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Structural use of aluminium

Part 1: Code of practice for design

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- Aluminium Federation
- Association of Consulting Engineers
- Institution of Civil Engineers
- Institution of Structural Engineers
- London Regional Transport
- Ministry of Defence
- Royal Institute of British Architects
- Royal Institution of Chartered Surveyors
- Welding Institute

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Foreword

This Part of BS 8118 has been prepared under the direction of the Civil Engineering and Building Structures Standards Policy Committee. BS 8118 is a document combining a code of practice to cover the design and testing of aluminium structures (Part 1) and a specification for materials, fabrication and protection (Part 2).

This Part of BS 8118 gives recommendations for the design of the elements of framed, lattice and stiffened plate structures, using wrought aluminium alloy.

Although BS 8118 is a revision of CP 118 it is written with a different design philosophy. Because of this CP 118 will not be withdrawn immediately so that a period of overlap in design procedures can be allowed.

It has been assumed in the drafting of this British Standard that the execution of its provisions is entrusted to appropriately qualified and experienced people and that construction and supervision is carried out by capable and experienced organizations.

The full list of organizations that have taken part in the work of the Technical Committee is given on the inside front cover. The Chairman of the Technical Committee is Dr P S Bulson CBE and the following people have made a particular contribution in the drafting of the code.

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Summary of pages

This document comprises a front cover, an inside front cover, pages 1 to 156, an inside back cover and a back cover.

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Section 1. General

1.1 Scope

This Part of BS 8118 gives recommendations for the design of the elements of framed, lattice and stiffened plate structures, using wrought aluminium alloy. Where castings or forgings are used they should be manufactured and designed in accordance with the appropriate British Standard and in close consultation with the specific manufacturer.

The design recommendations are for a variety of aluminium alloys suitable for structural use, and apply to a range of structures subjected to normal atmospheric conditions such as bridges, buildings, towers, road and rail vehicles, marine craft, cranes and offshore topside structures.

The recommendations do not cover aerospace alloys, the detail design of castings, curved shell structures or structures subjected to severe thermal or chemical conditions. They are not intended to be used for the design of containment vessels, pipework, airborne structures or naval vessels, or for any application for which specific alternative codes exist, e.g. BS 5500 for pressure vessels and BS 5649 for lighting columns.

NOTE. The titles of the publications referred to in this standard are listed on the inside of the back cover.

1.2 Definitions

For the purpose of this Part of BS 8118 the following definitions apply.

1.2.1 compact cross-section

A cross-section that can develop the full plastic capacity, either in compression or bending, with no reduction due to local buckling of thin-walled elements.

1.2.2 design life

The period in which the structure or component is required to perform safely, with an acceptable probability that it will not require repair or withdrawal from service.

1.2.3 design spectrum

A tabulation of the numbers of occurrences of all the stress ranges caused by loading events.

1.2.4 detail class

A rating given to a detail which indicates its level of fatigue resistance.

1.2.5 edge distance

Distance from the centre of a fastener hole to the nearest edge of an element.

1.2.6 effective length

Length between points of effective restraint of a member, multiplied by a factor to take account of end conditions and loading.

1.2.7 factored load

A nominal load multiplied by the relevant partial load factor.

1.2.8 factored life

The design life multiplied by the relevant partial life factor.

1.2.9 factored resistance

The resistance of a member divided by the relevant partial material factor.

1.2.10 fail safe

The ability of a structure to continue to be serviceable after the discovery and monitoring of fatigue cracks.

1.2.11 fatigue

The damage, by gradual cracking, to a structural member caused by repeated applications of a stress that is insufficient to cause failure by a single application.

1.2.12 fusion boundary

The material in a heat-affected zone immediately adjacent to the leg of a weld.

1.2.13 heat affected zone

A zone in which there is a reduction in strength of material in the vicinity of welds in certain classes of aluminium alloy.

1.2.14 imposed load

All loading on a structure other than dead or wind loading.

1.2.15 instability

A loss of stiffness of a structure (usually sudden) that limits its load-carrying capability and in certain instances can cause catastrophic failure.

1.2.16 lateral torsional buckling

The buckling of a beam accompanied by a combination of lateral displacement and twisting.

1.2.17 lateral restraint

Restraint that limits lateral movement of the compression flange of a beam.

1.2.18 limit state

Condition beyond which a structure is unfit for its intended use.

1.2.19 loading event

A defined loading cycle which, for design purposes, is assumed to repeat a given number of times.

1.2.20 load spectrum

A tabulation showing the relative frequencies of loading events of different intensities on a structure.

1.2.21 local buckling

Buckling of the thin walls of a component in compression, characterized by the formation of waves or ripples along the member.

1.2.22 Miner's summation

A cumulative fatigue damage summation based on a rule devised by Palmgren and Miner.

1.2.23 nominal load

The load to which a structure may be expected to be subjected during normal service.

1.2.24 outstand element

The element of a section, composed of flat or curved elements, which is supported along one longitudinal edge, free along the other.

1.2.25 reinforced element

The element of a section which is stiffened by the introduction of longitudinal reinforcement, either along the edge of the element, or within its width.

1.2.26 resistance

The strength of a member based on calculations, using acceptable maximum values for material strength.

1.2.27 safe life

A design against fatigue in which the calculated life is many times longer than the life required in service.

1.2.28 semi-compact cross-section

A cross-section of a beam in which the stress in the extreme fibres is limited to the 0.2 % proof stress, because local buckling of the compression elements would prevent development of the full plastic moment capacity.

1.2.29 serviceability limit states

Those limit states which when exceeded can lead to the structure being unfit for its intended use, even though the structure has not collapsed.

1.2.30 slenderness

The effective length of a strut divided by the radius of gyration.

1.2.31 stiffened elements

The element of a section, composed of flat or curved elements, which is supported along both longitudinal edges.

1.2.32 stress cycle

A pattern of variation of stress at a point, which is normally in the form of two opposing half-waves.

1.2.33 stress history

A record showing how the stress at a point varies during loading.

1.2.34 stress range

(1) The greatest algebraic difference between the principal stresses occurring on principal planes not more than 45° apart in any stress cycle on a plate or element.

(2) The algebraic or vector difference between the greatest and least vector sum of stresses in any one stress cycle on a weld.

1.2.35 stress spectrum

A tabulation of the numbers of occurrences of all the stress ranges of different magnitudes during a loading event.

1.2.36 torsional buckling

Buckling of a strut accompanied by twisting.

1.2.37 torsional/flexural buckling

Buckling of a strut accompanied by overall flexure as well as twisting.

1.2.38 ultimate limit states

Those limit states which when exceeded can cause collapse of part or whole of a structure

NOTE. Specific terms relating to limit state principles are defined in appendix B.

1.3 Major symbols

A	Area or Durability rating
A_e	Effective section area
A_v	Effective shear area
a	Spacing of transverse stiffeners or Width of unstiffened plates
B	Overall width of multi-stiffened plate or Durability rating
B_{RF}	Factored resistance in bearing of a fastener
b	Width of flat element
b_e	Effective width of web plate (plate girder)
C	Durability rating or Lip size
D	Diameter of round tube to mid-metal or Overall depth of web to outside flanges
d	Depth of web between flanges or Depth of unstiffened plates
d_f	Nominal diameter of fastener or pin
E	Modulus of elasticity
F	Fatigue test factor
F	Fusion boundary of heat-affected zone (HAZ)
F_c	Friction capacity of high strength friction grip bolt (HSFG bolt)

f	Reduction factor applied to k_z	M_{RSx}	Factored uniaxial moment resistance about major axis (with allowance for shear)
f_{oc}	Constant amplitude cut-off stress	M_{RSy}	Factored uniaxial moment resistance about minor axis (with allowance for shear)
f_{ov}	Variable amplitude cut-off stress	M_{Rx}	Factored moment of resistance to lateral torsional buckling
f_r	Design stress range	M_s	Semi-compact value of M_{RS}
f_u	Ultimate tensile stress (designated R_m in BS EN 10002-1)	M_x	Uniaxial moment about major axis
$f_{0.2}$	Minimum 0.2 % tensile proof stress (designated $R_{p0.2}$ in BS EN 10002-1)	$\bar{M}_x$	Equivalent uniform moment about major axis
G	Shear modulus	M_y	Uniaxial moment about minor axis
g	Stress gradient coefficient	M_y	Equivalent uniform moment about minor axis
g_t	Throat of weld	M_1	Maximum factored moment
g_e	Leg length of weld	M_2	Minimum factored moment
H	Warping factor	m	Inverse slope of $f_r - N$ curve (fatigue)
h	Reinforced elements coefficient or Distance to a free edge	m_1, m_2	Shear buckling factors (plate girders)
I_S	Second moment of area of full section of effective stiffener (plate girder)	N	Number of webs or Predicted cycles to failure (endurance)
I_{SU}	Second moment of area of one sub-unit of plating (multi-stiffened plates)	n	Equivalent number of cycles of stress range (fatigue) or Time in days between welding and loading
I_y	Second moment of area about centroid axis	P	Axial tensile or compressive force due to factored loading or Protection
J	Torsion constant	P_{cr}	Elastic critical load for torsional buckling
K	Effective length factor for struts	P_o	Proof load for a bolt
K_1	Coefficient in calculation of resistance of bolts	P_p	Prestress load
K_2	Constant in fatigue failure criterion	P_R	Factored axial resistance based on overall column or torsional buckling
k_L	Local buckling coefficient	P_{RB}	Factored resistance of butt weld
k_v	Reduction factor on longitudinal resistance to take account of high shear	P_{RF}	Factored resistance of fillet weld
k_z	Strength factor for HAZ material	P_{RFB}	Factored resistance of HAZ adjacent to butt weld fusion boundary (direct normal tensile force)
k'_z	Modified strength factor for HAZ material	P_{RFF}	Factored resistance of HAZ adjacent to fillet weld fusion boundary (direct normal tensile force)
L	Length between supports	P_{RG}	Factored resistance of bonded joint
l	Effective length between lateral supports	P_{RS}	Factored axial resistance (tensile or compressive)
l_e	Effective length of butt weld	P_{RTB}	Factored resistance of HAZ adjacent to butt weld toe (direct normal tensile force)
l_f	Effective length of fillet weld	P_{RTF}	Factored resistance of HAZ adjacent to fillet weld toe (direct normal tensile force)
M	Moment under factored loading	P_{Rx}	Factored axial resistance to overall column buckling about major axis
$\bar{M}$	Equivalent uniform moment		
M_{cr}	Elastic critical uniform moment for lateral torsional buckling		
M_f	Fully compact value of M_{RS}		
M_{RF}	Reduced value of M_{RS} for flanges only		
M_{RS}	Factored moment resistance of a section in the absence of shear		
M_{RSO}	Reduced factored moment resistance of a section to allow for shear		

P_{Ry}	Factored axial resistance to overall column buckling about minor axis	t_C	Thickness of thickest element connected by welding
P_{RZ}	Factored resistance of HAZ under direct loading	t_e	Effective throat thickness
p_a	Limiting stress for local capacity (tension and compression)	t_f	Flange thickness
p_{az}	Limiting direct stress in HAZ	t_2	Flange thickness
p_f	Limiting stress for solid rivets and bolts	V	Shear force under factored loading
p_o	Limiting stress for bending and overall yielding	V_{RFB}	Factored shear resistance of HAZ adjacent to butt weld fusion boundary
p_{of}	Limiting stress for flange material	V_{RFF}	Factored shear resistance of HAZ adjacent to fillet weld fusion boundary
p_{ow}	Limiting stress for web material	V_{RS}	Factored shear force resistance
p_s	Limiting stress for overall buckling stability	V_{RTB}	Factored shear resistance of HAZ adjacent to butt weld toe
or	Lateral torsional buckling stress	V_{RTF}	Factored shear resistance of HAZ adjacent to fillet weld toe
or	Buckling stress for web treated as a thin column between flanges	V_{RW}	Reduced value of V_{RS}
p_t	Weld penetration	V_{RZ}	Factored resistance of HAZ in shear
p_v	Limiting stress in shear	v_{tf}	Tension field factor (plate girders)
p_{vz}	Limiting shear stress in HAZ	v_1	Elastic critical shear buckling factor
p_w	Limiting stress of weld metal	v_2	Basic tension field shear buckling factor
p_{w1}	Stress arising at extreme edge of web due to localized force	v_3	Flange assisted tension field shear buckling factor
p_{w2}	Stress arising at mid-point of web due to localized force	W	Weld metal
p_1	Stress axis value of p_s in strut curve diagrams	w	Pitch of stiffeners in multi-stiffened plate
or	Value of p_o for unwelded fully compact section	y	Distance from centre of multi-stiffened plate to centre of outermost stiffener
R	Radius of curvature of curved internal element, to mid-metal	y_c	Distance from neutral axis to more heavily compressed edge
r_y	Minor axis radius of gyration	y_o	Distance from neutral axis to less heavily compressed edge, or edge in tension
S	Plastic section modulus of gross section, with no reduction for HAZ, local buckling, or holes	y_1	Distance from neutral axis to most severely stressed fibres
S_a, S_b	External loading actions under factored loading	y_2	Distance from neutral axis to the compression flange element in a beam
S_f	Plastic modulus of effective flange section (plate girder)	Z_e	Elastic modulus of effective section
S_n	Plastic modulus of net section	Z_n	Elastic modulus of net section
S_{ne}	Plastic modulus of net effective section	Z_{ne}	Elastic modulus of net effective section
s	Factor on p_1 to allow for strut not meeting tolerances of straightness or twist	z	Distance the HAZ extends from a weld
T	Toe of HAZ	z_o	Basic value of z
t	Thickness	α	Ratio of minimum to maximum shear stress in web (elastic stress distribution)
t_A	Lesser of $0.5(t_B + t_C)$ and $1.5t_B$	or	Modifying factor for extent of HAZ to allow for elevated temperature
t_B	Thickness of thinnest element connected by welding	α_S	Coefficient in calculation of bolt or rivet in single shear

β	Slenderness parameter	λ	Slenderness parameter for column buckling, torsional buckling, and lateral torsional buckling
β_o	Semi-compact limiting value of β		
β_1	Fully compact limiting value of β	λ_y	Slenderness ratio of strut about minor axis
γ_c	Consequences of failure factor	η	Modifying factor for extent of HAZ to allow for increased heat build-up
γ_f	Overall load factor	σ_{cr}	Elastic critical stress of element with reinforcement
γ_{f1}, γ_{f2}	Partial load factors	σ_{cro}	Elastic critical stress of element without reinforcement
γ_L	Fatigue life factor	σ_1	Normal stress on weld under factored loading
γ_m	Material factor	τ_1	Shear stress perpendicular to weld axis
γ_{mf}	Fatigue material factor	τ_2	Shear stress parallel to weld axis
γ_s	Coefficient in calculation of friction capacity	μ_s	Slip factor
ε	Constant $\left(\frac{250}{p_o}\right)^{1/2}$		

Section 2. Properties and selection of materials

2.1 Designation of materials

The designation of wrought aluminium and aluminium alloys for general engineering purposes used in this standard is in accordance with the international 4-digit classification system. Details of this system are given in appendix A. Table A.1 in appendix A shows by cross reference the current and old British Standard designations together with the nearest equivalent ISO and other foreign designations.

The designation for castings is in accordance with the system used in BS 1490 for aluminium alloy castings.

The alloy temper designation used in this standard is generally in accordance with the ISO 2107 'alternative' temper designation system. Details of this system together with the former system still used for some alloys and forms of materials are given in appendix A.

NOTE. To simplify the text and to avoid confusion, in sections four, five and six the temper designations M, TB, TF and TH are not used. The equivalent temper designations F, T4, T6 and T8 respectively are used.

2.2 Permitted materials

2.2.1 Extrusions, sheet, plate, drawn tube, forgings and castings

2.2.1.1 Standard materials

2.2.1.1.1 General

This Part of BS 8118 covers the design of structures fabricated from a range of aluminium alloys used in conditions and tempers listed in tables 2.1 and 2.2 and commonly supplied to the specifications given in BS 8118 : Part 2.

The alloys are in two categories, the first of heat-treatable alloys given in table 2.1 and described in 2.2.1.1.2 and the second of non-heat-treatable alloys in table 2.2 and described in 2.2.1.1.3.

Castings should only be used in load bearing structures after both adequate testing and the setting up of quality control procedures for production of the castings has been performed to the approval of the engineer. The design rules of this standard should not be applied to castings without close consultation with the manufacturers thereof.

2.2.1.1.2 Heat-treatable alloys

The following alloys derive strength from heat treatment.

(a) *Alloy 6082*. The commonest of these alloys is the medium strength alloy, 6082, (Al Si1MgMn) of durability rating B (see 2.4.2) used usually in the fully heat-treated condition, i.e. 6082-T6, and used in welded and non-welded structures.

The choice of this alloy is based on a combination of good physical properties and a good degree of resistance to corrosion. It is available in most forms; solid and hollow extrusions, plates, sheets, tubes and forgings. Care should be taken in design to account for loss of strength in welded joints in the heat-affected zone (HAZ).

(b) *Alloy 6061*. An alternative alloy to 6082 is 6061, (Al Mg1SiCu) of durability rating B which has very similar properties with slight improvement in formability and surface finish. It is available in extruded tubular form and mainly used for structures.

(c) *Alloy 6063*. In applications where strength is not of paramount importance and has to be compromised with appearance, the alloy 6063 (Al Mg0,7Si) of durability rating B is preferred, because it combines moderate strength with good durability and surface finish. It is particularly responsive to anodizing and similar patented finishing processes. Alloy 6063 has a lower strength than 6082, and like the latter there is a loss of strength in welded joints in the HAZ. It is available in extrusions, tubes and forgings and is particularly suitable for thin-walled and intricate extruded sections. It is used mainly for architectural applications such as curtain walling and window frames.

(d) *Alloy 7020*. A further alloy which is readily weldable (although not restricted to welded structures) is the medium strength 7 *** series alloy 7020 (Al Zn4,5Mg1) of durability rating C. It has better post-weld strength than the 6 *** series due to its natural ageing property. This material and others in the 7 *** series of alloys are however sensitive to environmental conditions and its satisfactory performance is as dependent on correct methods of manufacture and fabrication as on control of composition and tensile properties. If material in the T6 condition is subjected to any operations which induce cold work, such as bending, shearing, punching, etc. the alloy may be made susceptible to stress corrosion cracking; it is essential therefore that there be direct collaboration between the engineer and the manufacturer on the intended use and the likely service conditions. This alloy is available normally only in rolled forms and simple extruded solid and hollow sections, though forgings can sometimes be made to special order.

(e) *Alloy LM25*. Alloy LM25 (Al Si7Mg) of durability rating B is a casting alloy with good foundry characteristics, corrosion resistance and mechanical properties. It is available in four conditions of heat treatment in both sand and chill castings, and is mainly used for architectural and food manufacturing installations.

2.2.1.1.3 Non-heat-treatable alloys.

The following alloys derive enhanced strength only by strain hardening. They are normally produced in sheet and plate forms and occasionally in some simple extruded forms.

(a) *Alloy 1200.* The alloy 1200 (Al99,0) of durability rating A is 'commercially pure' aluminium with high ductility and a very good corrosion resistance. It is used for architectural work where components are not highly stressed and is available in sheet only.

(b) *Alloy 3103.* The alloy 3103 (Al Mn1) of durability rating A is stronger and harder than 'commercially pure' aluminium but with the same high ductility and very good corrosion resistance, and is used extensively for building sheet and vehicle panelling. It is available in sheet form.

(c) *Alloy 3105.* The alloy 3105 (Al Mn0,5Mg0,5) of durability rating A is becoming more prevalent in the profiled building sheet market due to its superior properties over 3103 in hardness and strength. It also has an economic advantage. Available forms are limited to sheet.

(d) *Alloy 5083.* The alloy 5083 (Al Mg4,5Mn0,7) of durability rating A is used for welded structures, plating and tank work, because it welds readily without significant loss of strength and has high ductility. The tensile strength of 5083 in the O and F conditions is lower than 6082-T6 but significantly higher if the latter is welded. However, subjection to long exposure at temperatures above 65 °C, it can result in grain-boundary precipitation of magnesium/aluminium intermetallic compounds which corrode preferentially in some adverse environments. This effect is aggravated if the alloy is subjected to subsequent cold working operations. It is available in plate, sheet, simple extruded sections, drawn tube and forging. Apart from its easy welding and good formability properties, it also exhibits very good durability, especially in marine environments.

(e) *Alloys 5251, 5154A and 5454.* Alloys 5251 (Al Mg2), 5154A (Al Mg3,5(A)) and 5454 (Al Mg3Mn) all of durability rating A are available in sheet, plate and simple extrusions. 5154A and 5251 are also available as forgings. Magnesium is the main addition and as a result the alloys are ductile in the soft condition, but work harden rapidly. They have good weldability and very good resistance to corrosive attack, especially in a marine atmosphere. For this reason they are used in panelling and structures exposed to marine atmospheres. 5154A and 5454 are stronger than 5251.

The strongest 5 *** series alloy which offers immunity to stress corrosion when exposed to elevated temperature is 5454. The 5 *** series alloys with greater than 3 % Mg may be rendered susceptible to stress corrosion when exposed to elevated temperatures.

(f) *Alloy 5251 : in seam welded tube.* Seam welded tubes are produced from 5251 strip (Al Mg2) giving a durability rating B to the tube, which has been further strengthened by work hardening through forming and finishing rolls. Its main uses are in general engineering such as garden furniture, handrails and ladders.

(g) *Alloy LM5.* Alloy LM5 (Al Mg5Si1) of durability rating A is a medium strength casting alloy possessing excellent finishing properties where it maintains a surface of high polish, but is only suitable for simple shapes. It is mainly used for sand castings for architectural and decorative purposes and where anodizing is required.

(h) *Alloy LM6.* Alloy LM6 (Al Si12) of durability rating B is a further medium strength casting alloy which has excellent foundry characteristics, high ductility and impact strength, together with good corrosion resistance. It is suitable for both sand and chill castings and for a wide range of uses in general, marine and electrical applications and in castings of above average complexity and size.

2.2.1.2 Materials in other thicknesses and alloys with other standard and non-standard properties

The alloys listed in tables 2.1 and 2.2 are sometimes used in other thicknesses and in other standard and non-standard tempers and conditions. Guaranteed minimum properties for such materials may be used if agreed between designer and client.

2.2.1.3 Other alloys

Other alloys are available which offer higher strengths, e.g. 2014A and/or better post-weld strengths, e.g. 7019, but these strengths may be achieved to the detriment of other properties. The engineer is therefore, advised against using any of these alloys without careful consideration, and in full consultation with a reputable manufacturer. Properties to be considered include durability, weldability, resistance to crack propagation, and behaviour in service. Other alloys in the 7 *** series having higher proof strengths such as 7019 will require particular control on manufacturing processes, for example control of micro structure, residual stress and cold working, see 2.2.1.1.1 (d).

2.2.2 Bolts and rivets

Bolt and rivet materials together with their durability ratings are given in table 2.3. Guidance on the selection of bolt and rivet materials is given in 2.4.3.2.

Table 2.1 Heat-treatable alloys

Alloy	Condition	Product	Thickness		Minimum 0.2 % tenile proof stress (see note 1)	Minimum tenile strength (see note 1)	Elongation (see note 1)		Approximate loss of strength due to welding (see note 2)	Durability rating	Related British Standard (see note 3)	Old BS alloy designation	ISO designation (nearest equivalent) (see ISO 209-1)
			Over	Up to and including			5.65/ S_0	50 mm					
6061	T6	Extrusions ¹⁾	-	mm	N/mm ²	N/mm ²	%	%	%	B	BS 1474	H20	Al Mg1SiCu
		Drawn tube	-	6.0	240	280	8	7	50		BS 1471		
	T4	Extrusions	-	150	240	295	7 ²⁾	7 ²⁾	50	B	BS 1474	H9	Al Mg0.7Si
		Drawn tube	-	10	255	295	9 ²⁾	9 ²⁾	50		BS 1471		
6063	T4	Extrusions	-	150	70	130	16	14	0	B	BS 1474	H9	Al Mg0.7Si
		Drawn tube	-	10	100	165	16 ²⁾	16 ²⁾	0		BS 1471		
	T6	Extrusions	-	150	85	140	16	-	0	B	BS 1472	H9	Al Mg0.7Si
		Drawn tube	-	10	110	150	8	7	25		BS 1474		
	T6	Extrusions	-	150	160	185	8	7	50	B	BS 1474	H9	Al Mg0.7Si
		Drawn tube	-	10	180	200	8 ²⁾	8 ²⁾	50		BS 1471		
	T6	Extrusions	-	150	160	185	10	-	50	B	BS 1472	H9	Al Mg0.7Si
		Drawn tube	-	10	160	185	10	-	50		BS 1471		
	T4	Extrusions	-	150	120	190	16	14	0	B	BS 1474	H30	Al Si1MgMn
		Drawn tube	-	10	120	200	-	15	0		BS 1470		
7020	T6	Extrusions	-	20	255	295	8	7	50	B	BS 1471	H30	Al Si1MgMn
		Drawn tube	-	6.0	115	215	12 ²⁾	12 ²⁾	0		BS 1471		
	T6	Extrusions	-	20	255	295	8	7	50	B	BS 1472	H30	Al Si1MgMn
		Drawn tube	-	6.0	115	215	12 ²⁾	12 ²⁾	0		BS 1471		
	T6	Extrusions	-	20	255	295	8	7	50	B	BS 1474	H30	Al Si1MgMn
		Drawn tube	-	6.0	115	215	12 ²⁾	12 ²⁾	0		BS 1471		
	T6	Extrusions	-	20	255	295	8	7	50	B	BS 1472	H30	Al Si1MgMn
		Drawn tube	-	6.0	115	215	12 ²⁾	12 ²⁾	0		BS 1471		
	T6	Extrusions	-	20	255	295	8	7	50	B	BS 1474	H30	Al Si1MgMn
		Drawn tube	-	6.0	115	215	12 ²⁾	12 ²⁾	0		BS 1471		
LM25	T6	Extrusions	-	25	170	280	10	12	0	C	BS 4300/15	H17	Al Zn4.5Mg1
		Drawn tube	-	6.0	240	310	8	7	50		BS 4300/14		
	T6	Extrusions	-	25	280	340	8	10	40	B	BS 4300/15	H17	Al Zn4.5Mg1
		Drawn tube	-	6.0	240	310	8	10	40		BS 4300/14		
	T6	Extrusions	-	25	270	320	8	10	40	B	BS 4300/15	H17	Al Zn4.5Mg1
		Drawn tube	-	6.0	240	310	8	10	40		BS 4300/14		
	T6	Extrusions	-	25	270	320	8	10	40	B	BS 4300/15	H17	Al Zn4.5Mg1
		Drawn tube	-	6.0	240	310	8	10	40		BS 4300/14		
	T6	Extrusions	-	25	270	320	8	10	40	B	BS 4300/15	H17	Al Zn4.5Mg1
		Drawn tube	-	6.0	240	310	8	10	40		BS 4300/14		
LM25	TB7	Sand cast	-	-	80 to 110	160 ³⁾	2.5	-	NA	B	BS 1480	LM25	Al Si7Mg
		Chill cast	-	-	90 to 110	230 ³⁾	5	-	NA		BS 1480		
	TF	Sand cast	-	-	200 to 250	230 ³⁾	-	-	NA	B	BS 1480	LM25	Al Si7Mg
		Chill cast	-	-	220 to 260	280 ³⁾	2	-	NA		BS 1480		

NA = not applicable.

1) Extrusions refer to bars, extruded round tubes and sections.

2) Elongation on 5.65/ S_0 for tubes with wall thickness of 3 mm and thinner, and on 60 mm for tubes with thicker walls.

3) Minimum value specified in BS 1480.

NOTE 1. Minimum value specified in BS 1470, BS 1471, BS 1472, BS 1474 and BS 4300/14 and BS 4300/15.

NOTE 2. Properties after 3 days natural ageing at 15 °C to 25 °C for 6 * * * series alloys and 30 days at 15 °C to 25 °C, or artificially aged for 24 h at 120 °C for alloy 7020 (see 4.4.2.1).

NOTE 3. For chemical compositions of alloy see relevant British Standard.

Table 2.2 Non-heat-treatable alloys

Alloy	Condition	Product	Thickness		Minimum 0.2 % tensile proof stress (see note 1)	Minimum tensile strength (see note 1)	Elongation (see note 1)		Approximate tensile strength due to welding (see 4.4.2.1)	Ductility rating	Related British Standard (see note 2)	Old BS alloy designation	ISO designation (current equivalent) (see ISO 200-1)
			Over	Up to and including			5.65/ S_0	50 mm					
			mm	mm	N/mm ²	N/mm ²	%	%					
1200	H14	Sheet	0.2	12.5	115 ¹⁾	105	-	3 to 6	50	A	BS 1470	IC	Al99.0
3103	H14	Sheet	0.2	12.5	140 ¹⁾	140	-	3 to 7	50	A	BS 1470	N3	Al Mn1
	H18		0.2	3	185 ¹⁾	175	-	2 to 4	65				
3105	H14	Sheet	0.2	3	145	160	-	2 to 4	75	A	BS 1470	N31	Al Mn0.5Mg0.5
	H16				170	185	-	1 to 3	80				
	H18				190	215	-	1 to 2	80				
5083	O	Extrusions ²⁾	-	150	125	275	14	13	0	A	BS 1474	N8	Al Mg4.5Mn0.7
		Sheet and plate	0.2	80	125	275	14	12 to 16	0		BS 1470		
		Drawn tube	-	10	125	275	12 ³⁾	12 ³⁾	0		BS 1471		
F		Extrusions	-	150	130 ¹⁾	280 ¹⁾	12 ¹⁾	11 ¹⁾	0		BS 1474		
		Sheet and plate	3	25	176 ¹⁾	320 ¹⁾	-	18 ¹⁾	0		BS 1470		
F		Forgings	-	150	130	280	12	-	0		BS 1472		
H22		Sheet and plate	0.2	6	235	310	-	5 to 10	45		BS 1470		
	H22	Drawn tube	-	10	235	310	6 ³⁾	6 ³⁾	45		BS 1471		
5154A	O	Extrusions	-	150	85	215	18	16	0	A	BS 1474	N5	Al Mg3.5(A)
		Sheet and plate	0.2	6	85	215	-	12 to 18	0		BS 1470		
		Drawn tube	-	10	85	215	16 ³⁾	16 ³⁾	0		BS 1471		
F		Extrusions	-	150	100 ¹⁾	215 ¹⁾	16 ¹⁾	14 ¹⁾	0		BS 1474		
F		Forgings	-	150	100	215	16	-	0		BS 1472		
H23		Sheet and plate	0.2	6	165	245	-	5 to 8	45		BS 1470		
H24		Sheet and plate	0.2	6	225	275	-	4 to 6	60		BS 1470		
	H24	Drawn tube	-	10	200	245	4 ³⁾	4 ³⁾	60		BS 1471		
5251	F	Seam welded tube	0.8	1.0	220	245	-	3	70	B	BS 4300/1	N4	Al Mg2
			1.2	2.0	220	245	-	5	70				
		Forgings	-	150	60	170	16	-	70	A	BS 1472		
H22		Sheet and plate	0.2	6	130	200	-	4 to 8	55		BS 1470		
H24			0.2	6	175	225	-	3 to 5	65				
5454	O	Extrusions	-	150	85	215	18	16	0	A	BS 4300/12	N51	Al Mg3Mn
		Sheet and plate	0.2	6	80	215	-	12 to 18	0		BS 1470		
	F	Extrusions	-	150	100	215	16	14	0		BS 4300/12		
H22		Sheet	0.2	3	180	250	-	4 to 8	55		BS 1470		
H24		Sheet	0.2	3	200	270	-	3 to 6	60				
LM5	F	Sand cast	-	-	90 to 110	140 ⁴⁾	3	NA	NA	A	BS 1490	LM5	Al Mg5Si1
		Chill cast	-	-	90 to 120	170 ⁴⁾	5						
LM6	F	Sand cast	-	-	60 to 70	160 ⁴⁾	5	NA	NA	B	BS 1490	LM6	Al Si12
		Chill cast	-	-	70 to 80	190 ⁴⁾	7						

NA - not applicable

1) Typical values.

2) Extrusions refer to bars, extruded round tubes and sections.

3) Extrusion on 5.65/ S_0 for tubes with wall thickness of 3 mm and thinner, and on 60 mm for tubes with thicker walls.

4) Minimum value specified in BS 1490.

NOTE 1. Minimum value specified in BS 1470, BS 1471, BS 1472, BS 1474, BS 4300/1 and BS 4300/12.

NOTE 2. For chemical compositions of alloy see relevant British Standard.

Table 2.3 Bolt and rivet material							
Type	Material	Process	Temper in use	Diameter	0.2 % proof strength	Ultimate strength	Durability rating
Bolts and proprietary threaded fasteners	6082	—	T6	mm ≤ 6	N/mm ² 255	N/mm ² 295	B ¹⁾
	6061		T8	6 – 12	270	310	B ¹⁾
	5056A ²⁾		H24	≤ 12	245	310	B ¹⁾
	Stainless steel { A4 (316S16) ³⁾ A2 (304S15) ³⁾		See the relevant British Standard specification for the material	≤ 12	240	310	(see note 1) (see note 1) (see note 2)
	Steel						
Solid rivets and proprietary blind rivets	5154A	Cold or hot driven	O or F	≤ 25	0.2 % proof stress is not quoted in BS 1473 for rivet stock	215	A ¹⁾
	6082	Cold driven	H22	≤ 25	245	200	B ¹⁾
		Cold driven in T4 temper	T4	≤ 25			
		Cold driven ⁴⁾ in T6 temper	T6	≤ 25			
	5056A ²⁾	Cold or hot driven	O or F	≤ 25	295	255	B ¹⁾
		Cold driven	H22	≤ 25			
		Cold or hot driven	O or F	≤ 25			
	Stainless steel { A4 (316S16) A2 (304S15)	Cold or hot driven	See the relevant British Standard specification for the material	≤ 25	280	255	(see note 1) (see note 1) (see note 1) (see note 2)
	Nickel-copper alloy	Cold driven (zinc plated)					
	Steel	Cold driven					

¹⁾ The durability of alloys joined if their durability is lower.

²⁾ 5056A bolts and rivets should not be used in corrosive or tropical environments.

For example BS 6105 for stainless steel bolts.

6082-T4 rivets are more readily driven immediately after solution heat treatment.

NOTE 1. See 2.4.3.2.

NOTE 2. Steel bolts should preferably be galvanized or sheradized to BS 729.

These materials may also be used for special proprietary rivet and bolt products, including thread inserts.

Special head shapes may be necessary for the larger diameter rivets, see BS 1974¹⁾.

2.2.3 Filler metals

Filler metals for tungsten inert-gas (TIG) welding and metal inert-gas (MIG) welding, are given in table 2.4 together with their durability ratings. Guidance on the selection of filler metals is given in 2.5.3.2.

2.3 Strength, mechanical and physical properties

2.3.1 Strength and mechanical properties

The range of the standard alloys together with their available forms, temper conditions and mechanical properties are shown in tables 2.1 and 2.2.

The mechanical properties for wrought materials for the tempers and conditions of the alloys given in tables 2.1 and 2.2 have been used to determine the limiting stresses given in table 4.1. Where alloys are welded the approximate percentage reduction in strength of the alloy is given for each temper. These strengths in the HAZ may not be achieved until after a period of natural or artificial ageing, see notes to table 2.1 for details.

The strength of bolt and rivet material is given in table 2.3.

Table 2.4 Welding filler metals			
Filler metal group	BS alloy designation ¹⁾	ISO alloy designation ²⁾	Durability rating
Type 1	1080A 1050A	Al99,8 Al99,5	A
Type 3	3103	Al Mn1	A
Type 4	4043A 4047A ³⁾	Al Si5 (A) Al Si12 (A)	B
Type 5	5056A 5356 5556A 5183	Al Mg5 Al Mg5Cr(A) Al Mg5,2MnCr Al Mg4,5Mn	A

¹⁾ See BS 2901 : Part 4 for chemical composition.
²⁾ Or nearest equivalent.
³⁾ 4047A is specifically used to prevent weld metal cracking in joining involving high dilution and high restraint. In most cases 4043A is preferable.

The mechanical properties of the alloys vary with temperature and those given in tables 2.1, 2.2 and 2.3 should be applied to the design of structures over a temperature range -50°C to 70°C except for 5083 (see 2.2.1.1.3 (d)). The 0.2 % proof stress and tensile strength improve at lower temperatures, but at higher temperatures are reduced. For properties outside the temperature range given, the manufacturer should be consulted. The alloy will melt within the range 550°C to 660°C , with the precise range dependent on the alloy.

2.3.2 Physical properties

The physical properties for the standard alloys although varying slightly may be taken as constant and are listed in table 2.5. In critical structures the engineer may wish to use the exact value which should be obtained from a reputable manufacturer.

Table 2.5 Physical properties	
Property	Value
Density	$2\,710\text{ kg/m}^3$
Modulus of elasticity	$70\,000\text{ N/mm}^2$
Modulus of rigidity	$26\,600\text{ N/mm}^2$
Coefficient of thermal expansion	$23 \times 10^{-6}\text{ per }^{\circ}\text{C}$

2.4 Durability and corrosion protection

2.4.1 General

In many instances the standard materials listed in tables 2.1 to 2.4 can be used in the mill-finish, as extruded or as welded condition without the need for surface protection.

The good corrosion resistance of aluminium and its alloys is attributable to the protective oxide film which forms on the surface of the metal immediately on exposure to air. This film is normally invisible, relatively inert and as it forms naturally on exposure to air or oxygen, and in many complex environments containing oxygen; the protective film is thus self-sealing.

In mild environments an aluminium surface will retain its original appearance for years, and no protection is needed for most alloys. In moderate industrial environments there will be a darkening and roughening of the surface. As the atmosphere becomes more aggressive such as in certain strongly acidic or strongly alkaline environments, the surface discoloration and roughening will worsen with visible white powdery surface oxides and the oxide film may itself be soluble. The metal ceases to be fully protected and added protection is necessary. These conditions may also occur in crevices due to high local acid or alkaline conditions, but agents having this extreme effect are relatively few in number.

¹⁾ Obsolete standard

In coastal and marine environments the surface will roughen and acquire a grey, stone-like, appearance, and protection of some alloys is necessary. Where aluminium is immersed in water special precautions may be necessary.

Where surface attack does occur corrosion/time curves for aluminium and aluminium alloys usually follow an exponential form, with a fairly rapid initial loss of reflectivity after slight weathering. After this there is very little further change over very extensive periods. On atmospheric exposure, the initial stage may be a few months or 2 to 3 years, followed by little, if any, further change over periods of 10, 30 or even 80 years. Such behaviour is consistent for all external freely exposed conditions and for all internal or shielded conditions, except where extremes of acidity or alkalinity can develop. Tropical environments are in general no more harmful to aluminium than temperate environments, although certain alloys (see BS 5500) are affected by long exposure to high ambient temperatures, particularly when in a marine environment.

2.4.2 Durability of alloys

The alloys listed in tables 2.1, 2.2, 2.3 and 2.4 are categorized into three durability ratings A, B and C in descending order of durability. These ratings are used to determine the need and degree of protection required. In constructions employing more than one alloy, including filler metals in welded construction, the protection should be in accordance with the lowest of their durability ratings.

2.4.3 Corrosion protection

2.4.3.1 Overall corrosion protection

The need to provide overall corrosion protection to structures constructed from the alloys or combination of alloys listed in tables 2.1, 2.2, 2.3 and 2.4 when exposed to different environments (see PD 6484) is given in table 2.6. The methods of providing corrosion protection in these environments are detailed in BS 8112 : Part 2.

In selecting the appropriate column of table 2.6 for an atmospheric environment there may be localities within a region that have 'microclimates' vastly different from the environmental characteristics of the region as a whole. A region designated 'rural' may have local environments more closely resembling an industrial atmosphere at sites close to and down wind of factories. Similarly, a site near the sea but close to shore installations may, with the appropriate prevailing winds, have the characteristics of an industrial, rather than marine, atmosphere. The environment is not necessarily the same for a structure inside a building as for one outside.

Because of these factors, localized conditions of increased severity may result. It is advisable to study the precise conditions prevailing at the actual site before deciding on the appropriate environment column of table 2.6.

Where hollow sections are employed consideration should be given to the need to protect the internal void to prevent corrosion arising from the ingress of corrosive agents. Because of the difficulty of painting such sections, chemical conversion coatings may be beneficial. Where the internal void is sealed effectively, internal protection is not necessary.

Table 2.6 General corrosion protection of aluminium structures

Alloy durability rating	Material thickness mm	Protection needed according to environment							
		Atmospheric						Immersed	
		Rural	Industrial/urban		Marine			Fresh water	Sea water
			Moderate	Severe	Non-industrial	Moderate	Severe		
A	All	None	None	P	None	None	P	None	None
B	<3	None	P	P	P	P	P	P	P
	≥3	None	None	P	None	None	P	P	P
C	All	None	P ¹⁾	P	P	P	P	P ²⁾	NR

Key

P Protection needed (see BS 8118 : Part 2).

P¹⁾ Requires only local corrosion protection to weld and HAZ in urban non-industrial environments.

P²⁾ Protection not recommended if of welded construction.

NR Immersion in sea water is not recommended.

2.4.3.2 Metal-to-metal contacts including joints

Consideration should also be given to contacting surfaces in crevices and contact with certain metals or washings from certain metals which may cause electrochemical attack of aluminium (see PD 6484). Such conditions can occur within a structure at joints. Contact surfaces and joints of aluminium to aluminium or to other metals and contact surfaces in bolted, riveted, welded and high strength friction grip (HSFG) bolted joints should be given additional protection to that required by table 2.6 as defined in table 2.7. Details of the corrosion protection procedure required are given in BS 8118 : Part 2.

2.4.3.3 Contact with other non-metallic materials**2.4.3.3.1 Contact with concrete, masonry or plaster**

Aluminium in contact with dense compact concrete, masonry or plaster in a dry unpolluted or mild environment should be coated on the contacting surface with a coat of bituminous paint, see BS 8118 : Part 2. In an industrial or marine environment the contacting surface of the aluminium should be coated with at least two coats of heavy duty bituminous paint; the surface of the contacting material should preferably be similarly painted. Submerged contact between aluminium and such materials is not recommended, but if unavoidable separation of the materials is recommended by the use of a suitable mastic or a heavy duty damp course layer.

Lightweight concrete and similar products require additional consideration when water or rising damp can extract a steady supply of aggressive alkali from the cement. The alkali water can then attack aluminium surfaces other than the direct contact surfaces.

2.4.3.3.2 Embedment in concrete

The aluminium surfaces before embedment in concrete should be protected with at least two coats of bituminous paint or hot bitumen, see BS 8118 : Part 2, and the coats should extend at least 75 mm above the concrete surface after embedment.

Where the concrete contains chlorides e.g. as additives or due to the use of sea-dredged aggregate, at least two coats of plasticized coal-tar pitch should be applied in accordance with BS 8118 : Part 2 and the finished assembly should be overpainted locally with the same material, after the concrete has fully set, to seal the surface. Care should be taken where metallic contact occurs between the embedded aluminium parts and any steel reinforcement.

2.4.3.3.3 Contact with timber

In an industrial, damp or marine environment the timber should be primed and painted in accordance with good practice.

Some wood preservatives may be harmful to aluminium. As a general guide the following preservatives have been agreed between the Aluminium Federation, the British Wood Preserving Association and Damp-proofing Association to be safe for use with aluminium without special precautions:

- a) coal tar creosote;
- b) coal tar oil;
- c) chlorinated naphthalenes;
- d) zinc naphthanates;
- e) pentachlorophenol;
- f) organo-tin oxides;
- g) orthophenylphenol.

Where timber, treated with the following preservatives, is used in damp situations the aluminium surface in contact with the treated timber should have a substantial application of sealant:

- 1) copper naphthanate;
- 2) copper-chrome-arsenate;
- 3) borax-boric acid.

Other preservatives should not be used in association with aluminium.

Reference may be made to CP 143 : Part 15.

Oak, chestnut and western red cedar, unless well seasoned, are likely to be harmful to aluminium.

2.4.3.3.4 Contact with soils

The surface of the metal in contact with soil should be protected with a least two coats of bituminous paint, hot bitumen, or plasticized coal-tar pitch, see BS 8118 : Part 2. Additional wrapping-tapes may be used to prevent mechanical damage to the coating.

2.4.3.3.5 Immersion in water

Where aluminium parts are immersed in freshwater or sea water including contaminated water, the aluminium should preferably be of durability rating A, with fastenings of aluminium or corrosion-resisting steel or fastened by welding. Tables 2.6 and 2.7 give the protection needed for fresh water and sea water immersion.

In addition the engineer should obtain competent advice on the oxygen content, pH number, chemical or metallic, particularly copper, content and the amount of movement of the water as these factors may affect the degree of protection required.

Table 2.7 Additional protection at metal-to-metal contacts to combat crevice and galvanic effects

Metal joined to aluminium	Bolt or rivet metal	Protection needed according to environment (see BS 8118 : Part 2)									
		Atmospheric				Marine			Immersed		
		Rural		Industrial urban		Non-industrial	Industrial		Fresh water	Sea water	
		Dry unpolluted	Mild	Moderate	Severe		Moderate	Severe			
Aluminium	Aluminium	0	0	0	2	2	0	2	0	2	
	Steel, aluminumized or galvanized steel, stainless steel	1	1	3	4	4	3	4	5	5	
Zinc or zinc coated steel	Aluminium	0	0	2	2	2	2	2	2	5	
	Steel, aluminumized or galvanized steel, stainless steel	1	1	3	4	4	3	4	5	5	
Steel stainless steel, cast iron, lead	Aluminium	0	0	3	3	3	3	3	5	5	
	Steel, aluminumized or galvanized steel, stainless steel	1	1	4	4	4	4	4	5	5	
Copper ¹⁾	Aluminium	0	NR	NR	NR	NR	NR	NR	NR	NR	
	Copper, copper alloy	0	3	5	5	5	5	5	5	5	

¹⁾ Contact surfaces and joints of aluminium to copper or copper alloys should be avoided if possible. If used, the aluminium should be of durability rating A or B, and the bolts and nuts of copper or copper alloy.

NR The use of aluminium rivets and bolts to join aluminium and copper in these environments is not recommended.

2.4.3.3.6 *Contact with chemicals used in the building industry*

Fungicides and mould repellents may contain metal compounds based on copper, mercury, tin and lead which, under wet or damp conditions could cause corrosion of the aluminium. The harmful effects may be countered by protecting the contacting surfaces which may be subject to washing or seepage from the chemicals.

Some cleaning materials can affect the surface of the aluminium. Where such chemicals are used to clean aluminium or other materials in the structure, care should be taken to ensure that the effects will not be detrimental to the aluminium. Often quick and adequate water rinsing will suffice, while in other situations temporary measures may be necessary to protect the aluminium from contact with the cleaners.

2.4.3.3.7 *Contact with insulating materials used in the building industry*

Products such as glass fibre, polyurethane and various insulation products may contain corrosive agents which can be extracted under moist conditions to the detriment of the aluminium. Insulating materials should be tested for compatibility with aluminium under damp and saline conditions. Where there is doubt, a sealant as described in BS 8118 : Part 2 should be applied to the associated aluminium surfaces.

2.5 Fabrication and construction

2.5.1 General

The fabrication and construction requirements to be detailed are included in the relevant design clauses. BS 8118 : Part 2 specifies the methods of fabrication to be followed. In addition 2.5.2 and 2.5.3 should be considered by the engineer.

2.5.2 Bending and forming

Aluminium alloys are available in a wide range of tempers which affect their formability. Where bending or forming is required the engineer should consult the manufacturer for guidance on the choice of alloy, temper and any subsequent heat treatment that may be required.

2.5.3 Welding

2.5.3.1 General

The loss of strength that can occur in the vicinity of the weld with some alloys and tempers should be considered by the engineer in the choice of the alloy or alloys to be used in welded construction. The engineer should 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 susceptibility of 6082, 6063, 6061 and 5251 alloys to cracking during solidification when welds are made under constraint. This may be avoided by the use of the filler materials and welding techniques recommended (see BS 8118 : Part 2 : 1990). This will ensure a suitable combination of filler material in the actual weld.

2.5.3.2 Filler metals.

The filler wire for use in welded construction should be chosen in accordance with table 2.8.

2.6 Selection of materials

The choice of an alloy or alloys for any structure is determined by a combination of a number of factors: strength, see 2.3; durability, see 2.4; physical properties, see 2.3; weldability, see 2.5; formability, see 2.5 and availability, see 2.7 in both the particular form and alloy required. The standard materials given in tables 2.1 and 2.2 are described in terms of the above factors in 2.2.1.1.2 and 2.2.1.1.3.

2.7 Availability

2.7.1 General

The range of alloys given in tables 2.1 and 2.2 are not available in all product forms. Table 2.9 indicates the alloys available in particular product forms and where materials may be stocked in limited quantities. Product and alloy combinations not normally manufactured but which may be manufactured by special arrangement are indicated, design in these materials should only be attempted after confirmation of their availability with the materials supplier.

2.7.2 Structural sections

A number of structural extruded sections complying with BS 1161 and some other structural sections are available in 6082-T6 or 6063-T6 from stock, but in most instances they will need to be produced to order, see table 2.9. Table 2.10 gives the range of sizes of sections given in BS 1161. Other sizes may be obtained from existing or new dies by arrangement with the manufacturer. Where sections are produced to order, minimum order quantities may be applied. Special new extruded sections are normally made to order and the low cost of simple dies gives great flexibility in this design. The engineer should consult the manufacturer at an early stage to verify the shape, thickness, size and feasibility of the design of a new section and delivery of both the new die and the extruded section. Some sections or products are made by drawing, forming or roll forming, these operations may require special tooling.

Table 2.8 Selection of filler wires and rods for inert-gas welding

Parent metal combination ¹⁾								
1st part	2nd Part							
	LM5 castings	LM6 LM5 castings	3103 3105	1200	7020	6061 6063 6082	5154A 5251 5454	5083
5083	Type 5	NR ³⁾	Type 5	Type 5	5556A	Type 5	Type 5	5556A
	Type 5		Type 5	Type 5	Type 5	Type 5	Type 5	Type 5
	Type 5		Type 5	Type 5	5556A	Type 5	Type 5	Type 5
5154A	Type 5	NR ²⁾	Type 5	Type 5	Type 5	Type 5	Type 5	
5251	Type 5		Type 5	Type 5	Type 5	Type 5	Type 5 ³⁾	
5454	Type 5		Type 5	Type 5	Type 5	Type 5	Type 5	
6061	Type 5	Type 4	Type 4	Type 4	Type 5	Type 4/5		
6063	Type 5	Type 4	Type 4	Type 4	Type 5	Type 4		
6082	Type 5	Type 4	Type 4	Type 4	Type 5	Type 4		
7020	Type 5	NR ²⁾	Type 5	Type 5	5556A			
	Type 5		Type 5	Type 5	Type 5			
	Type 5		Type 5	Type 5	Type 5			
1200	Type 5	Type 4	Type 4	Type 1 ⁴⁾				
	Type 5	Type 4	Type 3/4	Type 1				
	Type 5	Type 4	Type 4	Type 1 ⁴⁾				
3103	Type 5	Type 4	Type 3 ⁴⁾					
3105	Type 5	Type 4	Type 3					
	Type 5	Type 4	Type 3 ⁴⁾					
LM6	NR ²⁾	Type 4						
LM25		Type 4						
Castings		Type 4						
LM5 Castings	Type 5							
	Type 5							
	Type 5							

¹⁾ Filler metals for parent combination to be welded are shown in one box, which is located at the intersection of the relevant parent metal row and column. In each box, the filler metal for maximum strength is shown in the top line; in the case of 6 * * * and 7020 alloys, this will be below the fully heat-treated parent metal strength. The filler metal for maximum resistance to corrosion is shown in the middle line. The filler metal for freedom from persistent weld cracking is shown in the bottom line.

²⁾ NR = Not recommended. The welding of alloys containing approximately 2 % or more of Mg with Al-Si (5% to 12 % Si) filler metal (and vice versa) is not recommended because sufficient Mg₂Si precipitate is formed at the fusion boundary to embrittle the joint.

³⁾ The corrosion behaviour of weld metal is likely to be better if its alloy content is close to that of the parent metal and not markedly higher. Thus for service in potentially corrosive environments it is preferable to weld 5154A with 5154A filler metal or 5454 with 5554 filler metal. However, in some cases this may only be possible at the expense of weld soundness, so that a compromise will be necessary.

⁴⁾ If higher strength and/or better crack resistance is essential, type 4 filler metal can be used.

NOTE 1. Table derived from BS 3019 : Part 1 and BS 3571 : Part 1.

NOTE 2. For particular filler metal alloys in each alloy type see table 2.4.

Table 2.9 Product form availability

Alloy	Plate > 6 mm thick	Sheet and strip ≤ 6 mm thick	Extruded sections			Drawn tube	Longitudinally welded tube	Forgings	Castings
			Solid bar and simple shapes	Complex and special sections	Extruded round and rectangular tube				
1200	L	L ¹⁾	S			S			
3103	O	L							
3105		O							
5083	L	L	S			S		O	
5154A	O	O	S			S		O	
5251	L	L	S			S	L	O	
5454	L	L	S			S			
6061	S	S	O	O	O	O			
6063			L ²⁾	L	L	O		O	
6082	L ³⁾	L	L ²⁾	O	L	O		O	
7020	O	O	S		S			S	
LM5									O
LM6									O
LM25									O

Key

L Standard product manufactured to order with a limited range of sizes available from stock.

O Standard product manufactured to order.

S Alloy product combination not normally manufactured but possibly available by special arrangement.

Blank indicates the product is not available

¹⁾ Includes stocked patterned and embossed sheet.²⁾ Includes sections from BS 1161.³⁾ Includes stocked tread plate.

NOTE. Certain mechanical properties are given in tables 2.1 and 2.2.

Table 2.10 Range of sizes for extruded sections complying with BS 1161

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

2.7.3 Tube

Tube may be produced by extrusion, by drawing or seam welding. Tube is available from stock in some of these forms in a limiting range of sizes but generally it will be made to order, see table 2.9.

2.7.4 Sheet, strip and plate

A wide range of sheet, strip and plate is normally stocked in the standard alloys (see table 2.9). Some alloys are available as patterned sheet and as treadplate. There is a wide range of standard rolled roofing and cladding products, some of which are available in moderate quantities from stock in both mill finish and painted, but most are generally produced to order.

2.7.5 Forgings

Forgings are supplied to order as hand forgings or die forgings, the former normally requiring all over machining to achieve the finished dimensions whilst the latter are produced to the finished dimensions. Dies for forgings are relatively expensive and costs should include at least one forging made and cut up to check grain flow to prove the die for forgings used in structural applications.

2.7.6 Castings

Castings are supplied to order as sand casting or chill castings. Sand castings are produced from patterns made at moderate cost and are used normally for small quantity production. Chill castings are generally used for larger quantity production and where greater production rates are required, where greater dimensional accuracy and good surface finish is required. The cost of tooling may be high, especially for pressure die castings.

Section 3. Design principles

3.1 Limit state design

Structures should be designed by considering the limit states at which they become unfit for their intended use. Consideration should always be given to the following limit states:

- (a) static strength (ultimate limit state) (see 3.3);
- (b) deformation (serviceability limit state) (see 3.4);
- (c) durability (see 3.5).

In certain structures it will be necessary to consider one or both of the following:

- (1) fatigue (see 3.6);
- (2) vibration (see 3.7).

Design will normally be carried out by calculation using the guidance given in sections 4 to 7 and appendices B to L. It is permissible, however, to verify a proposed design by testing (see section 8).

3.2 Loading

3.2.1 General

A structure or structural component should be designed to resist all loads and actions to which, within reason, it can be subjected. These are classified as follows.

- (a) *Dead load.* Self-weight of the structure and of any permanently attached item it supports.
- (b) *Imposed load.* Any statically or dynamically applied load other than dead or wind loading.
- (c) *Wind load.* Dynamic loading due to wind gusts.
- (d) *Temperature effect.* Temperature fluctuations leading to forces in a structural component.

All relevant loads should be considered separately or in such realistic combinations as to comprise the most critical effects on the elements and the structure as a whole. The magnitude and frequency of fluctuating loads should also be considered. Particular attention should be given to loading conditions during assembly, and the settlement of supporting structures may need to be taken into account. The possibility of loads due to seismic forces, fire, explosion and vehicular impact should be considered.

3.2.2 Nominal loading

Nominal loads are defined as those to which the structure may be reasonably expected to be carrying during normal service. They are used for checking the limit states of deformation, fatigue and vibration.

Where possible they should be determined from the relevant British Standard. For dead and imposed loading refer to BS 6399 : Part 1. For wind loading on buildings refer to CP 3 : Chapter V: Part 2. British Standards also exist for nominal loads on cranes and lifts (including dynamic effects). Where no relevant British Standard exists nominal loads should be decided by the designer and the client. A method of assessing loads using a statistical and probability basis is given in appendix B.

When the imposed load consists of soil or other filling, consideration should be given to the material becoming saturated. In assessing temperature effects it may be assumed that in the UK, in the absence of local information, the average internal temperature of the structure varies between -5°C and $+35^{\circ}\text{C}$. The effect of the colour of external sheeting on internal temperature should also be considered.

3.2.3 Factored loading

Factored loads are used for checking the limit state of static strength. They are the nominal loads multiplied by the overall load factor, γ_f , which provides an allowance for variability in loading, accidental overload, etc. γ_f is defined as follows:

$$\gamma_f = \gamma_{f1} \gamma_{f2}$$

where

γ_{f1} and γ_{f2} are the partial load factors.

γ_{f1} is governed by the type of load, and γ_{f2} allows some relaxation when a combination of imposed and/or wind loads is applied to the structure. As a guide, tables 3.1 and 3.2 give values of γ_{f1} and γ_{f2} based on building structures, but different values may be used by agreement between the designer and the client. If different values are chosen by reference to other British Standards, care should be taken to ensure that γ_{f1} does not include a factor to allow for variability of material strength. For initial design of simple structures γ_{f2} may be conservatively taken as 1.0 for all imposed or wind loads.

Table 3.1 Load factors (based on building structures)

Type of load	γ_{f1}
Dead load	
Direct effect	1.2
Countering overturning or uplift	0.8
Imposed load (not including wind loads)	1.33
Wind load	1.2
Forces due to temperature effects	1.0

Table 3.2 Load factors for combined loads	
Load combination	γ_{f2}
Dead load	1.0
Imposed or wind load giving most severe loading action on the component	1.0
Imposed or wind load giving second most severe loading action on the component	0.8
Imposed or wind load giving third most severe loading action of the component	0.6
Imposed or wind load giving fourth most severe loading action on the component	0.4
NOTE. In some structures the wind load could be the most severe applied load, in others the wind load could produce load effects less severe than those due to the major imposed loads.	

3.2.4 Dynamic effects

In order to determine the nominal loading on a structure under dynamic conditions, reference should be made if possible to an appropriate British Standard. Forces from dynamic effects are treated as imposed loads in table 3.1.

In other cases, should a 'dynamic magnification factor' be used, the designer should be aware that this might be a dangerous procedure if the response of the structure is not taken into account. This applies particularly to aluminium structures of high flexibility that have a natural period of vibration similar in magnitude to that of the imposed load.

If initial calculations show that a problem exists, a more detailed computation based on the equations of motion should be carried out. The need to provide artificial damping should be examined, and tests on prototype components may also be necessary.

3.3 Static strength

3.3.1 General

A component is acceptable in terms of static strength if the following is satisfied:

$$\frac{\text{Action-effect under factored loading}}{\text{factored resistance (see appendix B)}} < 1$$

3.3.2 Action-effect under factored loading

This is the axial force, bending moment or shear force arising in a component due to the application of factored loading, found by using accepted structural analysis. The factored loading is found by taking the nominal loads and multiplying each by the appropriate load factor.

3.3.3 Factored resistance

This is the calculated resistance divided by the material factor γ_m . The calculated resistance is the actual capacity of the component in relation to the action-effect being considered (axial load, bending moment or shear force), based on recognized structural analysis and assuming satisfactory manufacture.

The material factor, γ_m , takes account of differences between the strengths of material test specimens and the strength of the actual material in the structure as manufactured, and reflects possible doubt as to the soundness of the component as built. γ_m should normally be taken from table 3.3, but different values may be used by agreement between the designer and the client.

Table 3.3 Material factors		
Type of construction	γ_m	
	Members	Joints
Riveted and bolted	1.2	1.2
Welded	1.2	1.3 ¹⁾
Bonded	1.2	3.0
¹⁾ For welding procedures which do not comply with BS 4870 : Part 2, γ_m should be increased to 1.6.		

Rules for establishing the calculated resistance are given in sections four and five (members) and section six (joints). A method of assessing the calculated resistance or the basis of statistics and probability is given in appendix B.

NOTE. In certain structures it is necessary to check that failure will not occur by overturning or sway failure.

3.4 Deformation

3.4.1 Recoverable elastic deformation

A structure is acceptable in terms of deformation if the following is satisfied:

$$\frac{\text{elastic deflection under nominal loading}}{\text{limiting deflection}} < 1$$

It is permissible, when different combinations of imposed loading are possible, to assume a reduced loading equal to $\gamma_{f2} \times$ nominal loads, where γ_{f2} is given in table 3.2.

The calculation of elastic deflection should generally be based on the properties of the gross cross-section. However, for slender sections it may be necessary to take reduced section properties to allow for local buckling (see section 4).

The limiting deflection should be based on the relevant British Standard, or agreed between the designer and the client. In the absence of such information table 3.4 gives suggested values for certain types of structure. In setting limiting deflections it is important to realise that aluminium is three times as flexible as steel, so unduly small limiting deflections should be avoided.

Table 3.4 Limiting deflections

Element	Recommended deflection limit (see note)
Cantilevers carrying floors	$L/180$
Beams carrying plaster or other brittle finish	$L/360$
Purlins and sheeting rails: (a) under dead load only (b) under worst combination of dead, imposed, wind and snow loads	$L/200$ $L/100$
Curtain wall mullions and transoms: (a) single glazed (b) double glazed	$L/175$ $L/250$
Tops of columns: horizontal deflection	$L/300$
NOTE. L is the length between supports.	

3.4.2 Permanent inelastic deformation

It may be generally assumed that components, whose static strength has been calculated in accordance with section four, will not suffer significant permanent deformation under action of nominal loading. This applies to all alloy groups.

3.4.3 Distortion due to frequent assembly

In certain structures which have to be assembled and disassembled frequently, it is necessary to consider the possibility of changes in major dimensions of the coupling system, leading to the gradual build-up of unacceptable errors in the assembled shape.

3.5 Durability

The durability rating of alloy groups is given in tables 2.1 to 2.4. If a structure is designed in a durable alloy and protected in accordance with BS 8118 : Part 2, it will be deemed satisfactory. The degree of exposure and the design life should be taken into consideration.

3.6 Fatigue

3.6.1 General

Any structure or structural component which is subject to significant variations in load should be checked for fatigue. In general two possible limit states should be considered:

- total collapse;
- stable crack growth (damage tolerant).

In both cases the design load spectrum (unfactored) is assumed to act.

3.6.2 Total collapse

The procedure for considering this limit state is to determine the predicted life in accordance with section seven, and check that this is not less than the design life. In certain circumstances the designer may wish to increase the nominal design life by multiplying by a factor (the fatigue life factor) γ_L (>1). The choice of γ_L could be influenced by the following:

- the possibility of increasing crack growth during the later stages of the life of the detail;
- the accuracy of the assumed loading spectrum;
- whether records of loading will be kept during the life of the detail;
- the possibility of a change of use of the structure in mid-life.

The designer may also wish to apply a fatigue material factor, γ_{mf} , to the design stress range given in figure 7.9. The stress range would be divided by γ_{mf} (>1), and the choice of γ_{mf} could be influenced by the following:

- the need for the detail to exist in a very hostile environment;
- whether failure of the detail will result in failure of the entire structure, or whether alternative load paths exist.

3.6.3 Stable crack growth

Damage to a structure under fatigue conditions is assessed by monitoring the rate of growth of fatigue cracks by inspection at regular intervals. Methods of inspection, allowable limiting crack lengths, allowable rates of crack growth, and the time between inspections should be agreed between the client and the designer. Crack growth is stable when the allowable rate of crack growth does not suddenly increase between inspections.

NOTE. Methods for calculating crack growth and limiting crack length are outside the scope of this code, but the ease with which a detail can be inspected for cracks can influence the choice of γ_{mf} (see 3.6.2).

3.7 Vibration

For certain structures the possibility of undesirable vibration under normal service conditions should be considered. In checking for the incompatibility of vibration amplitudes nominal loads should be used. If vibration is thought to be a potential problem, the possibility of fatigue failure should also be checked (see 3.6).

3.8 Testing

Structural components designed in accordance with sections 4 to 7 and the appropriate appendices are acceptable without testing. Components designed using other calculation methods, and components not amenable to calculation, are acceptable only if their resistance has been verified by testing. Such testing should be carried out in accordance with section 8.

Section 4. Static design of members

4.1 Introduction

4.1.1 General

All members should satisfy the limit states of static strength and of deformation. Deformation is covered in 4.9.

Where reference is made to design curves, it is permissible instead for the designer to use formulae from which the curves are derived (see appendix K).

Members are usually formed of extrusions, plate, sheet, tube or a combination of these. The rules below do not apply to castings, and designers wishing to employ castings should do so in close consultation with the manufacturers thereof.

4.1.2 Limit state of static strength

The factored resistance of a member to a specific action-effect should not be less than the magnitude of that action-effect arising under factored loading.

Rules for obtaining resistance to different actions are given as follows:

- (a) for beams (resistance to moment and shear force) (see 4.5);
- (b) for ties (resistance to axial tension) (see 4.6);
- (c) for struts (resistance to axial compression) (see 4.7).

The procedure for calculating the interaction between moment and axial load in members subject to combined actions is given in 4.8.

The formulae given contain limiting stresses (p_o , p_a , p_v) related to material properties, which should be taken in accordance with 4.2. They also contain the material factor γ_m which should be read from table 3.3.

The resistance of a member may be reduced as a result of local buckling, depending on the slenderness of its cross section. A proposed design is checked (except for a member under axial tension) by classifying the section in terms of its susceptibility to this type of failure. A method for checking the local buckling, including section classification, is given in 4.3.

4.1.3 Heat-affected zones (HAZs)

Structural aluminium material generally becomes weakened in the heat-affected zone (HAZ) adjacent to welds, and this should be allowed for in the design. This does not apply when the parent material is in the O or T4 condition; or when it is in the F condition and design is based on O-condition properties.

Rules for estimating the severity and extent of HAZ softening are given in 4.4. Subsequent clauses then show how to allow for the effect of this softening on member resistance.

It is important to realize that a small weld, as used for example in connecting a small attachment, may considerably reduce the resistance of a member, due to softening of part of the cross-section. In beams it is often beneficial to locate welds in low-stress areas, i.e. near the neutral axis or away from the region of peak moment.

4.1.4 Advanced design

Members can be safely designed using the recommendations of this section and the appropriate appendices. Other appendices provide a fuller treatment of certain specific aspects of member behaviour, and their use may lead to lighter designs.

4.2 Limiting stresses

Resistance calculations for members are made using assumed limiting stresses as follows:

- p_o is the limiting stress for bending and overall yielding;
- p_a is the limiting stress for local capacity of the section in tension or compression;
- p_v is the limiting stress in shear;
- p_s is the limiting stress for overall buckling stability.

Values of p_o , p_a and p_v depend on the material properties and should be taken as in table 4.1 or 4.2. For materials not covered in these tables refer to appendix D.

Values of p_s should be determined in accordance with 4.5.6.5 or 4.7.6.

4.3 Section classification and local buckling

4.3.1 General

4.3.1.1 Section classification

Resistance of members under moment or axial compression may become reduced by local buckling, if the slenderness of their component elements is high. The first step in checking such members is to establish the section classification, i.e. the susceptibility to local buckling. In order to do this, and also to allow for the effect of local buckling (when necessary), the designer should consider the slenderness of the individual elements comprising the section.

4.3.1.2 Types of element

The following basic types of thin-walled element are identified in these rules:

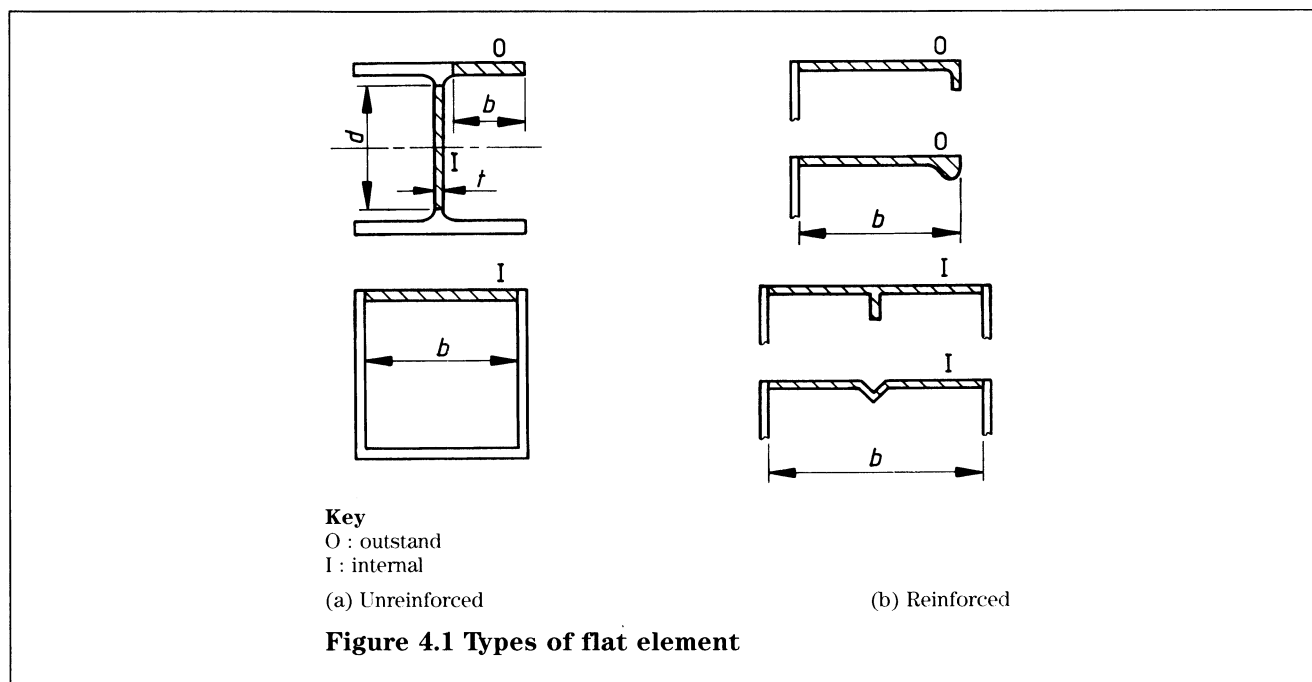
- (a) flat outstand element;
- (b) flat internal element;
- (c) curved internal element.

These are often unreinforced, i.e. not longitudinally stiffened (see figure 4.1 (a)). The stability of flat elements can be greatly improved by the provision of longitudinal stiffening ribs or lips, see figure 4.1 (b), in which case the elements are referred to as reinforced.

Table 4.1 Limiting stresses, heat-treatable alloys							
Alloy	Condition	Product	Thickness		Limiting stress		
			Over	Up to and including	p_o	p_a	p_v
6061	T6	Extrusion	mm	mm	N/mm ²	N/mm ²	N/mm ²
	T6	Drawn tube	—	150	240	260	145
	T6	Drawn tube	—	6	240	265	145
6063	T6	Drawn tube	6	10	225	260	135
	T4	Extrusion	—	150	65	85	40
	T4	Drawn tube	—	10	95	120	60
	T4	Forgings	—	150	80	100	50
	T5	Extrusion	—	25	110	130	65
	T6	Extrusion	—	150	160	175	95
	T6	Drawn tube	—	10	180	190	110
6082	T6	Forgings	—	150	160	170	95
	T4	Extrusion	—	150	115	145	70
	T4	Sheet	0.2	3	115	145	70
	T4	Plate	3	25	105	140	65
	T4	Drawn tube	—	10	105	140	65
	T4	Forgings	—	150	115	145	70
	T6	Extrusion	—	20	255	275	155
	T6	Extrusion	20	150	270	290	160
	T6	Sheet	0.2	3	255	275	155
	T6	Plate	3	25	240	265	145
	T6	Drawn tube	—	6	255	280	155
	T6	Drawn tube	6	10	240	275	145
	T6	Forgings	—	120	255	275	155
7020	T4	Extrusion	—	25	185	230	110
	T4	Sheet, plate	0.2	25	160	205	95
	T6	Extrusion	—	25	280	310	170
	T6	Sheet, plate	0.2	25	270	295	160

Table 4.2 Limiting stresses, non-heat-treatable alloys

Alloy	Condition	Product	Thickness		p_o	p_a	p_c
			Over	Up to and including			
1200	H14	Sheet	mm 0.2	mm 12.5	N/mm ² 90	N/mm ² 95	N/mm ² 55
3103	H14	Sheet	0.2	12.5	110	120	65
	H18	Sheet	0.2	3	150	150	90
3105	H14	Sheet	0.2	3	145	150	85
	H16	Sheet	0.2	3	170	175	100
	H18	Sheet	0.2	3	190	200	115
5083	O, F	Extrusion	—	150	105	150	65
	O	Sheet, plate	0.2	80	105	150	65
	O	Drawn tube	—	10	105	150	65
	F	Sheet, plate	3	25	130	170	75
	H22	Sheet, plate	0.2	6	235	270	140
	H22	Drawn tube	—	10	235	270	140
5154A	O, F	Extrusion	—	150	65	100	40
	O	Sheet, plate	0.2	6	65	100	40
	O	Drawn tube	—	10	65	100	40
	H22	Sheet, plate	0.2	6	160	200	95
	H24	Sheet, plate	0.2	6	225	250	135
	H24	Drawn tube	—	10	200	220	180
5251	F	Welded tube	0.8	2.0	220	230	130
	H22	Sheet, plate	0.2	6	125	155	75
	H24	Sheet, plate	0.2	6	175	200	105
5454	O, F	Extrusion	—	150	65	100	40
	O	Sheet, plate	0.2	6	60	95	35
	H22	Sheet	0.2	3	180	215	110
	H24	Sheet	0.2	3	200	235	120



4.3.1.3 Shear webs

The buckling of shear webs is treated separately (see 4.5.3.3 and also section 5).

4.3.2 Slenderness parameter β

4.3.2.1 General

The susceptibility to local buckling of an element in a beam (moment resistance) or in a strut (axial force resistance) depends on the parameter β as defined in 4.3.2.2 to 4.3.2.5.

4.3.2.2 Unreinforced flat elements

The parameter β depends on b/t or d/t for the element concerned, where t is the element thickness, b the width of an element generally, and d the depth of a web element in a beam. b and d should be taken as the flat element width, measured where relevant to the springing of a fillet or to the toe of a weld.

β is defined as follows:

- (a) element under uniform compression: $\beta = b/t$;
- (b) element under stress gradient:
 - (1) internal element with a stress gradient that results in a neutral axis at the centre: $\beta = 0.4d/t$ or $0.4b/t$
 - (2) for any other stress gradients $\beta = gb/t$ or gd/t

where g is the stress gradient coefficient and is read from figure 4.2. In figure 4.2 y_c and y_o are the distances from the neutral axis of the gross section to the more heavily compressed edge and the other edge respectively of the element, taken positive towards the compression side. They should generally be measured

from the elastic neutral axis, although in checking whether a section is fully compact it is permissible to use the plastic neutral axis.

4.3.2.3 Reinforced flat elements

Two possible buckling modes should be considered as follows (see figure 4.3), and separate β values found for each:

- (a) mode 1 : the reinforced element buckles as a unit taking the reinforcement with it;
- (b) mode 2 : the sub-elements comprising the reinforced element themselves buckle as individual elements the junctions between them staying straight.

For mode 2 buckling β is found separately for each sub-element in accordance with 4.3.2.2. For mode 1 it is generally determined as follows (but see the note to 4.5.2.1, concerning outstand elements in beams).

- (a) Mode 1, uniform compression.

- (1) Standard reinforcement, defined as reinforcement consisting of single-sided rib or lip of thickness equal to the element thickness t , located as in figure 4.4 :

$$\beta = hb/t$$

where

b and t are defined as in 4.3.2.2

h is read from figure 4.4 (a), (b) or (c) as appropriate.

For figure 4.4, c should be taken as the clear depth of the rib or lip measured to the surface of the plate

(2) Non-standard reinforcement. With any other shape of reinforcement β should be found by replacing it with an equivalent rib or lip of the standard form and proceeding as in (1). The value of c for the equivalent rib or lip is chosen so that its second moment of area about the mid-plane of the plate is the same as that for the true reinforcement.

(3) General method. For cases not covered by (1) or (2) β may be taken as follows:

$$\beta = (b/t)(\sigma_{cro}/\sigma_{cr})^{0.4}$$

where

σ_{cr} are the elastic critical stresses,
and assuming simple edge support, with
 σ_{cro} and without the reinforcement.

(b) Mode 1, stress-gradient.

β should be found using the expression in (a) (3) where σ_{cr} and σ_{cro} now relate to the stress at the more heavily compressed edge of the element.

4.3.2.4 Curved internal elements

For a shallow curved element under uniform compression, β should be determined as follows:

$$\beta = \frac{b/t}{\{1 + (0.006b^4/R^2t^2)\}^{1/2}}$$

where

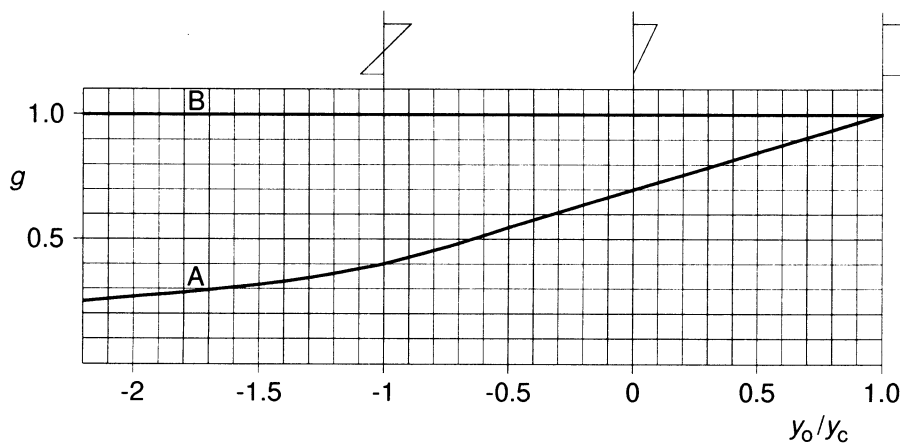
R is the radius of curvature to mid-metal;

b is the developed width of element at mid-metal

t is the thickness

For shallow curved elements under a stress gradient, a more favourable value of β may be taken, obtained by factoring the above value by g as found from figure 4.2.

The above treatment is valid, provided R/b is not less than $0.1b/t$. Sections containing more deeply curved elements require special study.



NOTE. For internal elements or outstands (peak compression at root) use curve A.
For outstands (peak compression at toe) use line B.

Figure 4.2 Flat elements under stress gradient, value of g

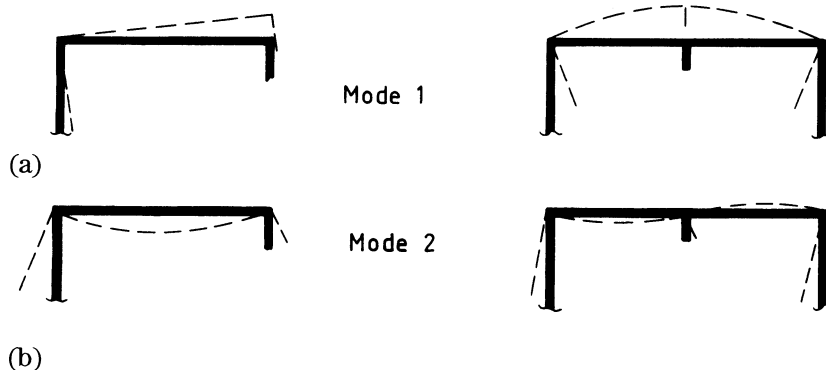
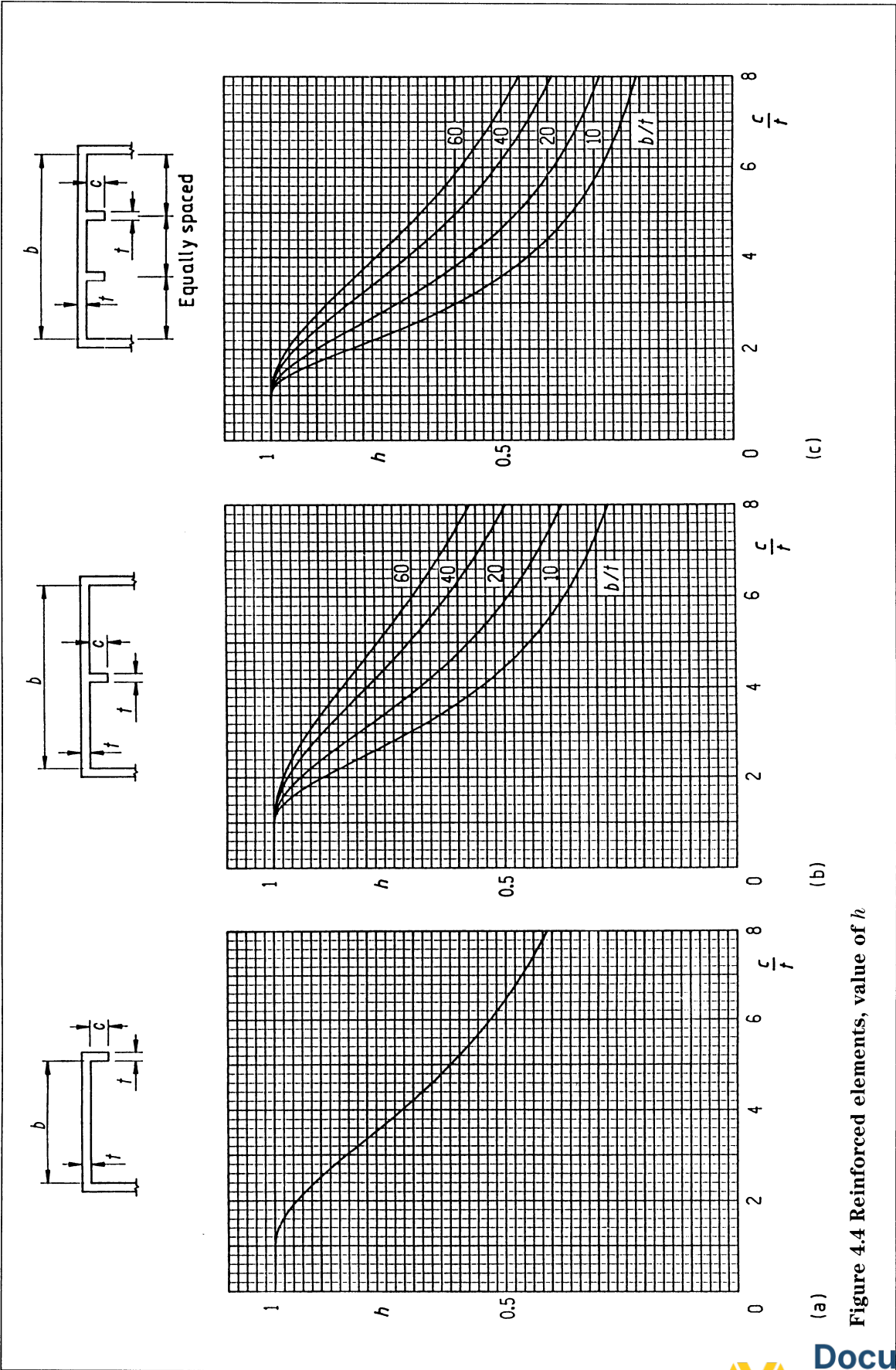


Figure 4.3 Buckling modes for flat reinforced elements



4.3.2.5 Round tubes

β should be found as follows, with no distinction between axial compression and bending:

$$\beta = 3 (D/t)^{1/2}$$

where

D is the diameter to mid-metal;

t is the thickness.

4.3.3 Section classification

4.3.3.1 General

The procedure is to classify the individual elements comprising the section, except for any element stressed wholly in tension. The classification of the section is then taken as that for the least favourable element. Individual elements are classified in accordance with 4.3.3.4 or 4.3.3.5.

4.3.3.2 Sections: beams and struts

For the section of a beam (moment resistance) or of a strut (axial force resistance) the following classifications apply.

(a) Moment resistance:

- (1) fully compact: local buckling can be ignored;
- (2) semi-compact: the section can develop a moment equal to p_0 times the elastic section modulus;
- (3) slender: the moment resistance is reduced by premature local buckling at an extreme fibre stress below p_0 .

(b) Axial compression resistance:

- (1) compact: local buckling can be ignored;
- (2) slender: local buckling lowers the resistance.

4.3.3.3 Sections subject to combined actions

For the classification of sections required to carry biaxial bending, or simultaneous bending with axial force, see 4.8.2.1.

4.3.3.4 Element classification

The classification of an individual element depends on the value of β (see 4.3.2) as follows:

(a) elements in beams (moment resistance):

$$\begin{aligned} \beta &\leq \beta_1 && \text{fully compact} \\ \beta_1 &< \beta \leq \beta_0 && \text{semi-compact} \\ \beta &> \beta_0 && \text{slender} \end{aligned}$$

(b) elements in struts (axial resistance):

$$\begin{aligned} \beta &\leq \beta_0 && \text{compact} \\ \beta &> \beta_0 && \text{slender} \end{aligned}$$

where β_0 and β_1 are as given in table 4.3.

Table 4.3 Limiting values of β

Elements	β_0		β_1	
	Unwelded	Welded	Unwelded	Welded
Outstand elements	7ε	6ε	6ε	5ε
Internal elements	22ε	18ε	18ε	15ε

NOTE 1. The quantity ε should generally be taken as follows (except for certain flange elements in beams, see 4.3.3.5):

$$\varepsilon = (250/p_0)^{1/2}$$

where

p_0 is the limiting stress (in N/mm²) (see tables 4.1 and 4.2).

NOTE 2. An element is considered as welded if it contains welding at an edge or at any point in its width. When the stability of a particular cross-section of a member is evaluated, however, it is permissible to consider an element as unwelded if it contains no welding at that section, even though it is welded elsewhere along its length.

NOTE 3. In a welded element the classification is independent of the extent of the HAZ.

4.3.3.5 Understressed flange elements

A more favourable classification may if desired be taken for flange elements in members under bending, or bending with axial force, that are both:

- a) parallel to the axis of bending; and
- b) less highly stressed than the most severely stressed fibres in the section.

For these it is permissible, in using table 4.3, to take a modified value of ε as follows:

$$\varepsilon = (250y_1/p_0y_2)^{1/2}$$

where y_1 and y_2 are the distances from the neutral axis of the gross section to the most severely stressed fibres and to the element respectively. They should generally be measured from the elastic neutral axis, although in checking whether a section is fully compact it is permissible to use the plastic one.

4.3.4 Local buckling

4.3.4.1 General

The possibility of local buckling in members classified as slender is generally allowed for by replacing the true section by an effective one. The effective section is obtained by employing a local buckling coefficient k_L to factor down the thickness, this being applied to any uniform thickness slender element that is wholly or partly in compression. Elements that are not uniform in thickness require special study.

4.3.4.2 Determination of k_L

The coefficient k_L , which is found separately for different elements of the section, is read from the appropriate curve in figure 4.5 selected in accordance with table 4.4. In order to select the correct curve the value of β/ε should be determined as follows:

- β is found as in 4.3.2;
- $\varepsilon = (250/p_0)^{1/2}$ generally (but see note 3 of 4.5.2.3 for beam compression flanges);

where

p_0 is the limiting stress for material (in N/mm²), regardless of HAZ effects.

Table 4.4 Curve selection for figure 4.5 (local buckling)		
Elements	Unwelded	Welded
Flat outstand elements	curve A	curve B
Internal elements (flat or curved)	curve C	curve D
Round tubes	Lower of curves C and E	Lower of curves D and E
NOTE. See note 3 to table 4.3		

In order to decide whether an element should count as unwelded or welded in table 4.4, refer to note 2 to table 4.3.

In the case of reinforced flat elements it is important to consider both possible modes of buckling (see figure 4.3) and take the more critical. In the case of mode 1 buckling the factor k_L should be applied to the area of the reinforcement as well as to the basic plate thickness.

4.3.4.3 Sections subject to combined actions

For the determination of k_L in sections required to carry biaxial bending, or simultaneous bending with axial force, see 4.8.2.2.

4.4 HAZ softening adjacent to welds

4.4.1 General

It is necessary in design to allow for the softening that usually occurs in the vicinity of welds. The region worst affected extends immediately around the weld, beyond which the material properties rapidly improve to their full parent values. The softening affects the 0.2 % proof stress more severely than the tensile strength.

For design purposes it is acceptable to approximate to the true condition by assuming that around each weld there is a zone, the HAZ, in which strength properties are reduced by a constant factor k_z . Outside this zone it is assumed that the full parent properties apply. The severity of the softening in the HAZ, as defined by k_z , is covered in 4.4.2. The extent of the HAZ, defined by a distance z from the weld, is considered in 4.4.3.

It is sometimes possible to mitigate the effects of HAZ softening by means of artificial ageing applied after welding (see appendix F).

4.4.2 Severity of softening

4.4.2.1 HAZ softening factor

The factor k_z should normally be taken from table 4.5. For certain calculations it is permissible instead to use a more favourable value as explained in appendix F.

This applies when the resistance of a member is governed by p_a or p_v , rather than p_0 . To find k_z for materials not covered in table 4.5 see appendix F.

4.4.2.2 7020 material

The alternative k_z values given in table 4.5 for 7020 material should normally be applied as follows, according to the nature of the stress acting on the HAZ material:

- (a) value (A): tensile stress acting transversely to the axis of a butt or fillet weld;
- (b) value (B): any other stress condition, i.e. longitudinal stress, transverse compression, shear.

It is sometimes permissible to increase value (A) to a figure above that in the table, depending on the degree of thermal control exercised during fabrication (see appendix F).

4.4.2.3 Recovery time for heat-treated alloys

The k_z values given in table 4.5 are valid from the following times after welding, provided the material has been held at a temperature not less than 15 °C:

- (a) 6 * * * series alloys 3 days;
- (b) 7 * * * series alloys 30 days.

In determining the resistance of components that are to be loaded sooner than this, but not less than 24 h after welding, the value of k_z should be reduced by a factor f found as follows:

- (1) 6 * * * series alloys $f = 0.9 + 0.1 \{(n - 1)/2\}^{1/2}$
- (2) 7 * * * series alloys $f = 0.8 + 0.2 \{(n - 1)/29\}^{1/2}$

where

n is the time (in days) between welding and loading.

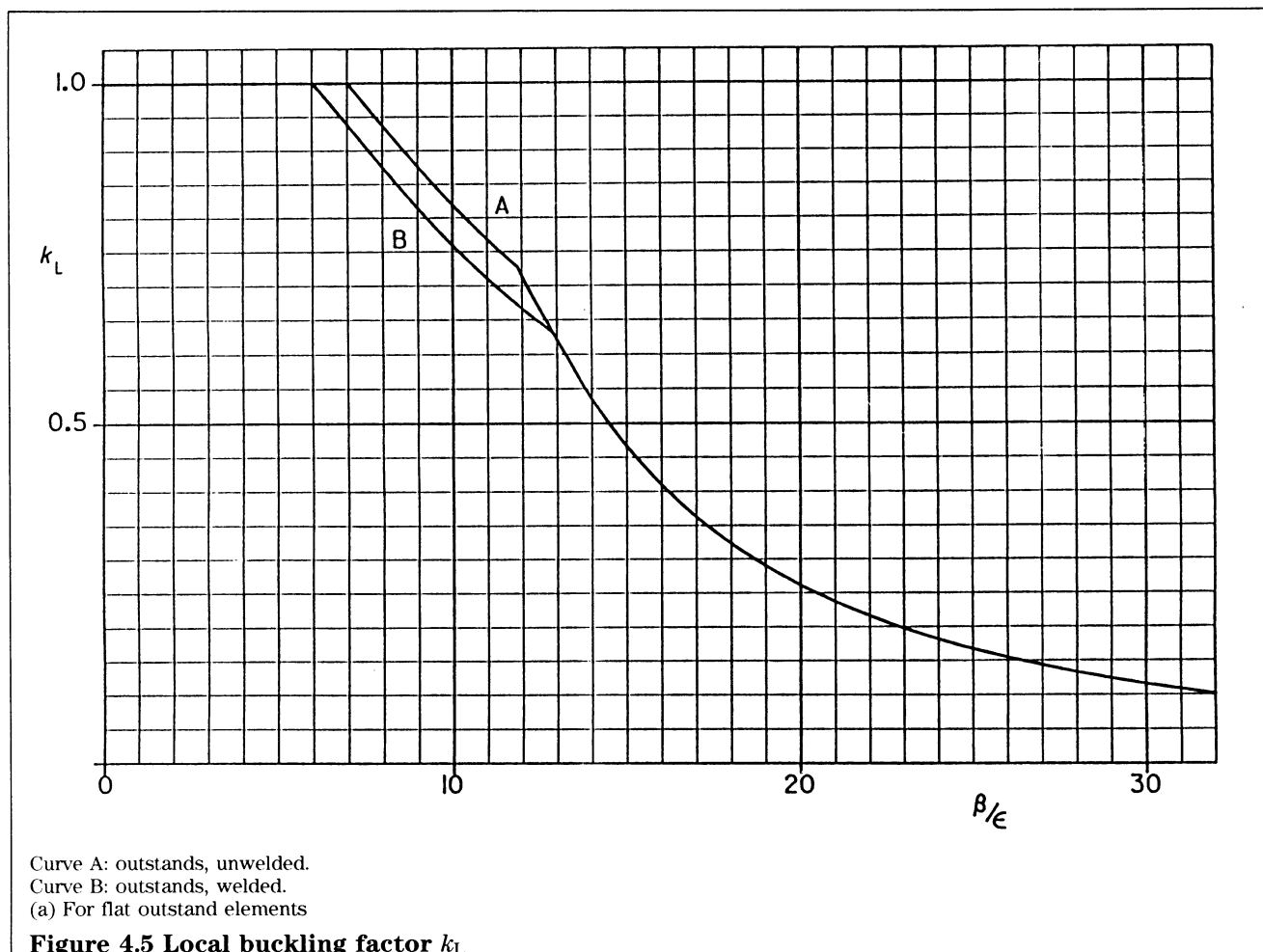
If the material is held at a temperature below 15 °C after welding, the recovery time will be prolonged and advice should be sought.

4.4.3 Extent of HAZ

4.4.3.1 Definition of z

The HAZ is assumed to extend a distance z in any direction from a weld, measured as follows:

- (1) transversely from the centre-line of an in-line butt weld (see figure 4.6(a));
- (2) at fillet welds, transversely from the point of intersection of the welded surfaces (see figures 4.6(e),(f),(g) and (h));
- (3) at butt welds used in corner, tee or cruciform joints, transversely from the point of intersection of the welded surfaces (see figures 4.6(b), (c) and (d));
- (4) in any radial direction from the end of a weld (see figures 4.6(i) and (j)).



The HAZ boundaries should generally be taken as straight lines normal to the metal surface, as shown in figure 4.6. However, it is permissible instead to assume a curved boundary of radius z as shown at B (in place of A) in figure 4.6(i). This will tend to be advantageous when surface welding is applied to thick material.

4.4.3.2 Basic formula for z

The following expression should generally be used for estimating z :

$$z = \alpha \eta z_0$$

where

- z_0 is the basic value (see 4.4.3.3);
 α and η are modifying factors, which may be found from 4.4.3.4 and 4.4.3.5, or alternatively using appendix F.

The use of appendix F will tend to be favourable when the interpass temperature during fabrication is held below the normal value required in BS 8118 : Part 2.

4.4.3.3 Determination of z_0

The basic value z_0 , which would relate to an isolated weld laid on unheated material with complete interpass cooling, should be taken as the lower of the two values given by (i) and (ii) (in mm) (depending on the parent material) as follows:

(a) in-line butt welds:

(1) 7 * * * series alloys:

(i) $z_0 = 30 + t_A/2$

(ii) $z_0 = 4.5t_A$

(2) other alloys:

(i) $z_0 = 20 + t_A/3$

(ii) $z_0 = 3t_A$

(b) All other types of butt weld and all types of fillet weld:

(1) 7 * * * series alloys:

(i) $z_0 = 30 + t_A/2$

(ii) $z_0 = 4.5t_B^2/t_A$

(2) other alloys:

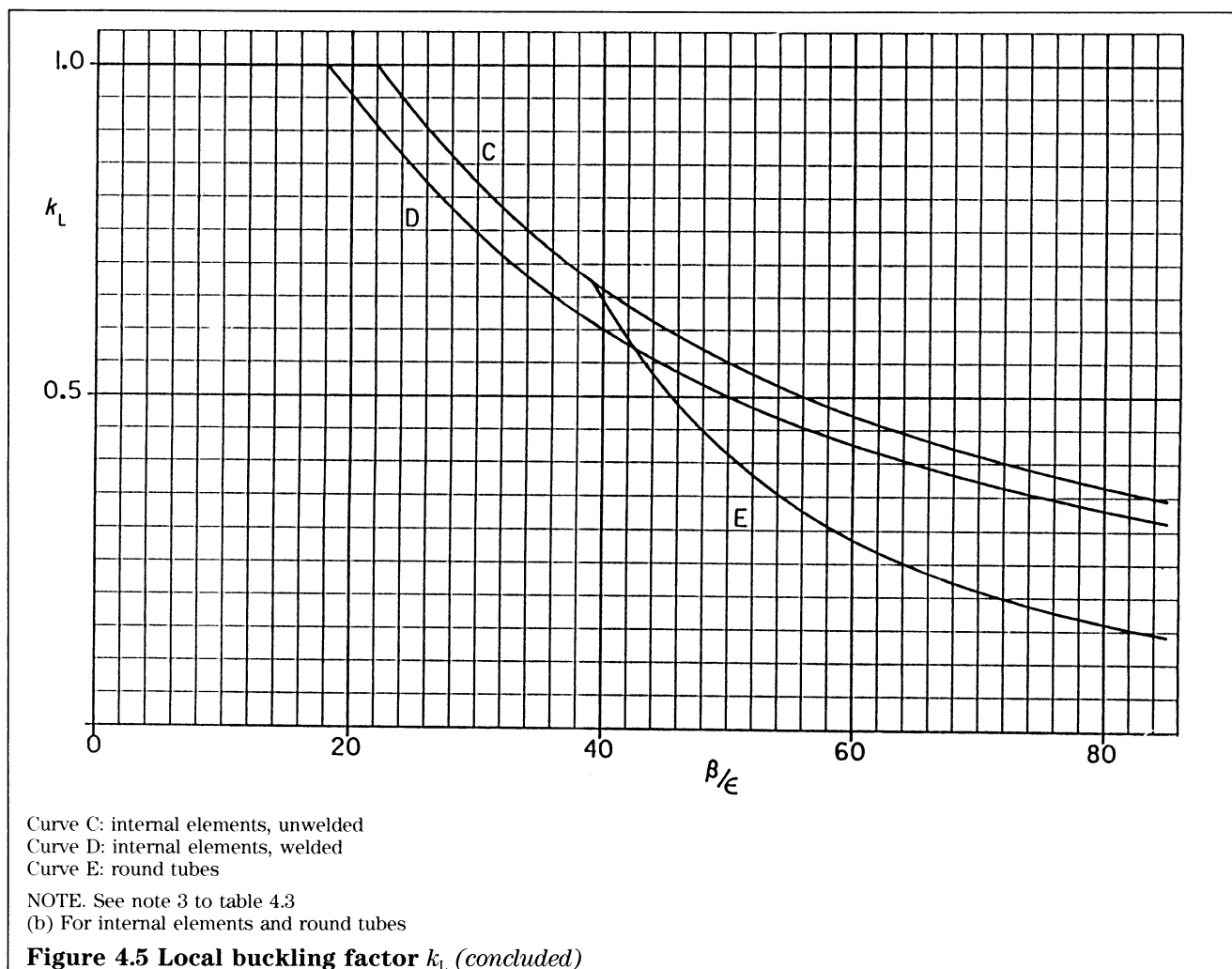
(i) $z_0 = 20 + t_A/3$

(ii) $z_0 = 3t_B^2/t_A$

where

t_A is the lesser of $0.5(t_B + t_C)$ and $1.5t_B$;

t_B, t_C are the thickness of the thinnest and thickest elements connected by welding respectively.



4.4.3.4 Determination of α

The factor α in 4.4.3.2 provides for the possibility of the material at the start of deposition of a weld pass being at an elevated temperature, due either to preheat, or to the laying of a previous pass or weld in the same joint. Its value may be taken from table 4.6, which is valid provided fabrication complies with BS 8118 : Part 2 (alternatively see appendix F).

4.4.3.5 Determination of η

The factor η in 4.4.3.2 covers the possibility of increased heat build-up due to the following:

- (a) proximity of a free edge or edges; or
- (b) other welding in the same vicinity.

The value of η may be found as in (1) or (2) as follows, provided fabrication satisfies BS 8118 : Part 2. Alternatively refer to appendix F.

- (1) For a joint away from which there are at least two valid heat-paths:

$$\eta = 1$$

a valid heat-path being one for which $h \geq h_1$, where

- h is the distance to a free edge, or half the distance to a nearby weld (see note);
- h_1 $4.5\alpha z_0$ for 7 *** series alloys, or
 $= 3\alpha z_0$ for other alloys.

When a weld is located too close to the free edge of an outstand, such that $h < h_1$, it should be assumed that the entire width of the outstand is subject to the factor k_Z .

NOTE. The distance h should be measured from the point of reference in the weld considered (see figure 4.6) and along the relevant heat-path through the metal at mid-thickness. The heat-path follows the profile of the section and need not necessarily be straight (see figure 4.7).

- (2) For a joint from which there is only one valid heat-path:

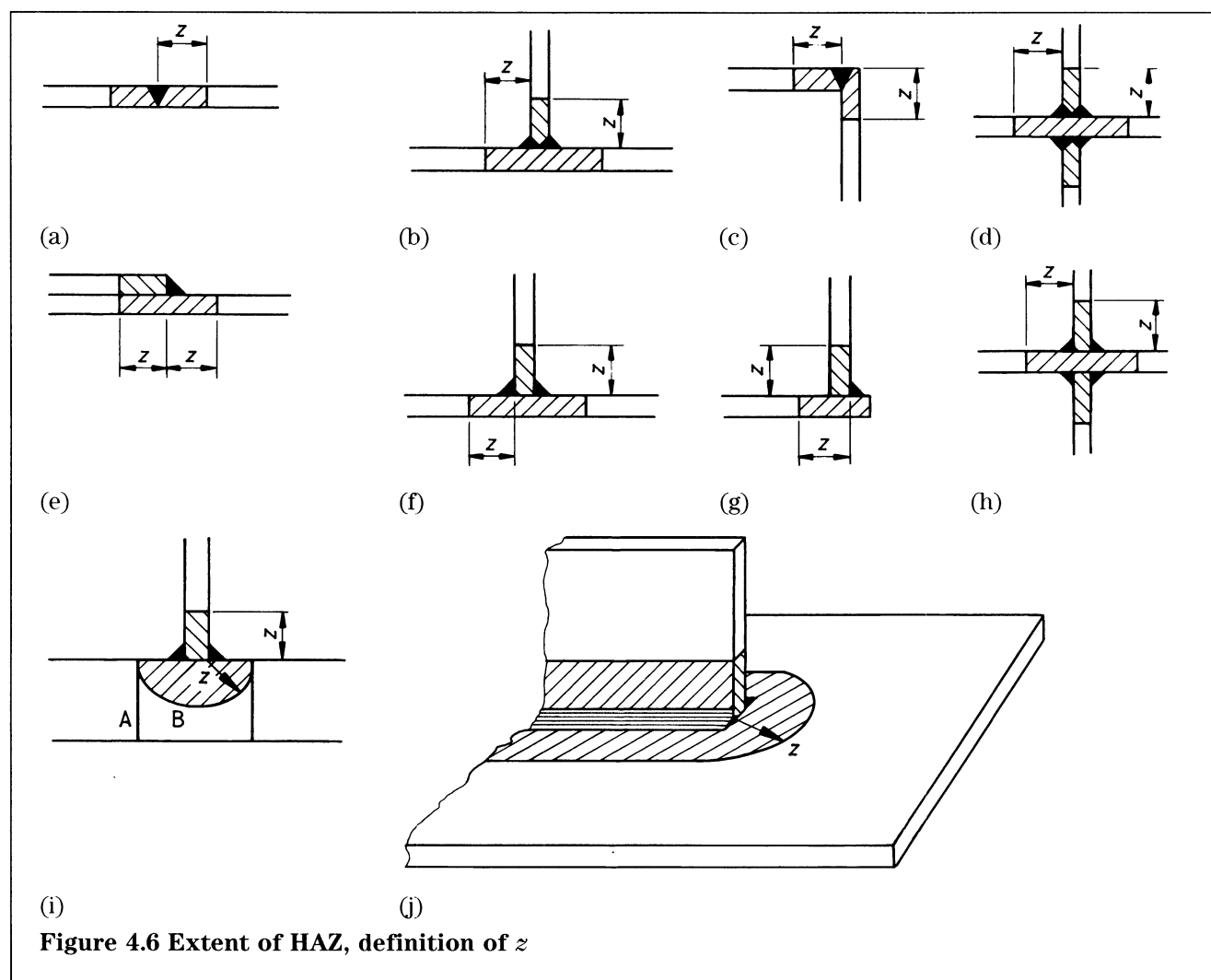
$$\begin{aligned} t_c \leq 25 \text{ mm} & \quad \eta = 1.50 \\ t_c > 25 \text{ mm} & \quad \eta = 1.33 \end{aligned}$$

Table 4.5 HAZ softening factor k_z

Alloy	Condition	Product (see note 1)	k_z
Non-heat treatable			
1200	H14	S	0.13
3103	H14	S	0.18
	H18	S	0.13
3105	H14	S	0.17
	H16	S	0.15
	H18	S	0.13
5083	O, F	E, S, P, DT	1.00
	H22	S, P	0.45
5154A	O, F	E, S, P	1.00
	H22	S, P	0.40
	H24	S, P	0.29
5251	F	WT	0.20
	F	F	1.00
	H22	S, P	0.35
	H24	S, P	0.24
5454	O, F	E, S, P	1.00
	H22	S	0.35
	H24	S	0.30
Heat-treatable			
6061	T6	E, DT	0.50
6063	T4	E	1.00
	T4	DT	0.65
	T4	F	0.80
	T5	E	0.75
	T6	E, F	0.50
	T6	DT	0.45
6082	T4	E, S, P, DT, F	1.00
	T6	E, S, P, DT, F	0.50
7020	T4	E, S, P	0.80(A) 1.00(B)
	T6	E, S, P	0.60(A) 0.80(B) (see note 2)

NOTE 1. In the product column, E, S, P, DT, WT and F refer respectively to extrusion, sheet, plate, drawn tube, welded tube and forgings.

NOTE 2. For 7020 material refer to 4.4.2.2, for the applicability of the A and B values.

**Table 4.6 Extent of HAZ, factor α**

Case	Joint configuration	Value of α	
		$t_c \leq 25 \text{ mm}$	$t_c > 25 \text{ mm}$
P	Substantially straight continuous weld figure (see figures 4.6(a), (c), (e) and (g)) total deposit area $\leq 50 \text{ mm}^2$	1.0	1.5
Q		1.5	2.0
R	Substantially straight continuous joint containing two or more adjacent welds (see figures 4.6 (b), (d), (f) and (h))	1.5	2.0
S	Localized irregular joint (a) member-to-member joints in trusses; (b) welds connecting transverse stiffeners in beams and plate-girders; (c) welds used to connect lugs and other attachments.	1.5	2.0

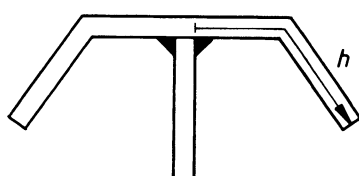


Figure 4.7 Typical heat-path measurement

4.4.3.6 Overlapping HAZs

When two joints are located so that their respective HAZs (determined as in 4.4.3) overlap, it may be assumed that the extent of the HAZ on the outer side of each joint is unaltered by the proximity.

In calculating whether HAZs overlap, the possibility of elevated temperatures should be taken into account by using the formula for z from 4.4.3.2.

4.4.3.7 Experimental determination of z

As an alternative to estimating the extent of the HAZ by calculation, it is permitted instead to determine it experimentally. This may be done by conducting a hardness survey on a representative specimen (see appendix F).

4.5 Beams

4.5.1 Introduction

4.5.1.1 General

The following checks should generally be carried out on all beams (including plate girders).

(a) *Moment check.* At any cross-section the moment M under factored loading should not exceed the factored moment resistance M_{RS} of that section, as found from 4.5.2 (or alternatively appendix E). M_{RS} should be suitably reduced to allow for coincident shear when necessary (see 4.5.4).

(b) *Shear check.* At any cross-section the shear force V under factored loading should not exceed the factored shear force resistance V_{RS} (see 4.5.3).

For some cases it is also necessary to make one or both of the following checks:

- (1) web bearing check (see 4.5.5);
- (2) lateral torsional buckling check (see 4.5.6).

4.5.1.2 Plate girders

Plate girders having slender stiffened webs should preferably be designed using 5.4. It is permissible to design them as beams, but with probable loss of economy.

4.5.1.3 Bending with axial load

For the design of beams required to carry load, in addition to moment, reference should be made to 4.8.

4.5.1.4 Biaxial bending

Beams subjected to simultaneous bending about both principal axes should also be checked using 4.8.

4.5.2 Uniaxial moment resistance of the section

4.5.2.1 Section classification for moment resistance

It is first necessary to classify the section as fully compact, semi-compact, or slender; the classification being based on that of the least favourable of its component elements. This should be carried out in accordance with 4.3.3.

In the case of a reinforced outstand element, forming part or all of the compression flange, the presence of reinforcement in the form of an outwardly facing lip should be ignored in classifying the section.

4.5.2.2 Basic calculation

The factored moment resistance M_{RS} at a given section, in the absence of shear should generally be found as follows:

- | | |
|-----------------------------|--|
| (a) unwelded, fully compact | $M_{RS} = p_o S_n / \gamma_m$ |
| (b) unwelded, semi-compact | $M_{RS} = p_o Z_n / \gamma_m$ |
| (c) welded, fully compact | $M_{RS} = p_o S_{ne} / \gamma_m$ |
| (d) welded, semi-compact | $M_{RS} = p_o Z_{ne} / \gamma_m$ |
| (e) unwelded, slender | $M_{RS} = p_o Z_e / \gamma_m$ or $p_o Z_n / \gamma_m$ whichever is the smaller; |
| (f) welded, slender | $M_{RS} = p_o Z_e / \gamma_m$ or $p_o Z_{ne} / \gamma_m$ whichever is the smaller; |

where

- | | |
|-----------------------|--|
| S_n and Z_n | are the plastic moduli respectively of the net section; |
| S_{ne} and Z_{ne} | are the plastic and elastic moduli respectively for the net effective section; |
| Z_e | is the elastic modulus of effective section; |
| p_o | is the limiting stress (see tables 4.1 and 4.2); |
| γ_m | is the material factor (see table 3.3). |

NOTE. For semi-compact and slender sections it is permissible, if found favourable, to take a moment resistance based on an elasto-plastic stress pattern as set out in appendix E, instead of using the expressions in 4.5.2.2. When this is done, note 5 to 4.5.2.3 is invalid.