspended solids is likely, a plasticized coal-tar pitch is recommended. Joints and contact surfaces shall be completely sealed.

Sea-water immersion is dealt with in **21.2** to **21.5**.

25. PROTECTION AGAINST FIRE

25.1 General — Aluminium is non-combustible; it neither burns, nor assists in the spread of fire. Its load-carrying capacity, however, is seriously reduced at temperatures above about 250°C and it melts at about 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.

25.1.1 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 shall be considered.

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

25.2.1 In buildings, all joints in a protective system such as occurring at each floor level of a long stanchion shall be sealed adequately.

25.3 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 shall match the resistance of the construction.

25.3.1 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.

25.3.2 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.

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

25.4 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.

APPENDIX A

(*Clause* 4.2.1)

NOMENCLATURE OF ALUMINIUM PRODUCTS

A-1. GENERAL

A-1.1 Complete information on new alloy designation system for aluminium and its alloys, based on 'Five digit system' for wrought aluminium alloys and unalloyed aluminium is given in IS : 6051-1970*.

A-2. TEMPER OR CONDITION

A-2.1 The non-heat-treatable alloy (for example 54300) 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:

Temper Designation	*Description*
O	Softest (i. e. annealed)
H1 to H4	Progressive degree of hardness
M	As manufactured (that is partly hardened in the ordinary course of manufacture)

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

The heat-treatable alloys (for example 64430) derive enhanced strength from either one or two stages of heat treatment. The first stage

*Code for designation of aluminium and its alloys.

(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 alloy 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:

Temper Designation	*Description*
O	Annealed
M	As manufactured, with no normal heat-treatment
W	Solution heat-treated
WP	Fully (that is 2-stage) heat-treated
P	Artificially aged without prior solution heat treatment

APPENDIX B

(*Clause* 4.2.1)

FOREIGN EQUIVALENTS OF ALUMINIUM ALLOYS

B.1 This Appendix lists some foreign equivalents of Indian Standard alloys referred to in this Code. They are not necessarily exact equivalents and for detailed information on their compositions reference shall be made to the relevant Indian Standards.

TABLE 23 FOREIGN EQUIVALENTS OF ALUMINIUM ALLOYS

INDIA (ISI)	ISO DESIGNATION	UK (BSI)	AUSTRIA (ÖNA)	BELGIUM (IBN)	CANADA (CSA)	FRANCE (AFNOR)	GERMANY (DIN)	ITALY (UNI)	NETHERLANDS (NNI)	SWEDEN (SIS)	SWITZERLAND (SNV)	USA (ANSI)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
64430	Al-Si1Mg ISO 209	H30	AlMgSi1 ÖNORM M 3430	AlMg1Si1 NBN 437	GS 11R HA series	A-SGM NF A 57-350 NF A 57-650	AlMgSi1 DIN 1725 Bl·1	P-AlSi1 MgMn UNI 3751	K AlMgSi	SIS14-4212	Al-Si-Mg VSM 10850	AA6351
64300	Al-Mg4, 5Mn ISO 209	N8	—	AlMg4 NBN 437	GM 41 HA series	A-G4 NF A 57-350 NF A 57-650	—	—	K AlMg4	—	—	AA5083
63400	Al-MgSi ISO 209	H9	AlMgSi 0·5 ÖNORM M 3430	AlMgSi NBN 437	GS 10 HA series	A-GS NF A 57-350 NF A 57-650	AlMgSi0·5 DIN 1725 Bl·1	P-AlMgSi UNI 3569	K AlMgSi½	SIS14-4104	—	AA6063
65032	Al-Mg1SiCu	H20	—	—	GS 11N HA series	—	—	—	—	—	—	A6061
24345	Al-Cu4SiMg ISO 209	H15	—	AlCu4MgSi NBN 437	CS 41N HA series	A-U4SG NF A 57-350 NF A 57-650	AlCuSiMn DIN 1725 Bl·1	P-AlCu4.4Si MnMg UNI 3581	K AlCu4 Mg	SIS14-4338	Al-4Cu-0·5Mg VSM10852	AA2014
31000	Al-Mn1 ISO 209	N3	AlMn ÖNORM M 3430	AlMn NBN 437	M1 HA series	A-M1 NF A 57-350 NF A 57-650	AlMn DIN 1725 Bl·1	P-AlMn1.2 UNI 3568	—	SIS14-4054	Al-Mn VSM10848	AA3003
52000	Al-Mg2·5 ISO 209	N4	AlMg2 ÖNORM M 3430	—	GR 20 HA series	A-G2 NF A 57-350 NF A 57-650	AlMg2 DIN 1725 Bl·1	P-AlMg2.5 UNI 3574	K AlMg2	SIS14-4120	Al-2Mg VSM 10849	AA5052
53000	Al-Mg3·5 ISO 209	N5	AlMg3 ÖNORM M 3430	AlMg3 NBN 437	GR 40 HA series	A-G3 NF A 57-350 NF A 57-650	AlMg3 DIN 1725 Bl·1	P-AlMg3.5 UNI 3575	K AlMg3	—	Al-3Mg VSM10849	AA5154
74530	Al-Mg5 ISO 209	H17	—	—	—	—	AlZnMg1 DIN 1725 Bl·1	—	—	—	—	—

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APPENDIX C

(*Clauses* 4.3.2 *and* 7.4.2)

SECONDARY ALLOYS

C-1. SELECTION OF MATERIAL

C-1.1 Four further alloys often used in general and structural engineering are listed, with their properties, in Table 24.

The use of 24345 (H15) is commonly confined to special applications (for example 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 WP condition this material has less resistance to crack-propagation than the other alloys in the Indian Standard general engineering series. It is not normally weldable.

Alloy 31000 (N3) is mainly used in the H4 conditions for corrugated and troughed sheet for roof and wall cladding; it has high durability. 52000 (N4) and 53000 (N5) generally used in sheet form, combine high durability with a wide range of mechanical properties. These materials have good weldability.

C-2. PERMISSIBLE STRESSES

C-2.1 The permissible stresses in tension and bearing, and in compression, bending and shear where buckling is not a factor, are given in Table 25; the values have been obtained by the procedures given in Appendix F, the further requirements of which shall be followed to obtain other permissible stresses.

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TABLE 24 PROPERTIES OF SECONDARY ALLOYS

(*Clause* C-1.1)

<table>
<tr><th rowspan="2">Alloy</th><th rowspan="2">Condition*</th><th rowspan="2">Form*</th><th colspan="2">Thickness*† mm</th><th rowspan="2">0·2 Percent Tensile Proof Stress‡ N/mm² (kgf/mm²)</th><th rowspan="2">Tensile Strength‡ N/mm² (kgf/mm²)</th><th rowspan="2">Elongation Percent on 50 mm‡</th><th rowspan="2">0·2 Percent Compressive Proof-Stress§ N/mm² (kgf/mm²)</th><th rowspan="2">Bearing Strength§ N/mm² (kgf/mm²)</th><th rowspan="2">Modulus of Elasticity|| N/mm² (kgf/mm²)</th><th rowspan="2">Coefficient of Linear Expansion¶ per°C</th><th rowspan="2">Density kg/m³</th><th rowspan="2">Durability Rating**</th></tr>
<tr><th>From</th><th>To</th></tr>
<tr><td>(1)</td><td>(2)</td><td>(3)</td><td>(4)</td><td>(5)</td><td>(6)</td><td>(7)</td><td>(8)</td><td>(9)</td><td>(10)</td><td>(11)</td><td>(12)</td><td>(13)</td><td>(14)</td></tr>
<tr><td rowspan="4">24345 (H15)</td><td>W</td><td rowspan="2">Extrusion</td><td>—</td><td>—</td><td>225 (23·0)</td><td>375 (38·0)</td><td>10</td><td rowspan="2">206 (21·0)</td><td>664 (67·6)</td><td rowspan="2">72400 (7380)</td><td rowspan="4">22 × 10^{−6}</td><td rowspan="4">2800</td><td rowspan="2">C</td></tr>
<tr><td rowspan="3">WP</td><td>—</td><td>—</td><td>375 (38·0)</td><td>435 (44·0)</td><td>6</td><td>772 (78·6)</td></tr>
<tr><td>Clad Sheet</td><td>—</td><td>6·3</td><td>320 (32·5)</td><td>395 (40·0)</td><td>7</td><td rowspan="2">Same as Tensile</td><td rowspan="2">726 (74·0)</td><td rowspan="5">68900 (7025)</td><td rowspan="2">A††</td></tr>
<tr><td>Clad Plate</td><td>3·15</td><td>25</td><td>345 (35·0)</td><td>420 (42·5)</td><td>7</td></tr>
<tr><td>31000 (N3)</td><td>H4</td><td rowspan="3">Sheet</td><td rowspan="3">—</td><td rowspan="3">6·3</td><td>—</td><td>170 (17·0)</td><td>2-3</td><td>—</td><td>355 (36·2)</td><td>23 × 10^{−6}</td><td>2740</td><td rowspan="3">A</td></tr>
<tr><td>52000 (N4)</td><td>HI</td><td>125 (12·5)</td><td>200 (20·5)</td><td>3-6</td><td>110 (11·0)</td><td>463 (47·2)</td><td>24 × 10^{−6}</td><td>2690</td></tr>
<tr><td>53000 (N5)</td><td>HI</td><td>160 (16·0)</td><td>240 (24·5)</td><td>4-7</td><td>145 (14·5)</td><td>494 (50·4)</td><td>23 × 10^{−6}</td><td>2670</td></tr>
</table>

*For other conditions, forms and thickness, refer relevant Indian Standards (*see* **4.4.1**).

†Each thickness includes its upper limit.

‡Specifies minimum values.

§Minimum expected value (*see* Appendix F).

||For modulus of rigidity multiply by 0·38.

¶Applies to range 20 to 100°C.

***See* **4.2.2.**

††*C* for immersion in fresh or sea water.

TABLE 25 PERMISSIBLE STRESSES FOR SECONDARY ALLOYS

N/mm² (kgf/mm²)

(*Clause* C-2.1)

Small figures in parenthesis refer to the notes.

ALLOY	CONDITION*	FORM*	THICKNESS*† mm		AXIAL‡		BENDING‡		SHEAR‡	BEARING§	λ_s‖
			From	To	p_t	p_c	p_{bt}	p_{bc}	p_c	p_b	
(1)	(2)	(3)	(4)	(5)	(6)		(7)		(8)	(9)	(10)
24345 (H15)	W	Extrusion	—	—	133 (13·5)	125 (12·5)	151 (15·1)	143 (14·3)	80 (8·0)	239 (24·0)	73
	WP	Extrusion	—	—	154¶ (15·5)	204 (21·0)	154¶ (15·5)	226 (23·0)	108¶ (11·0)	278 (28·5)	47
		Clad sheet	—	6·3	176 (18·0)		196 (20·0)		106 (10·8)	261 (26·5)	54
		Clad plate	3·15	25	190 (19·5)		211 (21·5)		114 (11·6)		51
31000 (N3)	H4	Sheet	—	6·3	**		**		**	128 (13·0)	**
52000 (N4)	H1				73 (7·3)	66 (6·6)	83 (8·3)	76 (7·6)	44 (4·5)	167 (17·0)	107
53000 (N5)	H1				92 (9·2)	85 (8·5)	104 (10·4)	97 (9·7)	55 (5·5)	178 (18·0)	83

*For other conditions, forms and thickness, refer relevant Indian Standards (*see* **4.4.1**).

†Each thickness includes its upper limit.

‡Applies only when buckling is not the criterion, *see* **8.2**, **8.3** and **8.4**.

§Joint in single shear (*see* **9.2.1**).

‖*See* Appendix F.

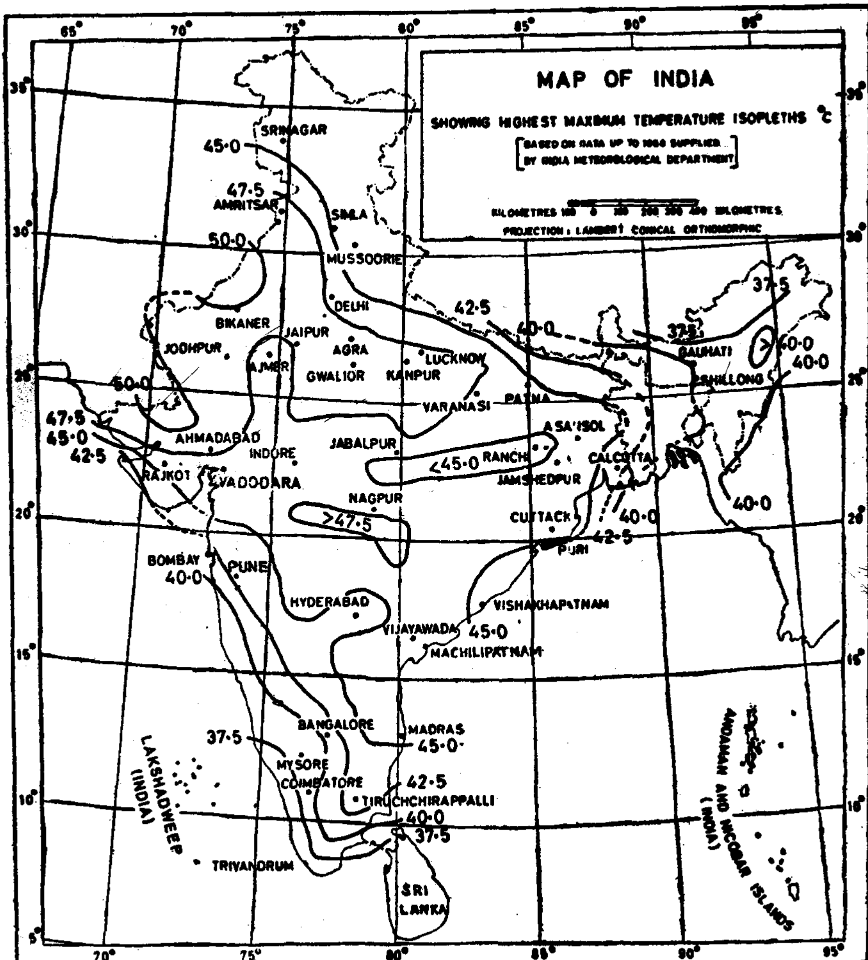
¶Arbitrary reduced values to allow for inferior crack propagation resistance.

**Values obtainable (*see* Appendix F) proof stress of suitable samples.

APPENDIX D

(*Clauses* 6.3.2 *and* 6.3.3)

CHART SHOWING HIGHEST MAXIMUM TEMPERATURE



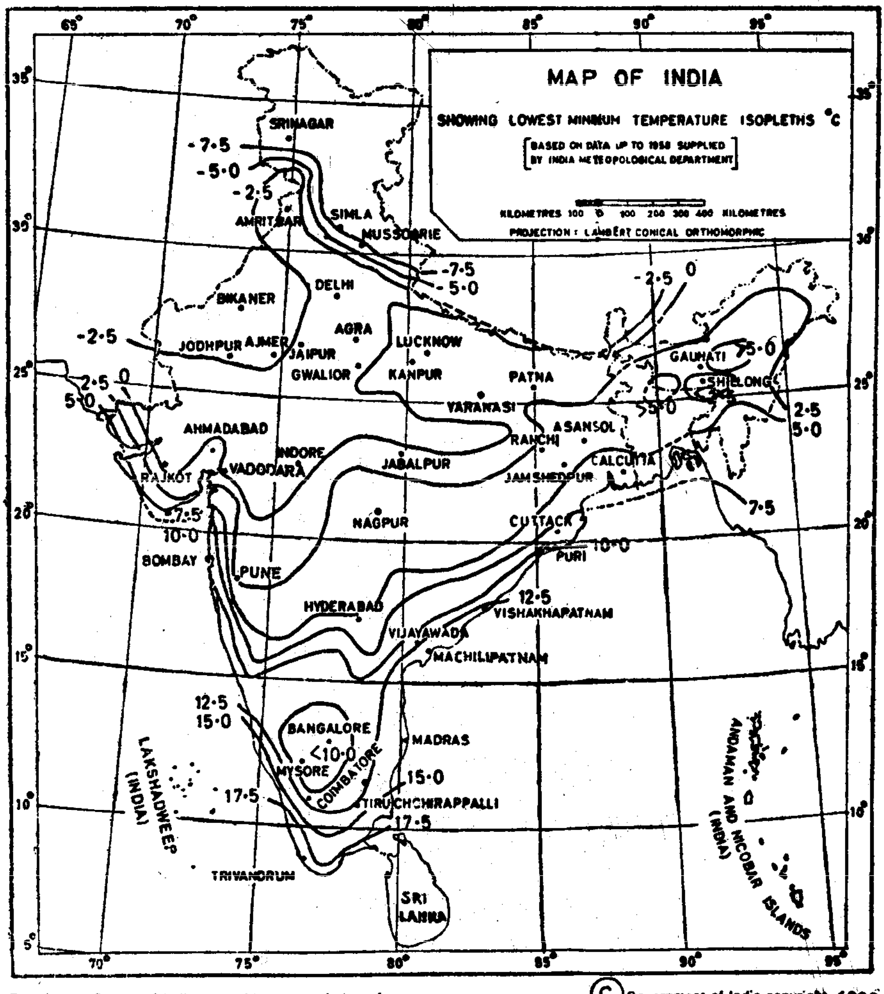
Based upon Survey of India map with the permission of the Surveyor General of India

The territorial waters of India extend into the sea to a distance of twelve nautical miles measured from the appropriate base line.

APPENDIX E

(*Clauses* 6.3.2 *and* 6.3.3)

CHART SHOWING LOWEST MINIMUM TEMPERATURE



Based upon Survey of India map with the permission of the Surveyor General of India

The territorial waters of India extend into the sea to a distance of twelve nautical miles measured from the appropriate base line.

APPENDIX F

(*Clauses* 7.4.1, 7.4.3, 7.4.4, 9.2.1 *and* 9.3.3)

DERIVATION OF PERMISSIBLE STRESSES

F-1. GENERAL

F-1.1 The procedures given in this appendix may be used to obtain permissible stresses for any of the alloys which have guaranteed non-standard properties (*see* **7.4.3**), and also as a guide to permissible stresses for other alloys (*see* **7.4.4**).

F-2. PERMISSIBLE STRESSES

F-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:

$$p_t = 0{\cdot}44 f_{2t} + 0{\cdot}09 f_u, \text{ and}$$
$$p_c = 0{\cdot}44 f_{2c} + 0{\cdot}09 f_u$$

where

f_{2t} = guaranteed or the minimum expected 0·2 percent proof stress in tension,

f_{2c} = guaranteed or the minimum expected 0·2 percent proof stress in compression, and

f_u = guaranteed or the minimum expected tensile strength.

The minimum expected values of f_{2t}, f_{2c} 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 (for example 24345-WP in Table 25) is in doubt.

For permissible stresses in axial compression where buckling is a factor, a diagram with a horizontal out-off at p_c is drawn relating those stresses to λ. The form of the diagram is shown in Fig. 25, in which λ_s is given by

$$\lambda_s = \sqrt{3{\cdot}4 \times 10^5 / p_s}$$

where

$$p_s = (0{\cdot}44 f_{2c} - 0{\cdot}02 f_u - 15) \text{ N/mm}^2,$$

The values of λ for entering the diagram are given in **8.2.3** and **8.2.5**.

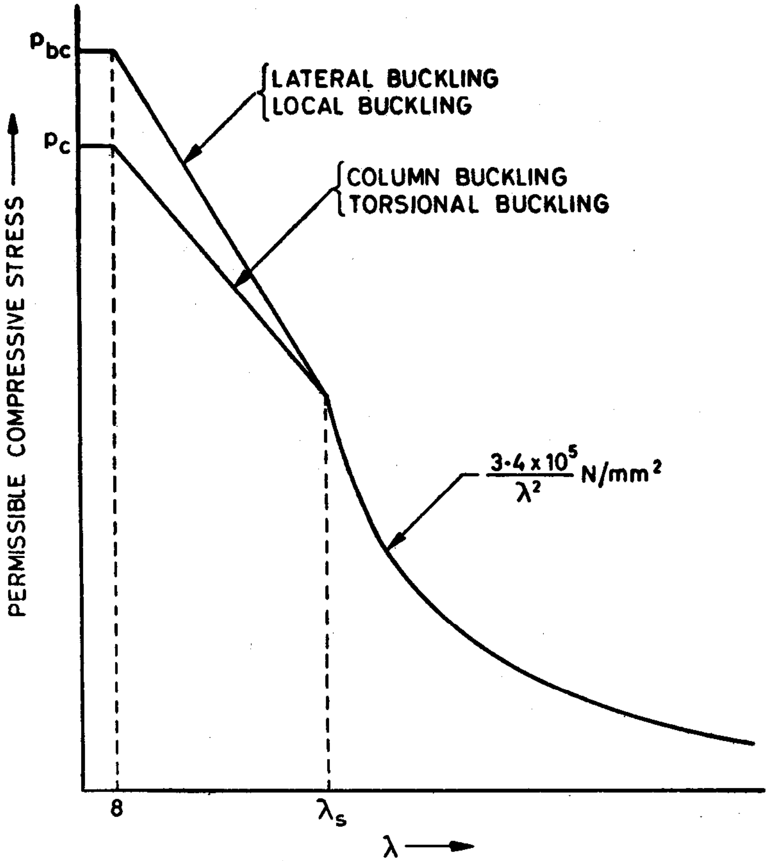


FIG. 25 FORM OF COMPRESSION BUCKLING DIAGRAMS

F-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:

$$p_{bt} = 0{\cdot}44\, f_{2t} + 0{\cdot}14\, f_u, \text{ and}$$

$$p_{bc} = 0{\cdot}44\, f_{2c} + 0{\cdot}14\, f_u \text{ respectively}$$

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 **F-2.1**; the form of the diagram with a horizontal cut-off at p_{bc}, is shown in Fig. 25. The values of λ for entering the diagram are given in **8.3.4, 8.4.1** and Appendices K and M.

F-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 Fig. 7 and 14 are used with horizontal cut-offs at 0·85 p_q (*see* **8.3** *and* **8.4.2**).

F-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* **9.2.2**), 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.

F-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 as in the actual structure.

The permissible shear stress in a close-fitting bolt (*see* **9.2.2**) 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.

F-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 percent proof stress divided by 1·5, the proof stress being measured on a gauge length of 50 mm normal to the weld and disposed symmetrically about its centre line.

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 shall be made for the effect of weld repairs.

F-2.7 Fatigue — The permissible stresses in fatigue for members in a non-standard alloy 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 G

(*Clause* 8.1.2.1)

DEDUCTION FOR HOLES IN MEMBERS

G-1. The following examples illustrate the rule given in **8.1.2.1**(a):

Consider a plate 460 mm wide and 25 mm thick, with 20·8 mm diameter holes as shown in Fig. 26 where $s = 50$ mm, $g_1 = 100$ mm and $g_2 = 150$ mm.

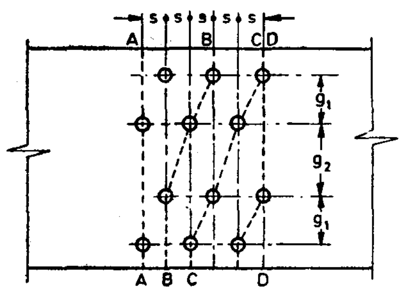


FIG. 26 CHOICE OF LINES FOR DEDUCTION OF HOLES

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

a) For holes in straight line *A-A*,

$$\text{Area} = 2 \times 20{\cdot}8 \times 25 = 1\,040 \text{ mm}^2$$

b) For holes in zig-zag line *B-B*,

$$\begin{aligned}\text{Area} &= (3 \times 20{\cdot}8 \times 25) - (1 \times s^2t/4g_1) - (1 \times s^2t/4g_2)\\ &= (3 \times 20{\cdot}8 \times 25) - (1 \times 50^2 \times 25/400)\\ &\quad - (1 \times 50^2 \times 25/600)\\ &= 1\,560 - 156{\cdot}3 - 104{\cdot}2\\ &= 1\,299{\cdot}5 \text{ mm}^2\end{aligned}$$

c) For holes in zig-zag line *C-C*,

$$\begin{aligned} \text{Area} &= (4 \times 20{\cdot}8 \times 25) - (2 \times s^2t/4g_1) - (1 \times s^2t/4g_2) \\ &= (4 \times 20{\cdot}8 \times 25) - (2 \times 50^2 \times 25/400) \\ &\quad - (1 \times 50^2 \times 25/600) \\ &= 2\,080 - 312{\cdot}5 - 104{\cdot}2 \\ &= 1\,663{\cdot}3 \text{ mm}^2 \end{aligned}$$

d) For holes in zig-zag line *D-D*,

$$\begin{aligned} \text{Area} &= (3 \times 20{\cdot}8 \times 25) - (1 \times s^2t/4g_1) \\ &= (3 \times 20{\cdot}8 \times 25) - (1 \times 50^2 \times 25/400) \\ &= 1\,560 - 156{\cdot}3 \\ &= 1\,403{\cdot}7 \text{ mm}^2 \end{aligned}$$

The area to be deducted from the gross area (11 500 mm^2) is therefore 1 663·3 mm^2.

APPENDIX H

(*Clause* 8.2.5)

TORSIONAL PROPERTIES OF THIN-WALLED OPEN SECTIONS

H-1. INTRODUCTION

H-1.1 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* **8.2.4** *and* Appendix J) involve the use of the torsion factor, the polar second moment of area of cross section about its shear centre and the warping factor as defined in **H-4**.

H-2. TORSION FACTOR

H-2.1 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 (*see* Reference 1) by:

$$T = GJ \frac{d_\theta}{d_z}$$

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 (*see* 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 (*see* Reference 1) by:

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

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:

$$J = \Sigma \frac{bt^3}{3}$$

where b and t are the width and thickness of each part respectively. Parts 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 (*see* Reference 3) by:

$$J = [(p + qN)\, t]^4$$

where t is the general thickness of the parts, N is the fillet or bulb dimension and p and q are empirical constants (*see* Fig. 27).

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.

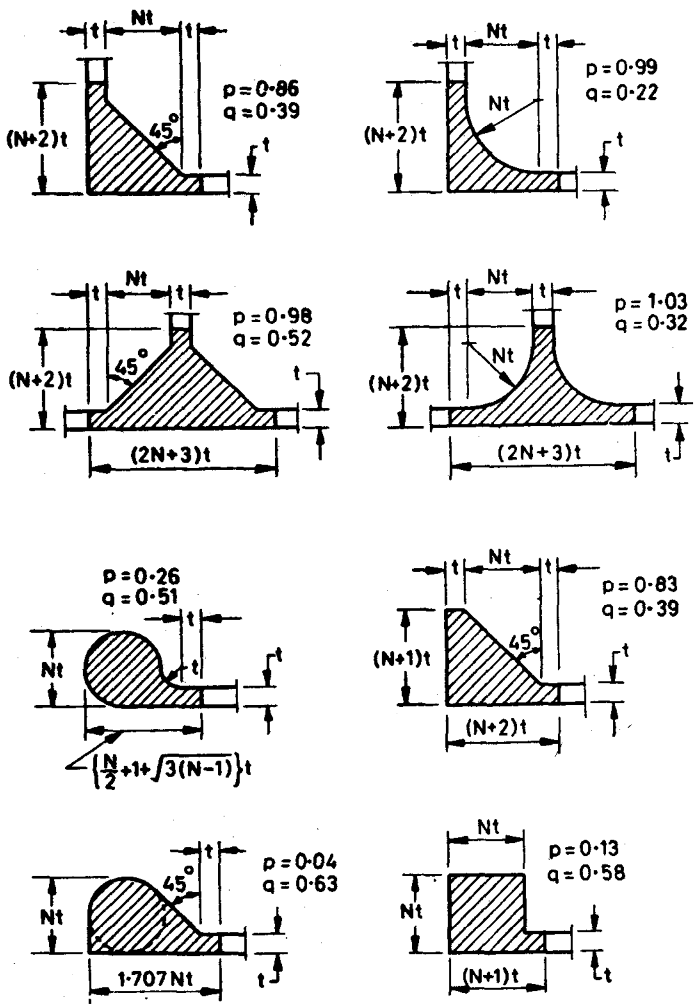


Fig. 27 Constants for Torsion Factor for Certain Fillets and Bulbs

H-3. SHEAR CENTRE

H-3.1 The shear centre S is the point on the cross section through which a transverse load shall act in order to cause bending without twisting. Its position shall 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 **H-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.

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* Fig. 29). 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 shall be located with respect to two axes, and reference should be made to the relevant literature (*see* References 4, 5, 6 and 8).

To locate the shear centre in a singly-symmetrical section the following procedure, using the notation given in Fig. 28 is convenient. The cross section is broken down into two 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 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:

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

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 Fig. 28; it begins with the second element since there is no contribution (d being zero) from the first element.

A specimen shear-centre calculation for a thin-walled section with one axis of symmetry is shown in Table 26. Expressions for the shear-centre position in some commonly used sections are given in Fig. 29.

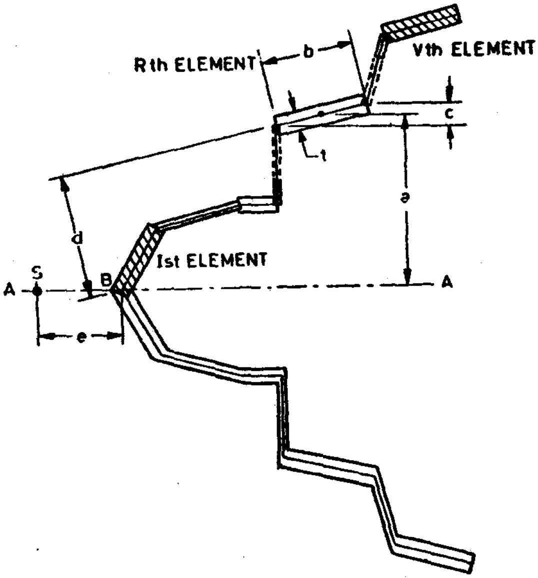


FIG. 28 NOTATION FOR CALCULATING SHEAR-CENTRE POSITION AND WARPING FACTOR

H-4. WARPING FACTOR

H-4.1 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.

The relation between torque and twist where there is warping restraint is given (*see* Reference 5) by:

$$T = GJ\frac{d\theta}{dz} - EH\frac{d^3\theta}{d_z^3}$$

where E is the modulus of elasticity.

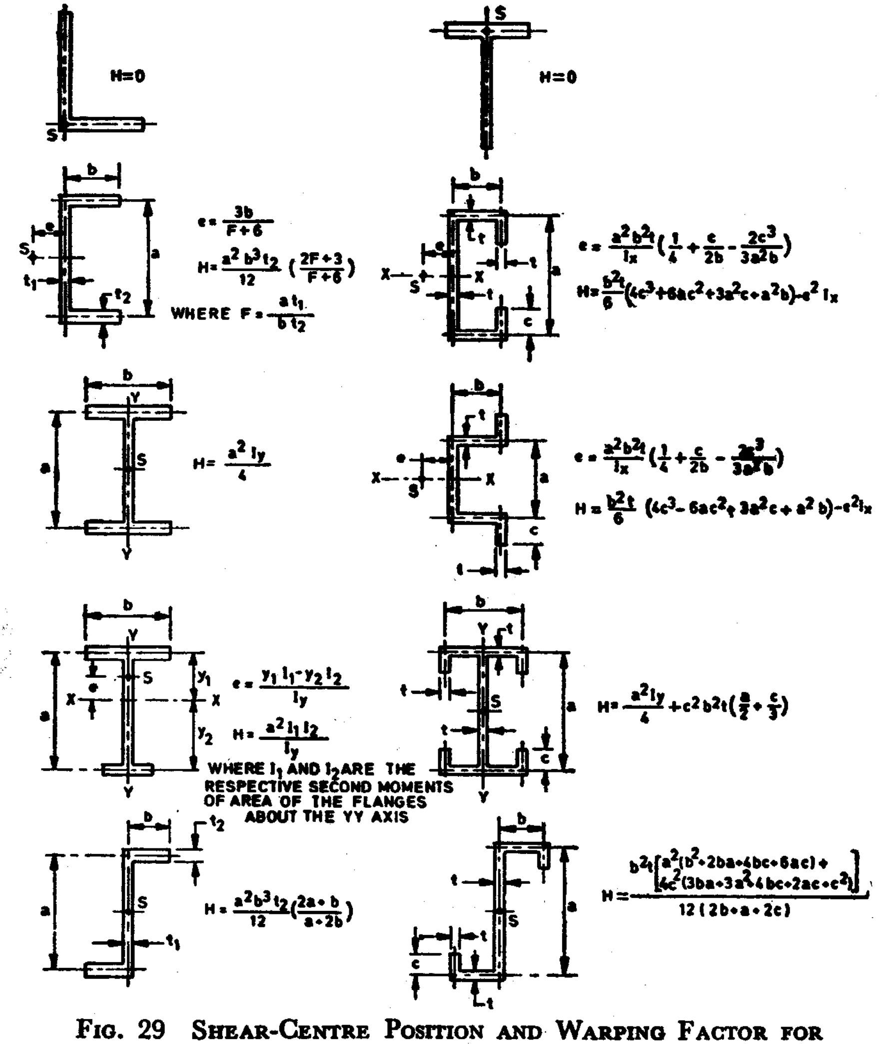


Fig. 29 Shear-Centre Position and Warping Factor for Certain Thin-Walled Sections

For thin-walled sections having one axis of symmetry and composed entirely of flat elements, the warping factor is given by the expression:

$$H = 2 \sum_{2}^{y} \left[bt \left(P^2 - bdP + \frac{b^2 d^2}{3} \right) \right] - e^2 I_A ,$$

where the notations are same as in **H-3.1.**

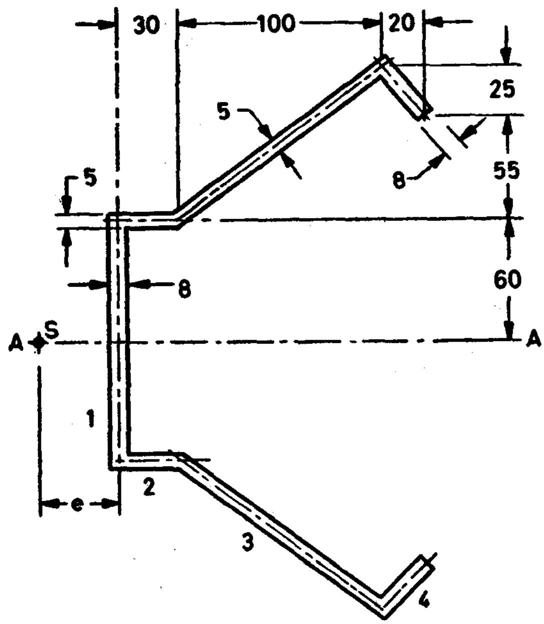
A specimen calculation of *H* for the singly-symmetrical section previously considered is also shown in Table 26. A completely general treatment of this nature cannot conveniently be given for either doubly-symmetrical or unsymmetrical sections, or indeed for any section consisting of other than a simple and symmetrical series of flat elements as in Fig. 28.

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 shall be taken into account. Expressions for *H* for some commonly used sections are given in Fig. 29.

TABLE 26 SPECIMEN CALCULATION OF SHEAR-CENTRE POSITION AND WARPING FACTOR

(*Clause* 5.4.1)

All dimensions in millimetres.



QUANTITY	SECOND ELEMENT	THIRD ELEMENT	FOURTH ELEMENT
(1)	(2)	(3)	(4)
b	30	128	32
t	5	5	8
a	60	100	127
c	0	80	—25
d	60	28	189

(*Continued*)

TABLE 26 SPECIMEN CALCULATION OF SHEAR-CENTRE POSITION AND WARPING FACTOR — *Contd*

Quantity (1)	Second Element (2)	Third Element (3)	Fourth Element (4)
bd	$1{\cdot}80 \times 10^3$	$3{\cdot}58 \times 10^3$	$6{\cdot}05 \times 10^3$
P	$1{\cdot}80 \times 10^3$	$5{\cdot}40 \times 10^3$	$1{\cdot}14 \times 10^4$
$2aP$	$2{\cdot}16 \times 10^5$	$1{\cdot}08 \times 10^6$	$2{\cdot}90 \times 10^6$
$bd\,(a - c/6)$	$1{\cdot}08 \times 10^5$	$3{\cdot}10 \times 10^5$	$7{\cdot}94 \times 10^5$
$2aP - bd(a - c/6)$	$1{\cdot}08 \times 10^5$	$7{\cdot}70 \times 10^5$	$2{\cdot}11 \times 10^6$
$bt(2aP - bd)(a - c/6)$	$1{\cdot}62 \times 10^7$	$4{\cdot}93 \times 10^8$	$5{\cdot}40 \times 10^8$
Summation of last line	$= 1{\cdot}05 \times 10^9$ mm^5		
I_A (obtained by calculation not shown)	$= 2{\cdot}35 \times 10^7$ mm^4		
Shear-centre position $e = \dfrac{1{\cdot}05 \times 10^9}{2{\cdot}35 \times 10^7}$	$= 45$ mm		
P^2	$3{\cdot}24 \times 10^6$	$2{\cdot}92 \times 10^7$	$1{\cdot}30 \times 10^8$
bdP	$3{\cdot}24 \times 10^6$	$1{\cdot}93 \times 10^7$	$6{\cdot}90 \times 10^7$
$b^2d^2/3$	$1{\cdot}08 \times 10^6$	$4{\cdot}28 \times 10^6$	$1{\cdot}22 \times 10^7$
$P^2 - bdP + b^2d^2/3$	$1{\cdot}08 \times 10^6$	$1{\cdot}42 \times 10^7$	$7{\cdot}32 \times 10^7$
$bt\,(P^2 - bdP + b^2d^2/3)$	$1{\cdot}62 \times 10^8$	$9{\cdot}09 \times 10^9$	$1{\cdot}87 \times 10^{10}$
Summation of last line	$= 2{\cdot}80 \times 10^{10}$ mm^6		
Warping factor H	$= (2 \times 2{\cdot}8 \times 10^{10}) - (45 \times 1{\cdot}05 \times 10^9)$ $= 8{\cdot}7 \times 10^9$ mm^6		

References for Appendix H

1) Cullimore (M S G) and Pugsley (A G). The torsion of aluminium alloy structural members. Aluminium Development Association Research Report No. 9, 1952.

2) Timoshenko (S P). Theory of elasticity. McGraw-Hill, New York. 1934.

3) Palmers (P J). 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) Bleich (F). Buckling strength of metal structures. McGraw-Hill, New York. 1952.

5) Timoshenko (S P). Strength of materials, Vol. 2, 1956.

6) Baker (J F) and Roderick (J W). The strength of light alloy struts. Aluminium Development Association Research Report No. 3, 1948.

7) Hoff (N J). Stresses in space-curved rings reinforcing the edges of cutouts in monocoque fuselages. Journal of Royal Aerounautical Society. February 1943.

8) Argyis (J H). The open tube. Aircraft Engineering, Vol. 26, April 1954.

APPENDIX J
(*Clause* 8.2.5)

TORSIONAL BUCKLING

J-1. GENERAL

J-1.1 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 **8.2.5**. They also apply to the sections dealt with in **8.2.5** 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 Fig. 1 at $\lambda = \lambda_t$ for the principal alloys; for other alloys, reference should be made to Appendix F.

The section properties may be obtained by the methods given in Appendix H.

Additional data including torsional buckling loads for a wide range of column types, for different end conditions, is given in Reference 1.

J-2. TWO AXES OF SYMMETRY

J-2.1 For a strut whose section has two axes of symmetry, or has point symmetry (for example, a zed), failure is by pure torsional buckling and the permissible stress is obtained as above at $\lambda = \lambda_t$

where

$$\lambda_t = \sqrt{\frac{I_p}{0{\cdot}038\,J + \frac{H}{l^2}}}$$

I_p = polar second moment of area about the shear centre,
J = torsion factor,
H = warping factor, and
l = 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 those two extremes.

Column buckling about either axis of symmetry is independent of torsional buckling and should be checked separately.

J-3. ONE AXIS OF SYMMETRY

J-3.1 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 kl/r, whichever is the greater,

where

k = interaction coefficient from Fig. 30;

λ_t = slenderness ratio for pure torsional buckling as calculated from **J-2**; and

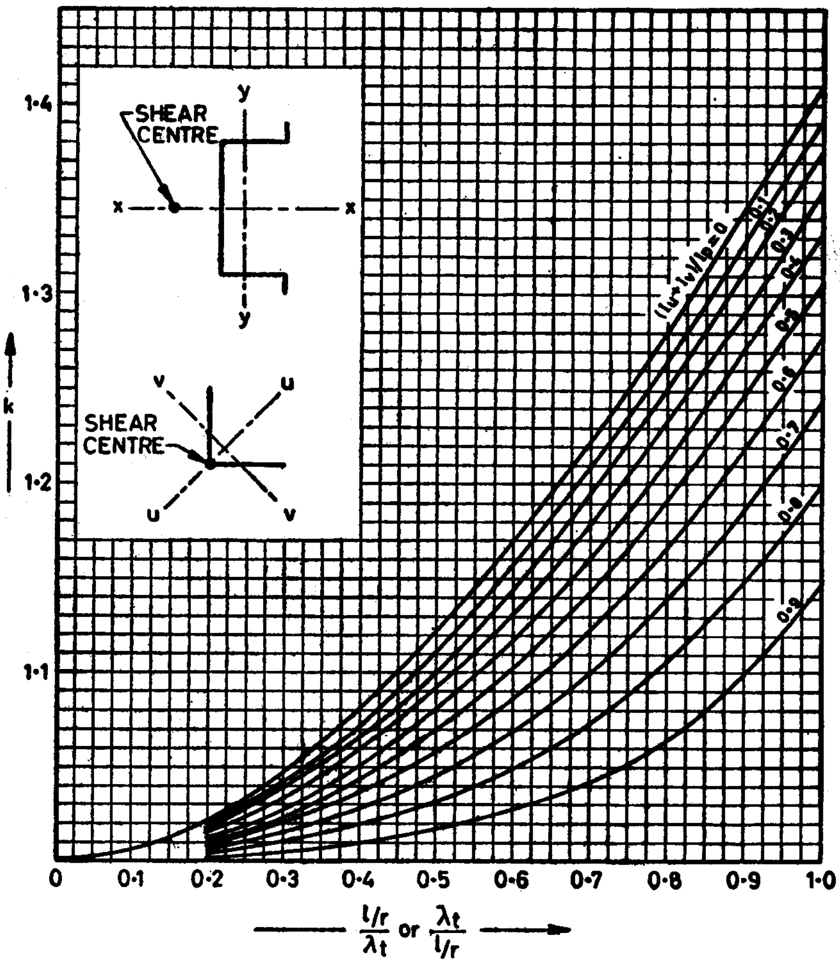


FIG. 30 VALUES OF THE INTERACTION COEFFICIENT k

l/r = slenderness ratio for ordinary column buckling in the plane normal to the axis of symmetry (that is, 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.

J-4. NO AXIS OF SYMMETRY

J-4.1 For a strut whose section has no symmetry, the interaction between torsional and column buckling is complex, and buckling stresses can only be determined by accurate theory (*see* Reference 2) or by test.

Column buckling of unsymmetrical sections does not occur independently of torsional buckling.

References for Appendix J

1) Hone (C P). 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) Timoshenko (S P). Strength of materials, Vol 2. 1956.

APPENDIX K

(*Clause* 8.3.4.2)

LATERAL BUCKLING OF BEAMS

K-1. DOUBLY-SYMMETRICAL SECTIONS NOT FREE TO MOVE SIDEWAYS AT LOAD POINTS

K-1.1 The methods given in **8.3.4.2** 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 0·75.

Warping resistance can be taken into account, and a higher permissible stress obtained for such members, by multiplying λ_{lat} by

$$\left(1 + \frac{26\,H}{L^2 J}\right)^{-\frac{1}{4}}$$

where

H = warping factor (*see* Appendix H),

L = distance between points of lateral support, and

J = torsion factor (*see* Appendix H).

K-2. DOUBLY-SYMMETRICAL SECTIONS FREE TO MOVE SIDEWAYS AT LOAD POINTS

K-2.1 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 **8.3.4.2** is

$$l_f = k_1 k_2 (L + k_3 y),$$

where

- L = the distance between points of lateral support,
- k_1 = a factor depending on the conditions of restraint at those points (*see* Table 27),
- k_2 = a factor depending on the shape of the bending moment diagram between those points (*see* Table 28),
- k_3 = a factor depending on the shape of the cross section (*see* Table 29), and
- y = 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.

TABLE 27 CONDITION OF RESTRAINT FACTOR k_1

(*Clause* K-2.1)

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 28 BENDING MOMENT SHAPE FACTOR k_2

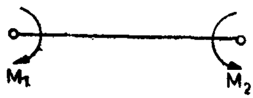
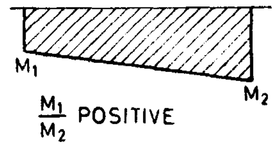
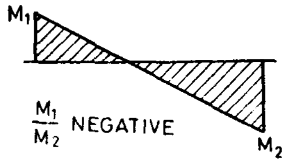
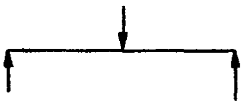
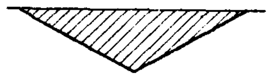
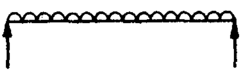
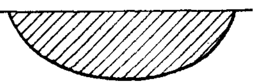
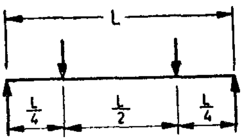
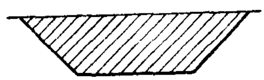
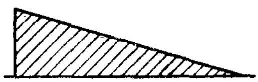
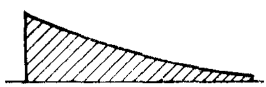
CONDITION OF RESTRAINT	TYPE OF LOADING	BENDING MOMENT DIAGRAM BETWEEN POINTS OF LATERAL SUPPORT	k_2
Seam or part of beam held laterally at points of load application			$\left(0.6+0.4\dfrac{M_1}{M_2}\right)$ or 0·4 whichever is greater
			M_2 is numerically greater than or equal to, M_1
Seam or part of 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 29 CROSS SECTION SHAPE FACTOR k_3

(*Clause* K-2.1)

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 Fig. 8, and I_y and J have the same meanings as in **K-3**

K-3. SECTIONS SYMMETRICAL ABOUT THE MINOR AXIS ONLY

K-3.1 For a beam having symmetry about the minor axis only (for example, a tee with a vertical stem), λ_{lat} may be calculated from the equation in **8.3.4.2** (c) provided l_t is obtained as follows:

a) For a beam which is not free to move sideways at the points of application of the loads:

$$l_t = k_1 k_2 \left\{ L + 5\,g \sqrt{\frac{I_y}{J}} \right\}, \text{ and}$$

b) For a beam which is free to move sideways at the points of application of the loads, but not for a cantilever:

$$l_t = k_1 k_2 \left\{ L + (5g + 2{\cdot}7y \sqrt{\frac{I_y}{J}} \right\}$$

where

I_y = the second moment of area about the minor axis;

J = the torsion factor (*see* Appendix H);

g = the distance of the shear centre from the centroid, taken as positive if on the tension side, and negative if not; and

L, k_1, k_2 and y have the same meanings as in **K-2**

APPENDIX L

(*Clause* 8.3.7.6)

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 designated by using more precise methods than those given in **8.3.7**.

The following papers may be referred to:

1) COOK (I T) and ROCKEY (K C). Shear buckling of clamped and simply supported infinitely long plates reinforced by closed section transverse stiffeners. *Aeronautical Quarterly*. Vol XIII. Aug 1962.
2) ROCKEY (K C) and COOK (I T). Influence of the torsional rigidity of transverse stiffeners upon the shear buckling of stiffened plates. *Aeronautical Quarterly*. Vol XV. May 1964.
3) MASSONNET (G), MAZY (G) and TANGHE (A). 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) ROCKEY (K C). Aluminium plate girders. *Proceedings of Symposium on Aluminium in Structural Engineering*. Aluminium Federation. London, 1963.

APPENDIX M

(*Clauses* 8.4.1.2 *and* 8.4.1.3)

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 **8.4.1** and Table **12**. It refers to certain thin-walled channels and I-sections, both with and without lips, in uniform axial compression.

The curves given in Fig. 31 and 32 apply to plain channels and I-sections respectively, and those in Fig. 33 and 34 to lipped channels and I-sections respectively. In the figures:

a = the depth of web (inside flanges),

b = the width of flange or half-flange (to face of web),

t_1 = the web thickness, and

t_2 = the flange thickness.

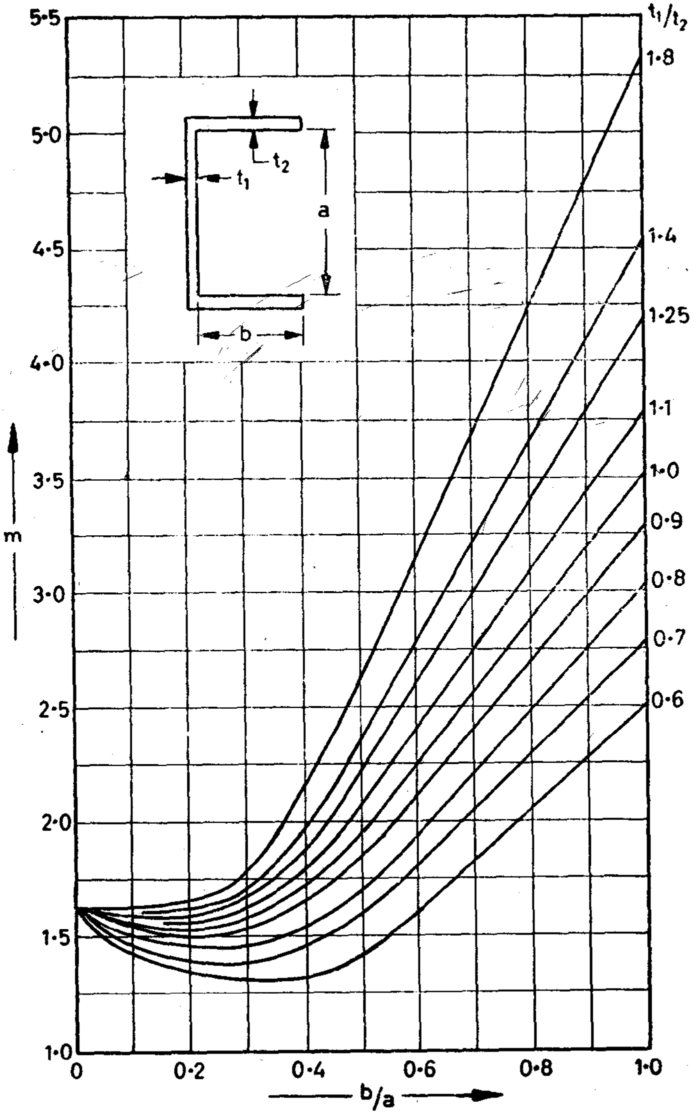


Fig. 31 Values of *m* for Plain Channels

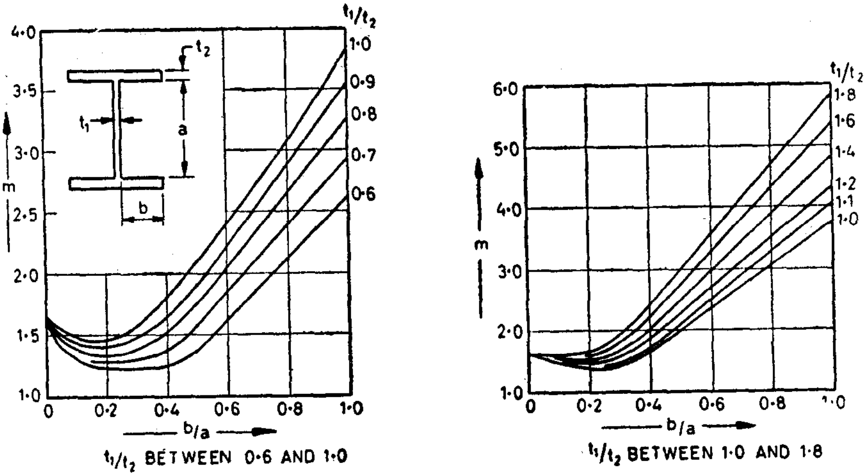


FIG. 32 VALUES OF *m* FOR PLAIN I-SECTIONS

These dimensions are further defined by the relevant diagrams, which also indicate the areas to be considered for lips.

The procedure for design is as follows:

a) *Plain Sections* — For a plain section, the value of the local buckling coefficient m for the entire section is obtained from Fig. 31 or Fig. 32 by entering with the appropriate values of b/a and t_1/t_2.

b) *Lipped Sections* — For a lipped section, the value of m for the entire section is obtained from Fig. 33 or Fig. 34 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 Fig. 33 and 34 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 Fig. 2 at $\lambda = ma/t_1$.

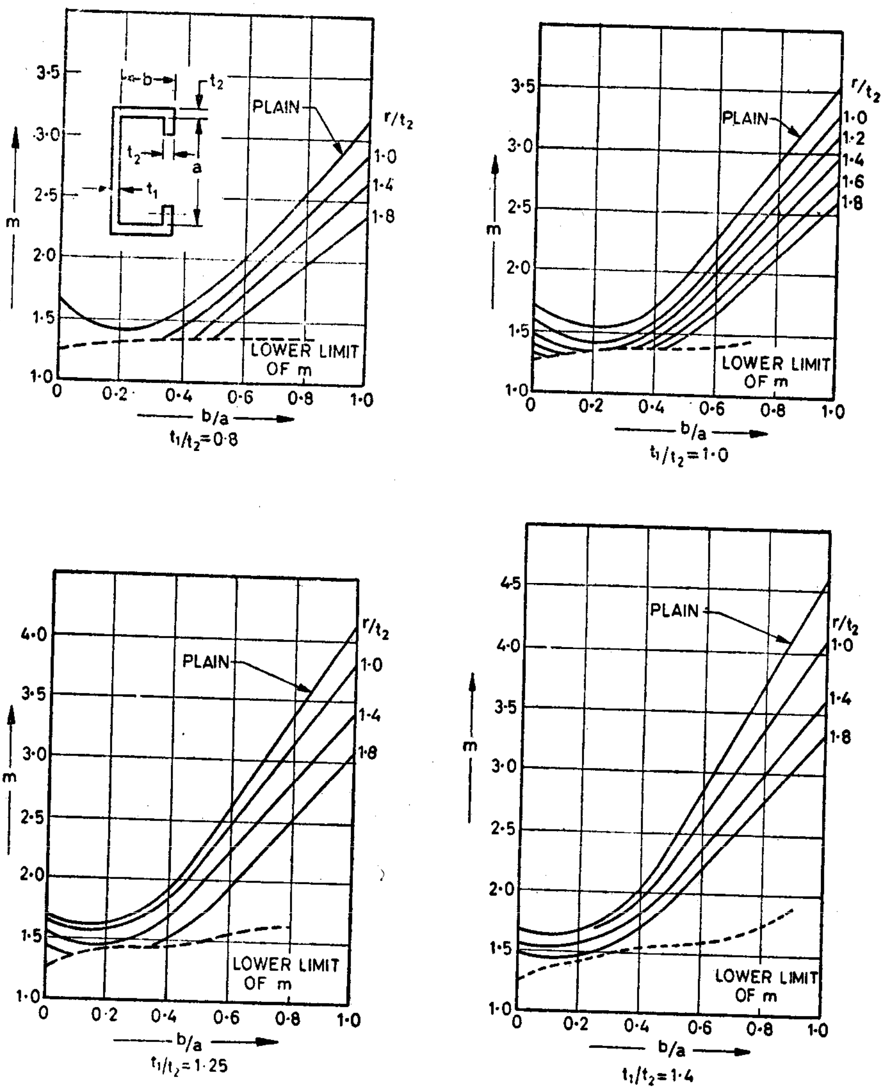


Fig. 33 Values of *m* for Lipped Channels

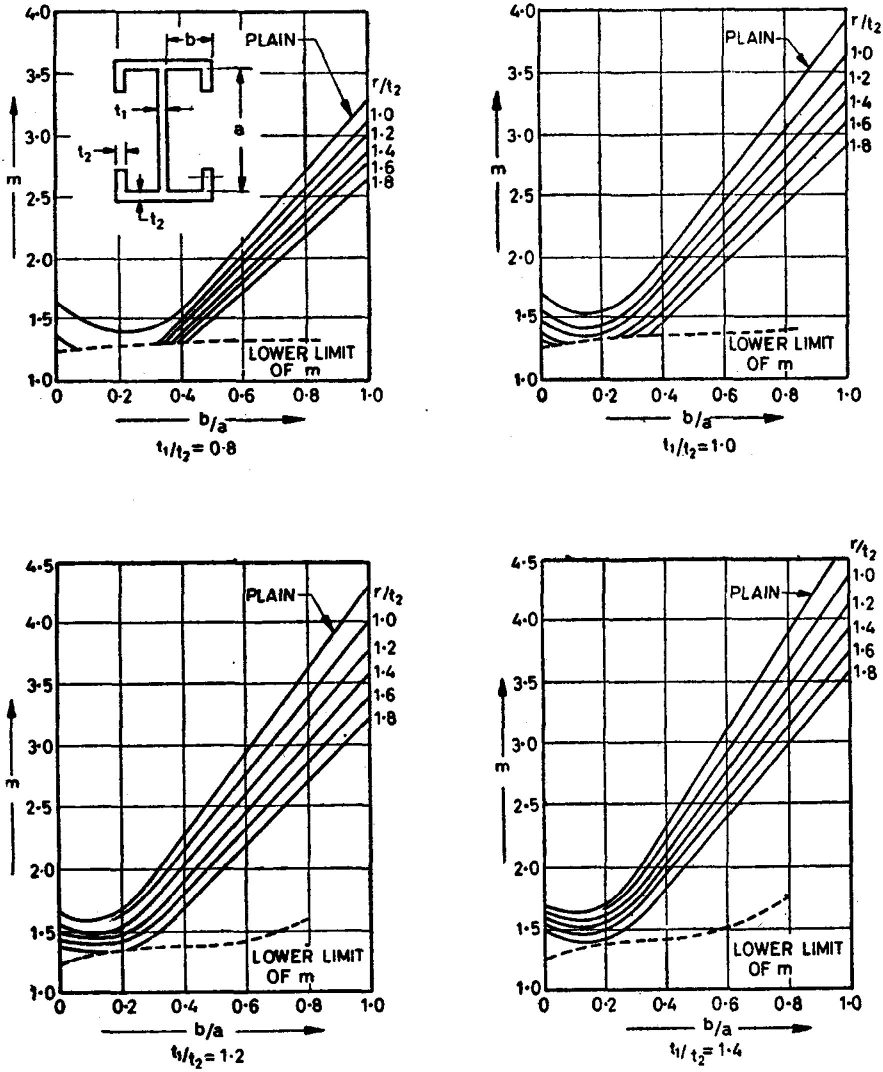


FIG. 34 VALUES OF *m* FOR LIPPED I-SECTIONS

APPENDIX N

(*Clause* 9.3.4)

DESIGN OF WELDED JOINTS

N-1. GENERAL

N-1.1 The versatility of welding enable joints between members to be made in many different ways. However, in selecting the type of joint to be used, the designer should consider:

a) the effect of the joint on the static strength of the member;

b) the effect of the joint on the fatigue strength of the member, and the choice of details to reduce stress concentrations,

c) the detailed arrangement of the joint to enable good-quality welds to be made;

d) the choice of suitable details to avoid corrosion; and

e) the effects of welding distortion.

These considerations are dealt with in **N-2** to **N-6**.

N-2. EFFECT ON STATIC STRENGTH

N-2.1 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* **9.3.2**). 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.

N-3. EFFECT ON FATIGUE STRENGTH

N-3.1 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.

N-3.2 The classification given in **10.4** forms a guide for the selection of weld details, and the examples in Table 30 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 **10.4** 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

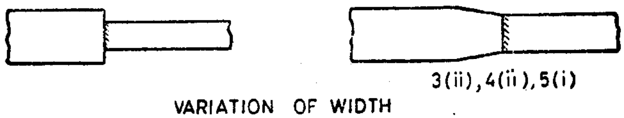
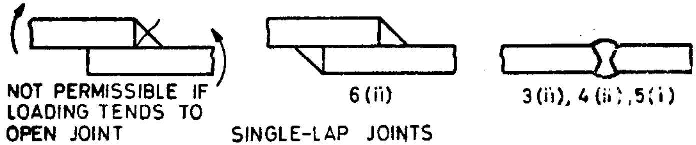
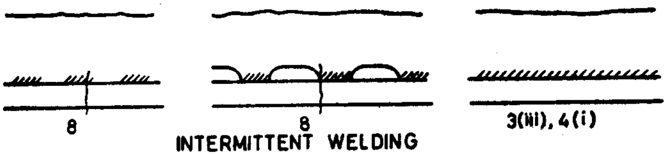
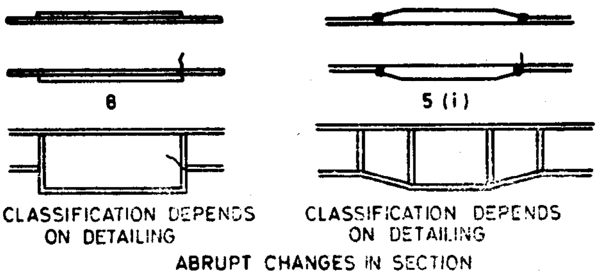
TABLE 30 ILLUSTRATIONS OF WELDED JOINTS

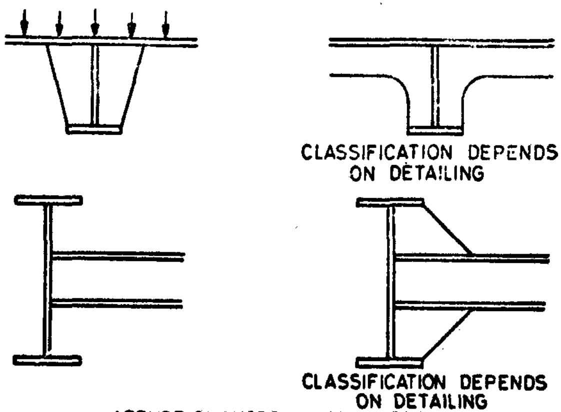
(*Clause* N-3.2)

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 reinforcement provides higher fatigue strength. For optimum fatigue strength, the weld should be dressed flush in accordance with **10.4.1** (Class 2).
 (see 10.2) 3 (ii), 4 (ii), 5 (i)  (see 10.2) 3 (ii), 4 (ii), 5 (i)  (see 10.2) 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* foot-note under **10.2**). Where a butt joint is made between two members differing in thickness by more than 3·2 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.

(*Continued*)

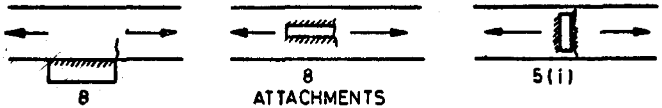
TABLE 30 ILLUSTRATIONS OF WELDED JOINTS — *Contd.*

WELD DETAIL	REMARKS
	Where a butt joint is made between members of unequal width, the wider should be tapered to the width of the narrower.
	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.
	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.
	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.



ABRUPT CHANGES IN STIFFNESS

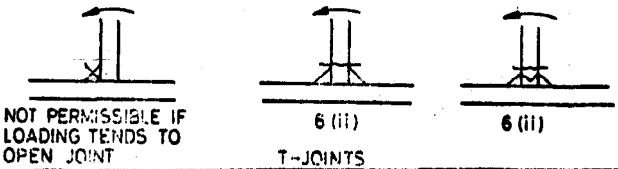
Abrupt changes in stiffness create stress concentrations and should as far as possible, be avoided. Nevertheless, at any point where load is applied to a member, the member should be made stiff enough to resist that load.



ATTACHMENTS

Attachments, even if carrying insignificant loads, produce severe stress concentrations in strength members to which they are welded.

Transverse attachments are less harmful than longitudinal once. Longitudinal welds on the edges of a strength member are particularly to be avoided.



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.

low-strength joints can not be avoided they should, if possible, be placed at points where the applied stress is low, for example, on the neutral axis or at a point of contraflexure.

N-4. ARRANGEMENT FOR WELDING

N-4.1 For good quality welding the proper edge preparation (*see* Appendix P) 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.

N-5. CORROSION

N-5.1 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* **22**).

N-6. DISTORTION

N-6.1 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.

N-6.2 In the early stages of design the fabricator should be consulted on the effects of welding sequence and the use of jigs.

APPENDIX P

(*Clauses* 9.3.4, 12.3.4 *and* N-4.1)

EDGE PREPARATIONS FOR WELDED JOINTS

Tables 31 to 38 give guidance on the choice of edge preparations. The preparations shown are applicable, except where otherwise stated, to both TIG and MIG welding.

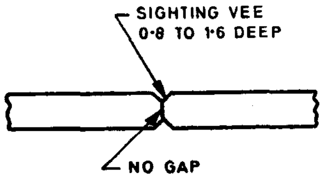
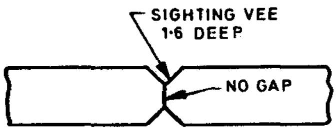
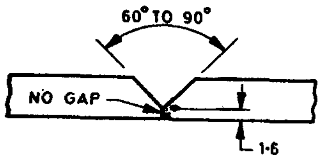
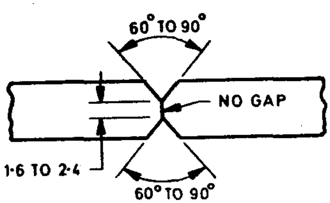
The ranges given for preparation angles and other dimensions are not manufacturing tolerances, but give scope for choice for individual cases; whichever angle and other dimensions are used, however, the edge preparation shall be identical on both sides of any symmetrical joint.

Where the requirement is for no gap, the accuracy of fit shall be such that the gap at any point exceeds neither 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.

TABLE 31 EDGE PREPARATIONS FOR BUTT WELDS WITHOUT BACKING BARS

All dimensions in millimetres.

Thickness	Edge Preparation	Procedure	Welding Positions
3·2 to 4·8 3·2 to 6·4		TIG, manual or mechanized MIG manual or mechanized	3·2 : Flat 4·8 to 6·4 Manual : All mechanized : Flat
4·8 to 25		MIG (high current), mechanized, weld both sides	Flat and horizontal-vertical
4·8 to 13		Manual or mechanized*	Manual : All Mechanized : Flat and horizontal-vertical
13 upwards		Manual or mechanized weld both sides†	

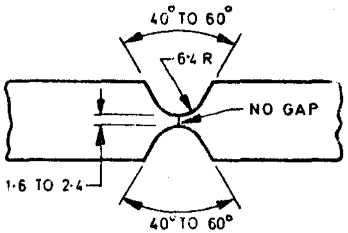
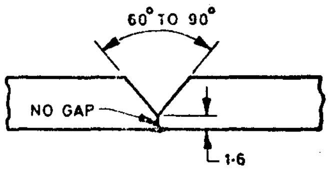
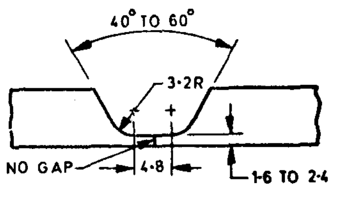
*Place sealing run on back of weld after chipping or machining to sound metal.

†Chip or machine back of first weld before placing first run of second weld.

(Continued)

TABLE 31 EDGE PREPARATIONS FOR BUTT WELDS WITHOUT BACKING BARS — *Contd*

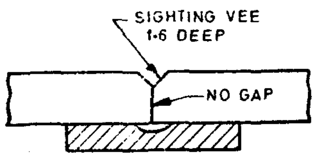
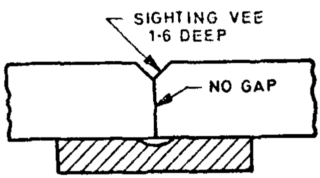
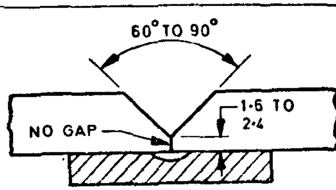
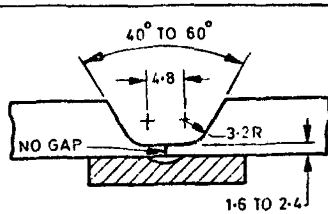
All dimensions in millimetres.

Thickness	Edge Preparation	Procedure	Welding Positions
19 upwards		Manual or mechanized Weld both sides*	
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)	Manual : All Mechanized : Flat and horizontal-vertical
4·8 upwards		MIG (but TIG for root run), manual or mechanized. Use where access to back of joint is impracticable (as with tubes)	

*Chip or machine back of first weld before placing first run of second weld.

TABLE 32 EDGE PREPARATIONS FOR BUTT WELDS WITH TEMPORARY BACKING BARS*

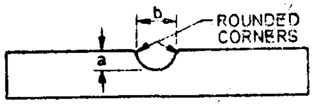
All dimensions in millimetres.

THICKNESS	EDGE PREPARATION*	PROCEDURE	WELDING POSITIONS
3·2 to 6·4		Manual, weld one side only	Flat
3·2 to 19		MIG (high current) mechanized, weld one side only	Flat
4·8 upwards		Manual or mechanized, weld one side only	Manual: All Mechanized: Flat and horizontal-vertical
6·4 upwards		Manual or mechanized, weld one side only (TIG for root run particularly with tubes)	

*Backing-bar dimensions are given in Table 33.

TABLE 33 RECOMMENDED TEMPORARY BACKING BAR DIMENSIONS

All dimensions in millimetres.

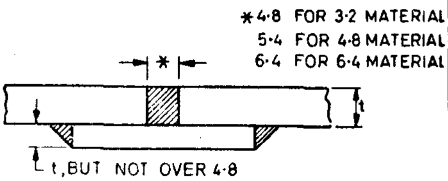
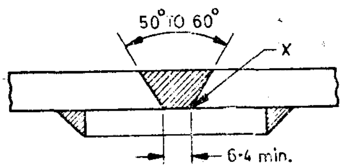


PARENT METAL THICKNESS	*a*	*b*
3·2 to 4·8	1·6	4·8
4·8 upwards	3·2	6·4

Backing bars should preferably be of corrosion-resisting steel or bright mild steel.

TABLE 34 EDGE PREPARATIONS FOR BUTT WELDS WITH PERMANENT BACKING BARS*

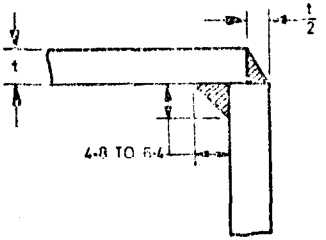
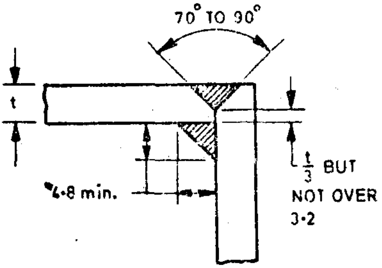
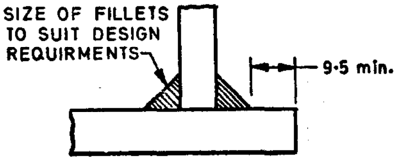
All dimensions in millimetres.

THICKNESS	EDGE PREPARATION	PROCEDURE	WELDING POSITIONS
3·2 to 6·4		MIG. Manual or mechanized	Flat
6·4 upwards		MIG. Manual or mechanized Fuse toes X before completing joint	Manual: All mechanized: Flat and horizontal-vertical

*Permanent backing shall be of same alloy as parent metal; it may be a structural section.

TABLE 35 EDGE PREPARATIONS FOR CORNER WELDS WITHOUT BACKING BARS

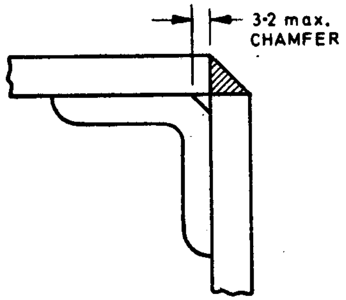
All dimensions in millimetres.

THICKNESS	EDGE PREPARATION	PROCEDURE	WELDING POSITIONS
6·4 to 9·5		Manual or mechanized*	Manual: All (but preferably flat) Mechanized: Flat and horizontal-vertical
4·8 upwards			
3·2 upwards		Manual or machanized	

*Place root run of outer weld first. Chip or machine back from inside, wherever possible, before placing inside run.

TABLE 36 EDGE PREPARATIONS FOR CORNER WELDS WITH TEMPORARY BACKING BARS

All dimensions in millimetres.

<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="2">Manual: All (but preferably flat)

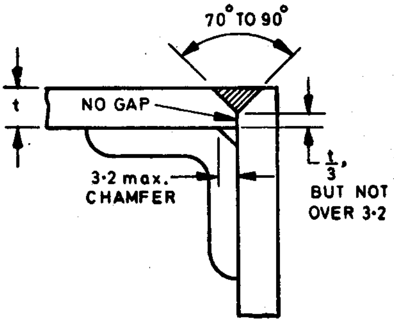
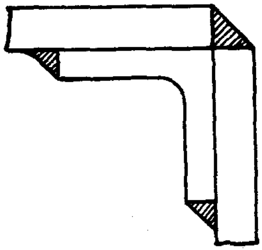
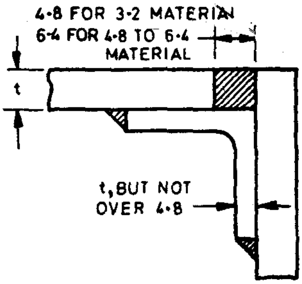
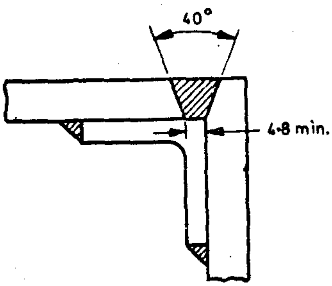
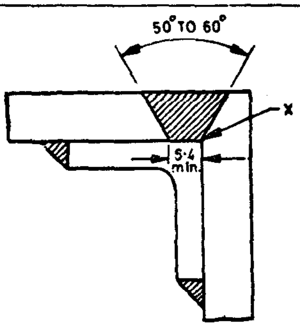
Mechanized: Flat and horizontal vertical</td></tr>
<tr><td>
</td></tr>
</table>

TABLE 37 EDGE PREPARATIONS FOR CORNER WELDS WITH PERMANENT BACKING BARS*

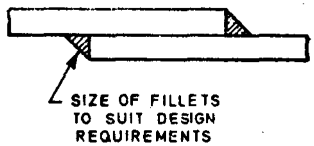
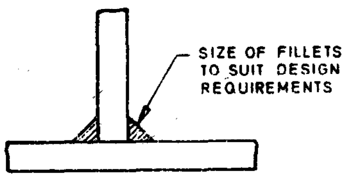
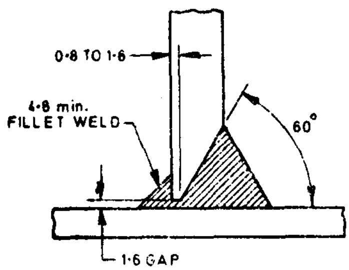
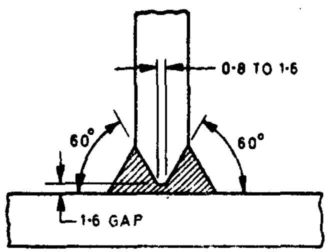
All dimensions in millimetres.

Thickness	Edge Preparation	Procedure	Welding Positions
3·2 to 13			
3·2 to 6·4		Manual or mechanized	Manual: All (but preferably flat) Mechanized: Flat and horizontal-vertical
6·4 to 9·5			
9·5 upwards		Manual or mechanized Fuse toes X before completing joint	—

*Permanent backing bar shall be of same alloy as parent metal.

TABLE 38 EDGE PREPARATIONS FOR LAP AND FILLET WELDS

All dimensions in millimetres.

THICKNESS	EDGE PREPARATION	PROCEDURE	WELDING POSITIONS
All	 	Manual or mechanized	
4·8 to 13		Manual or mechanized*	Manual: All (but preferably flat) Mechanized: Flat and horizontal-vertical
9·5 upwards		Manual or mechanized†	

*Place sealing run on back of weld after chipping or machining to sound metal.

†Chip or machine back of first weld before placing first run of second weld.

APPENDIX Q

(*Clause* 10.3.1)

TABULATED STRESSES FOR FATIGUE

The relationship between maximum stress, stress ratio and number of cycles, given graphically in Fig. 16 to 24 for the nine classes of members defined in **10.4**, are given in Tables 39 to 47 for the convenience of designers.

In the derivation of the tabulated quantities, the curves in Fig. 16 to 24 were in some cases slightly adjusted. The values, moreover, are rounded to two significant figures. In case of doubt, the curves of Fig. 16 to 24 are the definitive reference.

TABLE 39 RELATIONSHIP OF MAXIMUM STRESS, STRESS RATIO AND NUMBER OF CYCLES FOR CLASS 1 MEMBERS

A. Maximum Tensile Stress

f_{Min}/f_{Max}	f_{Max} in N/mm² (kgf/cm²) FOR NUMBER OF CYCLES				
	100 000	600 000	2000 000	10 000 000	100 000 000
0·6	—	230 (2 340)	200 (2 040)	190 (1 940)	190 (1 940)
0·5	230 (2 340)	190 (1 940)	170 (1 730)	150 (1 530)	150 (1 530)
0·4	190 (1 940)	150 (1 530)	140 (1 425)	120 (1 220)	120 (1 220)
0·3	170 (1 730)	140 (1 425)	120 (1 220)	120 (1 220)	120 (1 220)
0·2	150 (1 530)	120 (1 220)	110 (1 120)	110 (1 120)	110 (1 120)
0·1	130 (1 325)	110 (1 120)	110 (1 120)	110 (1 120)	110 (1 120)
0·0	120 (1 220)	110 (1 120)	110 (1 120)	100 (1 020)	100 (1 020)
−0·1	110 (1 120)	110 (1 120)	100 (1 020)	97 (990)	97 (990)
−0·2	110 (1 120)	100 (1 020)	97 (990)	94 (960)	94 (960)
−0·3	100 (1 020)	97 (990)	93 (950)	90 (920)	90 (920)
−0·4	100 (1 020)	94 (960)	90 (920)	86 (875)	86 (875)
−0·5	96 (980)	90 (920)	86 (875)	83 (845)	83 (845)
−0·6	93 (950)	86 (875)	83 (845)	80 (815)	80 (815)
−0·7	90 (920)	85 (865)	80 (815)	79 (805)	79 (805)
−0·8	86 (875)	82 (835)	77 (785)	76 (775)	76 (775)
−0·9	85 (865)	79 (805)	76 (775)	73 (745)	73 (745)
−1·0	82 (835)	77 (785)	73 (745)	71 (725)	71 (725)

B. Maximum Compressive Stress

f_{Min}/f_{Max}	f_{Max} in N/mm² (kgf/cm²) FOR NUMBER OF CYCLES				
	100 000	600 000	2 000 000	10 000 000	100 000 000
−0·1	−220 (−2 240)	−200 (−2 040)	−200 (−2 040)	−200 (−2 040)	−200 (−2 040)
−0·2	−190 (−1 940)	−170 (−1 730)	−170 (−1 730)	−150 (−1 530)	−150 (−1 530)
−0·3	−150 (−1 530)	−150 (−1 530)	−140 (−1 425)	−140 (−1 425)	−140 (−1 425)
−0·4	−140 (−1 425)	−130 (−1 325)	−130 (−1 325)	−120 (−1 220)	−120 (−1 220)
−0·5	−130 (−1 325)	−120 (−1 220)	−110 (−1 120)	−110 (−1 120)	−110 (−1 120)
−0·6	−110 (−1 120)	−110 (−1 120)	−100 (−1 020)	−99 (−1 010)	−99 (−1 010)
−0·7	−100 (−1 020)	−97 (−990)	−93 (−950)	−90 (−920)	−90 (−920)
−0·8	−96 (−980)	−90 (−920)	−85 (−865)	−82 (−835)	−82 (−835)
−0·9	−88 (−900)	−82 (−835)	−79 (−805)	−76 (−775)	−76 (−775)
−1·0	−82 (−835)	−77 (−805)	−73 (−745)	−71 (−725)	−71 (−725)

TABLE 40 RELATIONSHIP OF MAXIMUM STRESS, STRESS RATIO AND NUMBER OF CYCLES FOR CLASS 2 MEMBERS

A. Maximum Tensile Stress

f_{Min}/f_{Max}	f_{Max} in N/mm² (kgf/cm²) FOR NUMBER OF CYCLES				
	100 000	600 000	2 000 000	10 000 0000	100 000 000
0·6	—	—	—	150 (1 530)	140 (1 430)
0·5	—	—	140 (1 430)	120 (1 225)	110 (1 120)
0·4	—	140 (1 430)	120 (1 225)	110 (1 120)	100 (1 020)
0·3	140 (1430)	120 (1 225)	110 (1 120)	96 (980)	94 (960)
0·2	120 (1225)	110 (1 120)	97 (990)	90 (920)	89 (910)
0·1	110 (1120)	99 (1 010)	93 (950)	85 (870)	83 (845)
0·0	99 (1010)	93 (950)	89 (910)	82 (835)	79 (805)
−0·1	94 (960)	90 (920)	85 (870)	79 (805)	76 (775)
−0·2	91 (930)	85 (870)	82 (835)	76 (775)	74 (755)
−0·3	88 (900)	82 (835)	79 (805)	73 (745)	71 (725)
−0·4	85 (870)	79 (805)	76 (775)	69 (705)	68 (695)
−0·5	82 (835)	77 (785)	73 (745)	68 (695)	66 (675)
−0·6	79 (805)	74 (755)	71 (725)	65 (665)	63 (645)
−0·7	76 (775)	71 (725)	68 (695)	63 (645)	61 (625)
−0·8	74 (755)	69 (705)	66 (675)	61 (625)	60 (615)
−0·9	71 (725)	66 (675)	65 (665)	60 (615)	59 (600)
−1·0	69 (705)	65 (665)	62 (635)	57 (580)	56 (570)

B. Maximum Compressive Stress

f_{Min}/f_{Max}	f_{Max} in N/mm² (kgf/cm²) FOR NUMBER OF CYCLES				
	100 000	600 000	2 000 000	10 000 000	100 000 000
−0·1	—	—	—	—	−150 (−1 530)
−0·2	—	−150 (−1 530)	−140 (−1 430)	−130 (−1 330)	−130 (−1 330)
−0·3	−140 (−1 430)	−130 (−1 330)	−120 (−1 225)	−110 (−1 120)	−110 (−1 120)
−0·4	−120 (−1 225)	−110 (−1 120)	−110 (−1 120)	−100 (−1 020)	−97 (−990)
−0·5	−110 (−1 120)	−100 (−1 020)	−97 (−990)	−90 (−920)	−86 (−880)
−0·6	−97 (-990)	−91 (−930)	−86 (−880)	−80 (−820)	−79 (−805)
−0·7	−88 (-900)	−83 (−845)	−79 (−805)	−74 (−755)	−71 (−725)
−0·8	−80 (-820)	−76 (−775)	−73 (−745)	−68 (−695)	−65 (−665)
−0·9	−74 (-755)	−69 (−705)	−68 (−695)	−61 (−625)	−60 (−615)
−1·0	−69 (-705)	−65 (−665)	−62 (−635)	−57 (−580)	−56 (−570)

TABLE 41 RELATIONSHIP OF MAXIMUM STRESS, STRESS RATIO AND NUMBER OF CYCLES FOR CLASS 3 MEMBERS

A. Maximum Tensile Stress

f_{Min}/f_{Max}	f_{Max} in N/mm² (kgf/cm²) FOR NUMBER OF CYCLES				
	100 000	600 000	2 000 000	10 000 000	100 000 000
0·8	—	—	—	200 (2 040)	190 (1 940)
0·7	—	200 (2 040)	170 (1 730)	130 (1 325)	120 (1 225)
0·6	200 (2 040)	150 (1 530)	120 (1 225)	100 (1 020)	91 (930)
0·5	150 (1 530)	120 (1 225)	99 (1 010)	80 (820)	73 (745)
0·4	130 (1 325)	100 (1 020)	82 (835)	69 (705)	66 (675)
0·3	110 (1 120)	88 (900)	73 (745)	65 (665)	62 (635)
0·2	99 (1 010)	79 (805)	68 (695)	62 (635)	59 (600)
0·1	88 (900)	73 (745)	65 (665)	59 (600)	56 (570)
0·0	79 (805)	68 (695)	62 (635)	56 (570)	53 (540)
−0·1	76 (775)	65 (665)	59 (600)	53 (540)	49 (500)
−0·2	74 (755)	63 (645)	57 (580)	51 (520)	48 (490)
−0·3	71 (725)	60 (615)	54 (550)	49 (500)	45 (460)
−0·4	68 (695)	59 (600)	53 (540)	46 (470)	43 (440)
−0·5	66 (675)	57 (580)	51 (520)	45 (460)	42 (430)
−0·6	63 (645)	54 (550)	49 (500)	43 (440)	40 (410)
−0·7	62 (635)	53 (540)	48 (490)	42 (430)	39 (400)
−0·8	60 (615)	51 (520)	46 (470)	40 (410)	37 (380)
−0·9	59 (600)	49 (500)	45 (460)	39 (400)	36 (370)
−1·0	56 (570)	48 (490)	43 (440)	37 (380)	34 (345)

B. Maximum Compressive Stress

f_{Min}/f_{Max}	f_{Max} in N/mm² (kgf/cm²) FOR NUMBER OF CYCLES				
	100 000	600 000	2 000 000	10 000 000	100 000 000
0·2	—	—	—	−220 (−2 240)	−220 (−2 240)
0·1	—	−220 (−2 240)	−200 (−2 040)	−150 (−1 530)	−150 (−1 530)
0·0	−190 (−1 940)	−150 (−1 530)	−150 (−1 530)	−120 (−1 225)	−110 (−1 120)
−0·1	−150 (−1 530)	−130 (−1 325)	−120 (−1 225)	−100 (−1 020)	−93 (−950)
−0·2	−130 (−1 325)	−110 (−1 120)	−100 (−1 020)	−85 (−870)	−79 (−805)
−0·3	−110 (−1 120)	−94 (−960)	−85 (−870)	−73 (−745)	−66 (−675)
−0·4	−97 (−990)	−83 (−845)	−76 (−775)	−65 (−665)	−59 (−600)
−0·5	−86 (−880)	−74 (−755)	−66 (−675)	−57 (−580)	−53 (−540)
−0·6	−79 (−805)	−66 (−675)	−60 (−615)	−53 (−540)	−48 (−490)
−0·7	−71 (−725)	−60 (−615)	−54 (−550)	−48 (−490)	−43 (−440)
−0·8	−65 (−665)	−56 (−570)	−51 (−520)	−43 (−440)	−40 (−410)
−0·9	−60 (−615)	−51 (−520)	−46 (−470)	−40 (−410)	−37 (−380)
−1·0	−56 (−570)	−48 (−490)	−43 (−440)	−37 (−380)	−34 (−345)

TABLE 42 RELATIONSHIP OF MAXIMUM STRESS, STRESS RATIO AND NUMBER OF CYCLES FOR CLASS 4 MEMBERS

A. Maximum Tensile Stress

f_{Min}/f_{Max}	f_{Max} in N/mm² (kgf/cm²) for Number of Cycles				
	100 000	600 000	2 000 000	10 000 000	100 000 000
0·8	—	—	—	150 (1 530)	140 (1 425)
0·7	—	—	130 (1 325)	100 (1 020)	91 (930)
0·6	—	120 (1 220)	99 (1 010)	76 (775)	68 (690)
0·5	140 (1 425)	99 (1 010)	79 (805)	60 (615)	54 (550)
0·4	120 (1 220)	82 (835)	65 (665)	54 (550)	46 (470)
0·3	99 (1 010)	71 (725)	59 (600)	51 (520)	45 (460)
0·2	86 (875)	65 (665)	54 (550)	48 (490)	42 (430)
0·1	77 (785)	60 (615)	51 (520)	45 (460)	40 (410)
0·0	71 (725)	57 (580)	49 (500)	43 (440)	39 (400)
−0·1	68 (695)	56 (570)	48 (490)	42 (430)	37 (380)
−0·2	65 (665)	53 (540)	45 (460)	40 (410)	36 (370)
−0·3	63 (645)	51 (520)	43 (440)	37 (380)	34 (345)
−0·4	60 (615)	49 (500)	42 (430)	36 (370)	32 (325)
−0·5	59 (600)	46 (470)	40 (410)	36 (370)	31 (315)
−0·6	56 (570)	45 (460)	39 (400)	34 (345)	29 (295)
−0·7	54 (550)	43 (440)	39 (400)	32 (325)	28 (285)
−0·8	53 (540)	42 (430)	37 (380)	31 (315)	28 (285)
−0·9	51 (520)	42 (430)	36 (370)	31 (315)	26 (265)
−1·0	4[illegible] (490)	40 (410)	34 (345)	29 (295)	25 (255)

B. Maximum Compressive Stress

f_{Min}/f_{Max}	f_{Max} in N/mm² (kgf/cm²) for Number of Cycles				
	100 000	600 000	2 000 000	10 000 000	100 000 000
0·1	—	—	−150 (−1 530)	−130 (−1 325)	−110 (−1 120)
0·0	—	−130 (−1 325)	−110 (−1 120)	−96 (−980)	−83 (−845)
−0·1	−130 (−1 325)	−110 (−1 120)	−93 (−950)	−79 (−805)	−68 (−695)
−0·2	−110 (−1 120)	−91 (−930)	−79 (−805)	−66 (−675)	−57 (−580)
−0·3	−96 (−980)	−77 (−785)	−68 (−695)	−57 (−580)	−49 (−500)
−0·4	−83 (−845)	−68 (−695)	−60 (−610)	−51 (−520)	−43 (−440)
−0·5	−76 (−775)	−62 (−630)	−54 (−550)	−45 (−465)	−39 (−395)
−0·6	−68 (−695)	−56 (−570)	−48 (−490)	−40 (−410)	−36 (−365)
−0·7	−62 (−630)	−51 (−520)	−43 (−440)	−37 (−380)	−32 (−325)
−0·8	−57 (−580)	−46 (−470)	−40 (−410)	−34 (−345)	−29 (−295)
−0·9	−53 (−540)	−43 (−440)	−37 (−375)	−31 (−315)	−28 (−285)
−1·0	−48 (−490)	−40 (−405)	−34 (−345)	−29 (−295)	−25 (−255)

TABLE 43 RELATIONSHIP OF MAXIMUM STRESS, STRESS RATIO AND NUMBER OF CYCLES FOR CLASS 5 MEMBERS

A. Maximum Tensile Stress

f_{Min}/f_{Max}	f_{Max} in N/mm² (kgf/cm²) for Number of Cycles				
	100 000	600 000	2 000 000	10 000 000	100 000 000
0·8	—	—	—	130 (1 330)	120 (1 225)
0·7	—	150 (1 530)	120 (1 225)	90 (920)	79 (805)
0·6	—	110 (1 120)	86 (880)	68 (700)	59 (600)
0·5	130 (1 330)	88 (900)	69 (705)	54 (550)	46 (470)
0·4	110 (1 120)	74 (755)	57 (580)	46 (470)	42 (430)
0·3	91 (930)	63 (645)	51 (520)	43 (440)	39 (400)
0·2	79 (810)	57 (580)	48 (490)	40 (410)	36 (370)
0·1	71 (725)	53 (540)	45 (460)	39 (400)	34 (345)
0·0	65 (665)	51 (520)	43 (440)	36 (370)	32 (325)
−0·1	62 (635)	49 (500)	42 (430)	34 (345)	31 (315)
−0·2	59 (605)	46 (470)	40 (410)	32 (325)	29 (295)
−0·3	57 (580)	45 (460)	39 (400)	31 (315)	28 (285)
−0·4	56 (570)	43 (440)	37 (380)	29 (295)	26 (265)
−0·5	53 (540)	42 (430)	36 (370)	29 (295)	25 (255)
−0·6	51 (520)	40 (410)	36 (370)	28 (285)	25 (255)
−0·7	49 (500)	39 (400)	34 (345)	26 (265)	23 (235)
−0·8	48 (490)	39 (400)	32 (325)	26 (265)	23 (235)
−0·9	46 (470)	37 (380)	32 (325)	25 (255)	22 (225)
−1·0	45 (460)	36 (370)	31 (315)	23 (236)	20 (205)

B. Maximum Compressive Stress

f_{Min}/f_{Max}	f_{Max} in N/mm² (kgf/cm²) for Number of Cycles				
	100 000	600 000	2 000 000	10 000 000	100 000 000
0·2	—	—	—	−150 (−1 530)	−130 (−1 330)
0·1	—	−150 (−1 530)	−130 (−1 330)	−100 (−1 020)	−91 (−930)
0·0	−150 (−1 530)	−120 (−1 225)	−100 (−1 020)	−79 (−805)	−69 (−705)
−0·1	−120 (−1 225)	−96 (−980)	−82 (−840)	−65 (−665)	−56 (−570)
−0·2	−100 (−1 020)	−80 (−820)	−69 (−705)	−54 (−550)	−46 (−470)
−0·3	−88 (−900)	−69 (−705)	−59 (−600)	−46 (−470)	−40 (−410)
−0·4	−77 (−785)	−62 (−635)	−53 (−540)	−42 (−430)	−36 (−370)
−0·5	−69 (−705)	−54 (−550)	−46 (−470)	−37 (−380)	−32 (−325)
−0·6	−62 (−635)	−49 (−500)	−42 (−430)	−32 (−325)	−29 (−295)
−0·7	−57 (−580)	−45 (−460)	−39 (−400)	−31 (−315)	−26 (−265)
−0·8	−53 (−540)	−42 (−430)	−36 (−370)	−28 (−285)	−25 (−255)
−0·9	−48 (−490)	−39 (−400)	−32 (−325)	−26 (−265)	−23 (−235)
−1·0	−45 (−460)	−36 (−370)	−31 (−315)	−23 (−235)	−20 (−205)

TABLE 44 RELATIONSHIP OF MAXIMUM STRESS, STRESS RATIO AND NUMBER OF CYCLES FOR CLASS 6 MEMBERS

A. Maximum Tensile Stress

f_{Min}/f_{Max}	f_{Max} in N/mm² (kgf/cm²) for Number of Cycles				
	100 000	600 000	2 000 000	10 000 000	100 000 000
0·8	—	—	150 (1 530)	110 (1 120)	82 (835)
0·7	—	130 (1 325)	99 (1 010)	73 (745)	65 (665)
0·6	140 (1 425)	96 (980)	74 (755)	54 (550)	48 (490)
0·5	110 (1 120)	77 (785)	59 (600)	43 (440)	39 (400)
0·4	93 (945)	63 (640)	49 (500)	37 (380)	36 (370)
0·3	80 (815)	54 (550)	42 (430)	36 (370)	32 (325)
0·2	70 (715)	49 (500)	40 (410)	34 (350)	31 (315)
0·1	62 (630)	46 (470)	39 (400)	31 (315)	28 (285)
0·0	59 (600)	45 (460)	37 (380)	29 (295)	26 (265)
−0·1	56 (570)	43 (440)	36 (370)	29 (295)	26 (265)
−0·2	54 (550)	42 (430)	34 (350)	28 (285)	25 (255)
−0·3	51 (520)	40 (410)	32 (325)	26 (265)	23 (235)
−0·4	49 (500)	39 (400)	32 (325)	25 (255)	22 (225)
−0·5	48 (490)	37 (380)	31 (315)	25 (255)	22 (225)
−0·6	46 (470)	36 (370)	29 (295)	23 (235)	20 (205)
−0·7	45 (460)	34 (350)	29 (295)	22 (225)	20 (205)
−0·8	43 (440)	32 (325)	28 (285)	22 (225)	19 (195)
−0·9	42 (430)	32 (325)	26 (265)	20 (205)	19 (195)
−1·0	40 (410)	31 (315)	26 (265)	20 (205)	17 (175)

B. Maximum Compressive Stress

f_{Min}/f_{Max}	f_{Max} in N/mm² (kgf/cm²) for Number of Cycles				
	100 000	600 000	2 000 000	10 000 000	100 000 000
0·3	—	—	—	−150 (−1 530)	−140 (−1 430)
0·2	—	—	−130 (−1 325)	−100 (−1 020)	−91 (−925)
0·1	−150 (−1 530)	−120 (−1 220)	−99 (−1 010)	−76 (−775)	−66 (−675)
0·0	−120 (−1 220)	−93 (−945)	−79 (−805)	−60 (−610)	−53 (−540)
−0·1	−100 (−1 020)	−77 (−785)	−65 (−665)	−49 (−500)	−43 (−440)
−0·2	−86 (−875)	−66 (−675)	−56 (−570)	−43 (−440)	−37 (−380)
−0·3	−76 (−775)	−59 (−600)	−49 (−500)	−37 (−380)	−32 (−330)
−0·4	−66 (−675)	−51 (−520)	−43 (−440)	−31 (−315)	−29 (−295)
−0·5	−60 (−610)	−46 (−470)	−39 (−400)	−29 (−295)	−26 (−265)
−0·6	−54 (−550)	−42 (−430)	−36 (−370)	−28 (−285)	−23 (−235)
−0·7	−49 (−500)	−39 (−400)	−32 (−330)	−25 (−255)	−22 (−225)
−0·8	−46 (−470)	−36 (−370)	−31 (−315)	−23 (−235)	−20 (−205)
−0·9	−43 (−440)	−34 (−350)	−28 (−285)	−22 (−225)	−19 (−195)
−1·0	−40 (−410)	−31 (−315)	−26 (−265)	−20 (−205)	−17 (−175)

TABLE 45 RELATIONSHIP OF MAXIMUM STRESS, STRESS RATIO AND NUMBER OF CYCLES FOR CLASS 7 MEMBERS

A. Maximum Tensile Stress

f_{Min}/f_{Max}	f_{Max} in N/mm² (kgf/cm²) for Number of Cycles				
	100 000	600 000	2 000 000	10 000 000	100 000 000
0·8	—	—	130 (1 325)	88 (895)	77 (785)
0·7	—	110 (1 120)	83 (845)	59 (600)	51 (520)
0·6	130 (1 325)	83 (845)	63 (640)	45 (460)	39 (400)
0·5	100 (1 020)	66 (675)	49 (500)	36 (370)	31 (315)
0·4	83 (845)	56 (570)	42 (430)	31 (315)	29 (295)
0·3	71 (725)	48 (490)	36 (370)	29 (295)	26 (265)
0·2	63 (640)	45 (460)	34 (350)	28 (285)	25 (255)
0·1	56 (570)	42 (430)	32 (330)	26 (265)	23 (235)
0·0	53 (540)	39 (400)	31 (315)	25 (255)	22 (225)
−0·1	51 (520)	37 (380)	29 (295)	23 (235)	20 (205)
−0·2	48 (490)	36 (370)	28 (285)	22 (225)	20 (205)
−0·3	46 (470)	34 (350)	28 (285)	22 (225)	19 (195)
−0·4	45 (460)	32 (330)	26 (265)	20 (205)	19 (195)
−0·5	43 (440)	31 (315)	25 (255)	20 (205)	17 (175)
−0·6	40 (410)	29 (295)	25 (255)	19 (195)	17 (175)
−0·7	40 (410)	29 (295)	23 (235)	19 (195)	15 (155)
−0·8	39 (400)	28 (285)	23 (235)	17 (175)	15 (155)
−0·9	37 (380)	28 (285)	22 (225)	17 (175)	14 (145)
−1·0	36 (370)	26 (265)	22 (225)	15 (155)	14 (145)

B. Maximum Compressive Stress

f_{Min}/f_{Max}	f_{Max} in N/mm² (kgf/cm²) for Number of Cycles				
	100 000	600 000	2 000 000	10 000 000	100 000 000
0·3	—	—	—	−120 (−1 220)	−100 (−1 020)
0·2	—	−130 (−1 325)	−110 (−1 120)	−80 (−815)	−68 (−695)
0·1	−130 (−1 325)	−97 (−990)	−80 (−815)	−60 (−610)	−51 (−520)
0·0	−110 (−1 120)	−79 (−815)	−65 (−665)	−48 (−490)	−42 (−430)
−0·1	−88 (−895)	−66 (−675)	−54 (−550)	−40 (−410)	−34 (−350)
−0·2	−76 (−775)	−56 (−570)	−46 (−470)	−34 (−350)	−29 (−295)
−0·3	−66 (−675)	−49 (−500)	−40 (−410)	−31 (−315)	−26 (−265)
−0·4	−59 (−600)	−43 (−440)	−36 (−370)	−26 (−265)	−23 (−235)
−0·5	−53 (−540)	−39 (−400)	−32 (−330)	−25 (−255)	−20 (−205)
−0·6	−48 (−490)	−36 (−370)	−29 (−295)	−22 (−225)	−19 (−195)
−0·7	−45 (−460)	−32 (−330)	−26 (−265)	−20 (−205)	−17 (−175)
−0·8	−40 (−410)	−31 (−315)	−25 (−255)	−19 (−195)	−15 (−155)
−0·9	−39 (−400)	−28 (−285)	−23 (−235)	−17 (−175)	−15 (−155)
−1·0	−36 (−370)	−26 (−265)	−22 (−225)	−15 (−155)	−14 (−145)

TABLE 46 RELATIONSHIP OF MAXIMUM STRESS, STRESS RATIO AND NUMBER OF CYCLES FOR CLASS 8 MEMBERS

A. Maximum Tensile Stress

f_{Min}/f_{Max}	f_{Max} IN N/mm² (kgf/cm²) FOR NUMBER OF CYCLES				
	100 000	600 000	2 000 000	10 000 000	100 000 000
0·9	—	—	—	130 (1 325)	110 (1 120)
0·8	—	130 (1 325)	93 (945)	65 (665)	56 (570)
0·7	140 (1 425)	85 (865)	62 (630)	43 (440)	37 (380)
0·6	100 (1 020)	65 (665)	46 (470)	32 (330)	28 (285)
0·5	83 (845)	51 (520)	37 (380)	26 (265)	22 (225)
0·4	69 (705)	42 (430)	31 (315)	23 (235)	20 (205)
0·3	60 (610)	37 (380)	28 (285)	22 (225)	19 (195)
0·2	53 (540)	34 (350)	26 (265)	20 (205)	17 (175)
0·1	49 (500)	32 (330)	25 (255)	19 (195)	15 (155)
0·0	45 (460)	31 (315)	23 (235)	19 (195)	15 (155)
−0·1	43 (440)	29 (295)	22 (225)	17 (175)	14 (145)
−0·2	42 (430)	28 (285)	22 (225)	17 (175)	13 (135)
−0·3	39 (400)	26 (265)	20 (205)	15 (155)	12 (125)
−0·4	37 (380)	26 (265)	20 (205)	15 (155)	12 (125)
−0·5	35 (360)	25 (255)	19 (195)	14 (145)	11 (110)
−0·6	34 (350)	25 (255)	19 (195)	14 (145)	11 (110)
−0·7	32 (330)	23 (235)	17 (175)	13 (135)	10 (100)
−0·8	31 (315)	22 (225)	17 (175)	13 (135)	9·7 (100)
−0·9	31 (315)	22 (225)	17 (175)	12 (125)	9·3 (95)
−1·0	29 (195)	22 (225)	17 (175)	12 (125)	9·0 (90)

B. Maximum Compressive Stress

f_{Min}/f_{Max}	f_{Max} IN N/mm² (kgf/cm²) FOR NUMBER OF CYCLES				
	100 000	600 000	2 000 000	10 000 000	100 000 000
0·4	—	—	—	−130 (−1 325)	−110 (−1 120)
0·3	—	−140 (−1 425)	−110 (−1 120)	−76 (−775)	−60 (−610)
0·2	−130 (−1 325)	−97 (−990)	−76 (−775)	−54 (−550)	−42 (−430)
0·1	−100 (−1 020)	−74 (−755)	−59 (−500)	−42 (−430)	−32 (−330)
0·0	−99 (−1 010)	−60 (−610)	−49 (−500)	−34 (−350)	−26 (−265)
−0·1	−71 (−725)	−51 (−510)	−40 (−410)	−28 (−285)	−22 (−225)
−0·2	−60 (−610)	−43 (−440)	−34 (−350)	−25 (−255)	−19 (−195)
−0·3	−54 (−550)	−39 (−400)	−29 (−295)	−22 (−225)	−17 (−175)
−0·4	−49 (−500)	−34 (−350)	−26 (−265)	−19 (−195)	−15 (−155)
−0·5	−43 (−440)	−31 (−315)	−25 (−255)	−17 (−175)	−13 (−135)
−0·6	−40 (−410)	−28 (−285)	−22 (−225)	−15 (−155)	−12 (−125)
−0·7	−37 (−380)	−26 (−265)	−20 (−205)	−15 (−155)	−11 (−115)
−0·8	−34 (−350)	−25 (−255)	−19 (−195)	−13 (−135)	−10 (−100)
−0·9	−31 (−315)	−23 (−235)	−17 (−175)	−12 (−125)	−9·6 (−100)
−1·0	−29 (−295)	−22 (−225)	−17 (−175)	−12 (−125)	−9·0 (−90)

TABLE 47 RELATIONSHIP OF MAXIMUM STRESS, STRESS RATIO AND NUMBER OF CYCLES FOR CLASS 9 MEMBERS

A. Maximum Tensile Stress

f_{Min}/f_{Max}	f_{Max} in N/mm² (kgf/cm²) for Number of Cycles				
	100 000	600 000	2 000 000	10 000 000	100 000 000
0·9	—	—	150 (1 520)	96 (980)	80 (815)
0·8	—	110 (1 120)	76 (775)	43 (490)	40 (410)
0·7	120 (1 220)	71 (725)	49 (500)	32 (330)	26 (265)
0·6	88 (895)	53 (540)	37 (380)	25 (255)	20 (205)
0·5	71 (725)	42 (430)	29 (295)	19 (195)	15 (155)
0·4	59 (600)	36 (370)	25 (255)	17 (175)	14 (145)
0·3	51 (520)	31 (315)	22 (225)	17 (175)	13 (135)
0·2	46 (470)	28 (285)	20 (205)	15 (155)	12 (125)
0·1	43 (440)	26 (265)	19 (195)	15 (155)	11 (115)
0·0	40 (410)	25 (255)	19 (195)	14 (145)	11 (115)
−0·1	39 (400)	25 (255)	17 (175)	13 (135)	10 (100)
−0·2	37 (380)	23 (235)	17 (175)	13 (135)	9·6 (100)
−0·3	34 (350)	22 (225)	17 (175)	12 (125)	9·0 (95)
−0·4	32 (330)	22 (225)	15 (155)	12 (125)	8·5 (90)
−0·5	31 (315)	20 (205)	15 (155)	11 (115)	8·2 (85)
−0·6	29 (295)	20 (205)	15 (155)	11 (115)	7·7 (80)
−0·7	29 (295)	19 (195)	14 (145)	10 (100)	7·4 (80)
−0·8	28 (285)	19 (195)	14 (145)	9.9 (100)	7·1 (75)
−0·9	26 (265)	17 (175)	14 (145)	9.6 (100)	6·8 (70)
−1·0	25 (255)	17 (175)	13 (135)	9.3 (95)	6·5 (70)

B. Maximum Compressive Stress

f_{Min}/f_{Max}	f_{Max} in N/mm² (kgf/cm²) for Number of Cycles				
	100 000	600 000	2 000 000	10 000 000	100 000 000
0·4	—	—	−130 (−1 330)	−91 (−925)	−65 (−665)
0·3	—	−99 (−1 010)	−79 (−805)	−56 (−570)	−39 (−400)
0·2	−110 (−1 120)	−73 (−745)	−57 (−580)	−39 (−400)	−28 (−205)
0·1	−86 (−875)	−57 (−580)	−45 (−460)	−31 (−315)	−22 (−225)
0·0	−71 (−725)	−48 (−490)	−37 (−380)	−25 (−255)	−19 (−195)
−0·1	−60 (−610)	−40 (−410)	−31 (−315)	−22 (−225)	−15 (−155)
−0·2	−53 (−540)	−36 (−370)	−26 (−265)	−19 (−195)	−13 (−135)
−0·3	−46 (−470)	−31 (−315)	−23 (−235)	−15 (−155)	−12 (−125)
−0·4	−42 (−430)	−28 (−285)	−22 (−225)	−15 (−155)	−11 (−115)
−0·5	−37 (−380)	−25 (−255)	−19 (−195)	−13 (−135)	−9·6 (−105)
−0·6	−34 (−350)	−23 (−235)	−17 (−175)	−12 (−125)	−8·6 (−90)
−0·7	−31 (−315)	−22 (−225)	−15 (−155)	−11 (−115)	−8·0 (−85)
−0·8	−29 (−295)	−20 (−205)	−15 (−155)	−11 (−115)	−7·4 (−80)
−0·9	−28 (−285)	−19 (−195)	−14 (−145)	−9·9 (−100)	−6·9 (−75)
−1·0	−25 (−255)	−17 (−195)	−13 (−135)	−9·3 (−95)	−6·5 (−70)

INDIAN STANDARDS

ON

STRUCTURAL ENGINEERING

Structural Sections

IS:

808-1964 Rolled steel beam channel and angle sections (*revised*)
808 (Part I)-1973 Dimensions for hot rolled steel beams; MB series (*second revision*)
811-1964 Cold formed light gauge structural steel sections (*revised*)
1252-1958 Rolled steel sections, bulb angles
1730-1961 Dimensions for steel plate, sheet and strip for structural and general engineering purposes
1730 (Part I)-1974 Dimensions for steel plate, sheet and strip for structural and general engineering purposes: Part I Plate (*first revision*)
1730 (Part II)-1974 Dimensions for steel plate, sheet and strip for structural and general engineering purposes: Part II Sheet (*first revision*)
1730 (Part III)-1974 Dimensions for steel plate, sheet and strip for structural and general engineering purposes: Part III Strip (*first revision*)
1852-1973 Rolling and cutting tolerances for hot-rolled steel products (*second revision*)
2713-1969 Tubular steel poles for overhead power lines (*first revision*)
3908-1966 Aluminium equal leg angles
3909-1966 Aluminium unequal leg angles
3921-1966 Aluminium channels
3954-1966 Hot rolled steel channel sections for general engineering purposes
5384-1969 Aluminium I beam
6445-1971 Aluminium tee sections

Codes of Practice

800-1962 Use of structural steel in general building construction (*revised*)
801-1975 Use of cold formed light gauge steel structural members in general building construction
802 (Part I)-1973 Use of structural steel in overhead transmission-line towers: Part I Loads and permissible stresses
803-1962 Design, fabrication and erection of vertical mild steel cylindrical welded oil storage tanks
805-1968 Use of steel in gravity water tanks
806-1968 Use of steel tubes in general building construction (*revised*)
807-1963 Code of practice for design, manufacture, erection and testing (structural portion) of cranes and hoists
3177-1965 Code of practice for design of overhead travelling cranes and gantry cranes other than steel work cranes
4000-1967 Assembly of structural joints using high tensile friction grip fasteners
4014 (Part I)-1967 Steel tubular scaffoldings: Part I Definitions and materials
4014 (Part II)-1967 Steel tubular scaffoldings: Part II Safety regulations for scaffolding
4137-1967 Heavy duty electric overhead travelling cranes including special service machines for use in steel works
6533-1971 Design and construction of steel chimneys
7205-1974 Safety code for erection of structural steel work

General

804-1967 Rectangular pressed steel tanks (*first revision*)
7215-1974 Tolerances for fabrication of steel structures

Handbooks for Structural Engineers:

No. 1 Structural Steel Sections
No. 2 Steel Beams and Plate Girders
No. 3 Steel Column and Struts
No. 4 High tensile friction grip bolts
No. 5 Structural use of Light Gauge Steel
No. 6 Application of Plastic Theory in design of