PD 6702-1:2009

BSI Standards Publication

PUBLISHED DOCUMENT

Structural use of aluminium

Part 1: Recommendations for the design of aluminium structures to BS EN 1999

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Foreword

Publishing information

This part of PD 6702 is published by BSI and came into effect on 31 December 2009. It was prepared by Subcommittee B/525/9, *Structural use of aluminium*. A list of organizations represented on this committee can be obtained on request to its secretary.

Relationship with other publications

This Published Document gives guidance on the use of BS EN 1999-1-1 and BS EN 1999-1-3, for the design of aluminium structures in the UK.

Information about this document

BS EN 1999, Parts 1-1, 1-2, 1-3, 1-4 and 1-5, will replace BS 8118-1 after a period of coexistence. The replacement of BS 8118-1 will represent a substantial change in design practice in the UK. This Published Document aims to ensure that aluminium structures are designed with the same level of assurance of reliability as that implicit in BS 8118-1.

The guidance given in this Published Document consists of non-contradictory complementary information (NCCI) to enable the user to apply BS EN 1999 in a safe and cost-effective manner, with particular reference to the following:

a) provision in the National Annexes for nationally determined parameters where supporting information is required;

b) alternative information where options are permitted in BS EN 1999.

This Published Document is likely to be subject to amendment following harmonization of nationally determined parameters by CEN, when this process has been completed and the National Annexes withdrawn.

Presentational conventions

The provisions in this Published Document are presented in roman (i.e. upright) type. Its recommendations are expressed in sentences in which the principal auxiliary verb is "should".

Commentary, explanation and general informative material is presented in smaller italic type, and does not constitute a normative element.

Contractual and legal considerations

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

Compliance with a Published Document cannot confer immunity from legal obligations.

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1 Scope

This part of PD 6702 gives guidance on the use of the following parts of BS EN 1999, *Design of aluminium structures*:

- Part 1-1, *General structural rules*;
- Part 1-3, *Structures susceptible to fatigue*.

It is applicable to the same scope of application as BS EN 1999 unless otherwise stated.

The design information included in this document is applicable only when the recommendations in PD 6705-3 are followed for the execution of the structure.

NOTE This document covers those items identified in the UK National Annexes to BS EN 1999-1-1 and BS EN 1999-1-3 as requiring additional guidance. Further material, not necessarily identified in the relevant National Annex, is also given for information.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

BS 4395-1, *Specification for high strength friction grip bolts and associated nuts and washers for structural engineering – Part 1: General grade*

BS EN 1090-3, *Execution of steel structures and aluminium structures – Part 3: Technical requirements for aluminium structures*

BS EN 1990:2002+A1:2005, *Eurocode – Basis of structural design*

BS EN 1999-1-1:2007, *Eurocode 9: Design of aluminium structures – Part 1-1: General structural rules*

BS EN 1999-1-3:2007, *Eurocode 9: Design of aluminium structures – Part 1-3: Structures susceptible to fatigue*

PD 6705-3, *Structural use of steel and aluminium – Part 3: Recommendations for the execution of aluminium structures to BS EN 1090-3*

3 Terms and definitions

For the purposes of this part of PD 6702, the terms and definitions given in BS EN 1999-1-1 and BS EN 1999-1-3 and the following apply.

3.1 quantified service category
category that characterizes a component or structure (or part thereof), in terms of the circumstances of its use within specified limits of static and cyclic stressing

*NOTE See **4.1.1.2, 4.1.2, 4.1.4** and **4.1.5**.*

4 Recommendations for the use of BS EN 1999-1-1

4.1 Reliability differentiation [see BS EN 1999-1-1:2007, 2.1.2(3) and Annex A]

4.1.1 General principles

4.1.1.1 Reliability class

The quality of the work required by BS EN 1090-3 is specified on the basis that the values of partial factor γ_M required by BS EN 1999 provide a safe level of resistance commensurate with Reliability Class 2 (RC2) in BS EN 1990:2002+A1, Annex B. If the design circumstance justifies the use of a higher or lower degree of reliability, the measures specified in BS EN 1990 should be taken in order to make such an adjustment in the design. However, it should be noted that BS EN 1990 recommends that reliability differentiation is not achieved by the adjustment of γ_M (i.e. the quality of the work).

4.1.1.2 Service category

Different structural types and/or different parts of the same structure could be subjected to significant differences in static and/or cycle stressing. As the quality of the work necessary to provide a consistent value of γ_M across such a wide potential range of conditions can vary considerably, there would be a severe economic penalty if one quality level was specified which gave a safe degree of reliability for all the conditions permitted by BS EN 1999.

A major factor in the determination of the quality requirements is the degree of cyclic loading which the structural components need to resist. BS EN 1999-1-3 does not provide normative fatigue design data. However, recommended rules for such data are given in Clause **5** of this document. Furthermore, Clause **5** provides a quantitative method for differentiating the required quality level according to seven levels of service category (F12 through to F63). These are a refinement of the two service categories (SC1 and SC2) used in BS EN 1090-3, which are based on an unquantified differentiation between the static limits state rules in BS EN 1999-1-1 and the informative fatigue design data in BS EN 1999-1-3. The National Annex to BS EN 1999-1-3 does not recommend the latter for UK use.

A range of quantified service categories, designated F12, F20, F25, F31, F40, F50 and F63, is provided (see **4.1.4**) which enables a safe, but economical, quality level to be specified for the full range of conditions. The method of specifying the appropriate quantified service category on drawings is given in **4.1.5**.

NOTE This system has been adapted using the principles already applied in structural design and execution standards for metal structures, including ISO 10721-1 and ISO 10721-2.

4.1.1.3 Execution class

The execution class provides a means of varying the degree of assurance that the work meets the relevant quality requirements of BS EN 1090-3. The assurance is only provided by the documentation required under the contract.

4.1.2 Default service category and execution class

In order to simplify the administration of contracts where BS EN 1090-3 is specified, the choice of quantified service categories and execution classes has been selected so that the majority of structural aluminium generally falls into one category and class, namely:

- quantified service category F20;
- Execution Class 2 (EXC2).

These are the default category and class and are deemed to apply unless other categories or classes are specifically prescribed. It should be noted that it is an important design responsibility to specify any parts of the structure which need a service category of F25 or above.

Where EXC2 is selected, it is recommended that Design Supervision Level 2 (DSL2) or 3 (DSL3) of BS EN 1990 is employed for the design check and that Inspection Level 2 (IL2) of BS EN 1990 is employed for the inspection of the work (see BS EN 1990:2002+A1, Annex B).

4.1.3 Choice of execution class

4.1.3.1 Use of Execution Class 1 (EXC1)

EXC1 should only be used for simple constructions when the consequences of failure are low and the workmanship requirements are readily achievable.

It is essential that EXC1 is not used for structures with regular human occupancy or where structural failure would be likely to directly or indirectly result in human injury or death.

In assessing the economic consequences of failure, account should be taken of the likely number of constructions based on the same design which might be placed on the market.

As a guide to the construction features which might be suitable for EXC1, the restrictions given in Table 1 are recommended.

Table 1 **Restrictions on construction features for use with EXC1**

Feature	Recommended restrictions
Type of structure	Single storey buildings with span < 10 m carrying roof only, not cranes
	Masts, fences and similar structures < 5 m high
	Architectural features etc.
	Other minor structural works (e.g. screens, panelling, supports for lightweight services)
Quantified service category	F12 and F20 only
Type of product	Open section extrusions
	Sheeting
	Plate
	Simple single cell extrusions
Materials	3000, 5000 and 6000 series only
Joining methods	Non-preloaded bolts
	Proprietary fasteners (e.g. blind rivets)
	Shop fillet welding only (⩽ 15 mm thick parent metal only)

NOTE It is anticipated that EXC1 would be suitable for small workshops fabricating light weight simple forms of construction, where quality requirements are easily met by personnel with basic training and conditions require relatively limited assurance measures.

Where EXC1 is specified, it is essential that this is indicated in the project specification and/or on the drawings (see **4.1.5**).

4.1.3.2 Use of Execution Class 2 (EXC2)

It is anticipated that EXC2 (which is the default class, see **4.1.2**) would be appropriate for the majority of structural aluminium applications.

It is recommended that DSL2 or DSL3 and IL2 of BS EN 1990 are employed for this class (see **4.1.2**).

4.1.3.3 Use of Execution Class 3 (EXC3)

EXC3 is suitable for complex constructions where the consequences of failure are exceptionally high and workmanship requirements are particularly critical.

It is anticipated that the use of EXC3 would be limited to designs where unusual circumstances exist, which require a higher degree of assurance than usual. Typical examples are where:

- novel forms of construction are being used;
- conditions are close to, or beyond, the limits of previous experience;
- quality levels are generally expected to be difficult to achieve;
- the designer considers that the measures recommended in BS EN 1990:2002+A1, Annex B, are insufficient on their own to cover a case where a particularly high target reliability is necessary.

It is recommended that Design Supervision Level 3 (DSL3) and Inspection Level 3 (IL3) of BS EN 1990 are employed for this class.

4.1.3.4 Use of Execution Class 4 (EXC4)

The execution requirements for EXC4 in BS EN 1090-3 are identical to those for EXC3, apart from the use of lock nuts and certain differences in the degree of the welding co-ordinator's knowledge. It is recommended that EXC4 is only used in place of EXC3 where additional quality or assurance requirements outside the scope of BS EN 1090-3 are needed.

4.1.4 Determination of quantified service category

The quantified service category is dependent on the orientation and intensity of the static and cyclic stressing at a cross-section of a member or in a joint. The stresses used to calculate the quantified service category should be determined using the design methods specified in the relevant part of BS EN 1999. The quantified service categories are defined in Table 2.

The procedure for determining the appropriate quantified service categories in the structure is as follows.

a) If no fatigue check is required, it should be assumed that F20 applies throughout.

b) If a fatigue check is required, a detail category of 20-3,2 should be ascribed to all details. A fatigue check to BS EN 1999-1-3 and this document should be carried out using that detail category and nominal (or modified nominal, where relevant) stress ranges. If all parts pass this check, F20 applies to the whole structure and no further action is required.

c) If any details fail the check in b), the check on the failed details should be repeated assuming a detail category of 25-3,2 applies to them. If they pass this check, these details should be identified as F25 (see **4.1.5**).

d) If any parts fail the check in c), the procedure should be repeated using assumed detail categories 31-3,2, 40-3,2 etc., as necessary until all parts pass.

Table 2 **Performance criteria for designation of quantified service category**

Level of service stresses		**Quantified service category designation**	**Static utilization factor U** [A]		**Minimum required value of reference fatigue strength $\Delta\sigma_C$** [B] N/mm^2
Static	**Fatigue**				
Reduced	Very low	F12	Tension	$U \leqslant 0,6$	$\Delta\sigma_C \leqslant 12$
			Shear	$U \leqslant 0,8$	$\Delta\sigma_C \leqslant 12$
			Compression	$U \leqslant 0,8$	$\Delta\sigma_C \leqslant 12$
Full	Low	F20		$U \leqslant 1,0$	$\Delta\sigma_C \leqslant 20$
Full	Significant	F25		$U \leqslant 1,0$	$20 < \Delta\sigma_C \leqslant 25$
		F31		$U \leqslant 1,0$	$25 < \Delta\sigma_C \leqslant 31$
		F40		$U \leqslant 1,0$	$31 < \Delta\sigma_C \leqslant 40$
		F50		$U \leqslant 1,0$	$40 < \Delta\sigma_C \leqslant 50$
		F63		$U \leqslant 1,0$	$50 < \Delta\sigma_C \leqslant 63$

[A] The static utilization factor, U, is the ratio of the ultimate limit state (ULS) design action on the member cross-section or joint divided by its design resistance. Where the resistance depends on an interaction formula for more than one stress mode, the U value is equal to the interaction formula sum divided by the permissible limit. This applies to all static failure modes at the joint or member in question.

[B] The minimum required value of $\Delta\sigma_C$ is the lowest value for which the damage $D_L \leqslant 1$ for safe life design (see **4.1.4**). The fatigue service category depends on the direction of stress fluctuation.

4.1.5 Designation of quantified service category on drawings

4.1.5.1 General

Where no quantified service category is designated on a drawing, F20 should be deemed to apply to all work described on that drawing.

Where a service category is designated for a joint or member, it should apply to the full extent of the joint or member, unless otherwise noted.

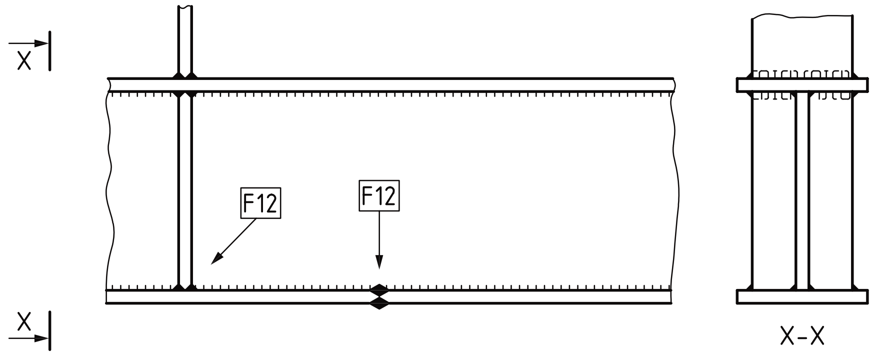
4.1.5.2 Quantified service category F12 (reduced static)

Where the reduced static service category (i.e. F12) applies to all structural items on a drawing, it should be stated in a general note.

NOTE The use of F12 as a general category is unlikely to apply except in designs where consideration of stiffness/deflection, as opposed to strength, is an overriding factor throughout the design.

Where this service category applies to selected parts of a structure, each joint concerned should be identified individually as shown in Figure 1.

Figure 1 **Method of designation of quantified service category F12 on drawings**



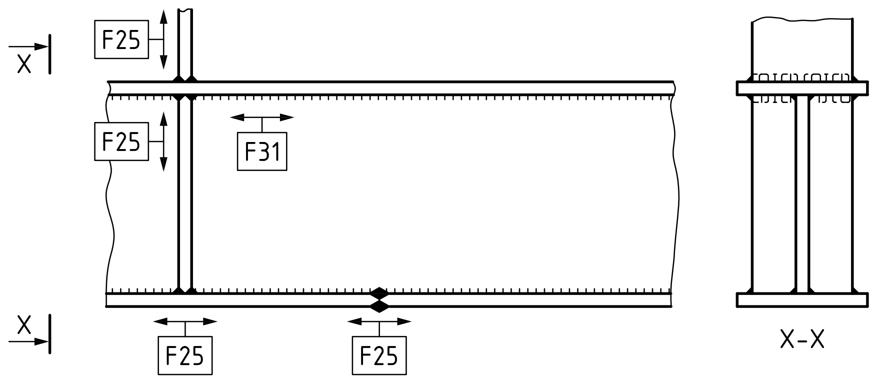
4.1.5.3 Quantified service categories F25 and above (significant fatigue)

The quantified service categories should be designated on all joints where the default quantified service category F20 is inadequate (see Table 2). The method of designation should show the direction of stress fluctuation and the quantified service category as shown in Figure 2.

The use of a general note covering all items on a drawing, based on the joint with the highest service category, should be avoided, as this is likely to result in unnecessary inspection and repair. However, if a significant number of details in a distinct part of a structure require a quantified service category of F25 (or even F31), it might be justifiable to designate that category for the entire part by means of a general note.

NOTE There might be applications where more than one fatigue service category is required for an individual joint, depending on the directions of stressing. If so, the service category needs to be indicated for each direction.

Figure 2 **Method of designation of quantified service categories F25 and above on drawings** A)



A) Double-headed arrows denote direction of stress fluctuation; quantified service categories are examples only.

4.2 Use of other wrought alloys [see BS EN 1999-1-1:2007, 3.2.1(1)]

To enable the use of materials held in stock which were produced prior to the adoption of European material standards, it is permitted to use the aluminium alloys listed in Table 3 and Table 4. The use of these alloys should be approved by the designer and the values for minimum 0,2% tensile proof stress and minimum tensile strength given in the tables should be applied, when calculating the design resistance of the relevant material. The values in BS EN 1999-1-1:2007, Table 3.2a, Table 3.2b and Table 3.2c, should not be used in such circumstances.

NOTE 1 Table 3 and Table 4 are based on BS 8118-1:1991+A1, Table 2.1 and Table 2.2, and refer to British Standards that have now been superseded and withdrawn.

NOTE 2 The information in these tables might also be useful when assessing existing structures conforming to BS EN 1999.

Table 3 **Mechanical properties of original British Standard heat-treatable alloys**

Alloy	**Condition**	**Product**	**Thickness range** > mm	**Thickness range** ⩽ mm	**Minimum 0,2% tensile proof stress** (see Note) N/mm²	**Minimum tensile strength** (see Note) N/mm²	**Elongation** (see Note) $5,65\sqrt{S_o}$ %	**Elongation** (see Note) **50 mm** %	**Related British Standard**
6061	T6	Extrusions A)	—	150	240	280	8	7	BS 1474
		Drawn tube	—	6,0	240	295	7 B)	7 B)	BS 1471
			6,0	10	255	295	9 B)	9 B)	
6063	T4	Extrusions	—	150	70	130	16	14	BS 1474
		Drawn tube	—	10	100	155	15 B)	15 B)	BS 1471
		Forgings	—	150	85	140	16	—	BS 1472
	T5	Extrusions	—	25	110	150	8	7	BS 1474
	T6	Extrusions	—	150	160	185	8	7	BS 1474
		Drawn tube	—	10	180	200	8 B)	8 B)	BS 1471
		Forgings	—	150	160	185	10	—	BS 1472
6082	T4	Extrusions	—	150	120	190	16	14	BS 1474
		Sheet	0,2	3,0	120	200	—	15	BS 1470
		Pile	3,0	25	115	200	12	15	BS 1470
		Drawn tube	—	6,0	115	215	12 B)	12 B)	BS 1471
			6,0	10	115	215	14 B)	14 B)	
		Forgings	—	150	120	185	16	—	BS 1472
	T6	Extrusions	—	20	255	295	8	7	BS 1474
			20	150	270	310	8	—	
		Sheet	0,2	3,0	255	295	—	8	BS 1474
		Plate	3,0	25	240	295	8	8	BS 1470
		Drawn tube	—	6,0	255	310	7 B)	7 B)	BS 1471
			6,0	10	240	310	9 B)	9 B)	
		Forgings	—	120	255	295	8	—	BS 1472

Table 3 **Mechanical properties of original British Standard heat-treatable alloys** *(continued)*

Alloy	Condition	Product	Thickness range > mm	Thickness range ⩽ mm	Minimum 0,2% tensile proof stress (see Note) N/mm^2	Minimum tensile strength (see Note) N/mm^2	Elongation (see Note) $5,65\sqrt{S_o}$ %	Elongation (see Note) 50 mm %	Related British Standard
7020	T4	Extrusions	—	25	190	300	10	12	BS 4300/15
		Sheet and plate		25	170	280	10	12	BS 4300/14
	T6	Extrusions	—	25	280	340	8	10	BS 4300/15
		Sheet and plate		25	270	320	8	10	BS 4300/14
LM25	TB7	Sand cast	—	—	80 to 110	160 C)	2,5	—	BS 1490
		Chill cast	—	—	90 to 110	230 C)	5	—	
	TF	Sand cast	—	—	200 to 250	230 C)	—	—	
		Chill cast	—	—	220 to 260	280 C)	2	—	

A) Extrusion refers to bars, extruded round tubes and sections.

B) Elongation on $5,65\sqrt{S_o}$ for tubes with wall thickness of 3 mm and thinner, and on 50 mm for tubes with thicker walls.

C) Minimum value specified in BS 1490.

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

Table 4 **Mechanical properties of original British Standard non-heat-treatable alloys**

Alloy	Condition	Product	Thickness range > mm	Thickness range ⩽ mm	Minimum 0,2% tensile proof stress (see Note) N/mm^2	Minimum tensile strength (see Note) N/mm^2	Elongation (see Note) $5,65\sqrt{S_o}$ %	Elongation (see Note) 50 mm %	Related British Standard
1200	H14	Sheet	0,2	12,5	115 A)	105	—	3 to 6	BS 1470
3103	H14	Sheet	0,2	12,5	140 A)	140	—	3 to 7	BS 1470
	H18	Sheet	0,2	3	185 A)	175	—	2 to 4	
3105	H14	Sheet	0,2	3	145	160	—	2 to 4	BS 1470
	H16	Sheet	0,2	3	170	185	—	1 to 3	
	H18	Sheet	0,2	3	190	215	—	1 to 2	
5083	O	Extrusions B)	—	150	125	275	14	13	BS 1474
		Sheet and plate	0,2	80	125	275	14	12 to 16	BS 1470
		Drawn tube	—	10	125	275	12 C)	12 C)	BS 1471
	F	Extrusions	—	150	130 A)	280 A)	12 A)	11 A)	BS 1474
		Sheet and plate	3	25	175 A)	320 A)	—	18 A)	BS 1470
		Forgings	—	150	130	280	12	—	BS 1472
	H22	Sheet and plate	0,2	6	235	310	—	5 to 10	BS 1470
		Drawn tube	—	10	235	310	5 C)	5 C)	BS 1471

Table 4 **Mechanical properties of original British Standard non-heat-treatable alloys** *(continued)*

Alloy	Condition	Product	Thickness range > mm	Thickness range ⩽ mm	Minimum 0,2% tensile proof stress (see Note) N/mm²	Minimum tensile strength (see Note) N/mm²	Elongation (see Note) $5,65\sqrt{S_o}$ %	Elongation (see Note) 50 mm %	Related British Standard
5154A	O	Extrusions	—	150	85	215	18	16	BS 1474
		Sheet and plate	0,2	6	85	215	—	12 to 18	BS 1470
		Drawn tube	—	10	85	215	16 C)	16 C)	BS 1471
	F	Extrusions	—	150	100 A)	215 A)	16 A)	14 A)	BS 1474
		Forgings	—	150	100	215	16	—	BS 1472
	H22	Sheet and plate	0,2	6	165	245	—	5 to 8	BS 1470
	H24	Sheet and plate	0,2	6	225	275	—	4 to 6	BS 1470
		Drawn tube	—	10	200	245	4 C)	3 to 5	BS 1471
5251	F	Seam welded tube	0,8	1,0	220	245	—	3	BS 4300/1
			1,2	2,0	220	245	—	5	
		Forgings	—	150	60	170	16	—	BS 1472
	H22	Sheet and plate	0,2	6	130	200	—	4 to 8	BS 1470
	H24	Sheet and plate	0,2	6	175	225	—	3 to 5	
5454	O	Extrusions	—	150	85	215	18	16	BS 4300/12
		Sheet and plate	0,2	6	80	215	—	12 to 18	BS 1470
	F	Extrusions	—	150	100	215	16	14	BS 4300/12
	H22	Sheet	0,2	3	180	250	—	4 to 8	BS 1470
	H24	Sheet	0,2	3	200	270	—	3 to 6	
LM5	F	Sand cast	—	—	90 to 110	140 D)	3	—	BS 1490
		Chill cast	—	—	90 to 120	170 D)	5	—	
LM6	F	Sand cast	—	—	60 to 70	160 D)	5	—	BS 1490
		Chill cast	—	—	70 to 80	190 D)	7	—	

A) Typical values.

B) Extrusion refers to bars, extruded round tubes and sections.

C) Elongation on $5,65\sqrt{S_o}$ for tubes with wall thickness of 3 mm and thinner, and on 50 mm for tubes with thicker walls.

D) Minimum value specified in BS 1490.

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

4.3 Application of electrical welded tubes [see BS EN 1999-1-1:2007, 3.2.2(1)]

The tube can conservatively be treated as having a longitudinal weld laid with the MIG (metal inert gas) process for its full length, and with buckling class B when using BS EN 1999-1-1:2007, **6.1.4.4**, **6.1.5**, and **6.3.1**.

4.4 Mechanical fasteners [see BS EN 1999-1-1:2007, 3.3.2.2(1)]

To enable the use of (HSFG) bolts held in stock which were produced prior to the adoption of European material standards, it is permitted to use general grade HSFG bolts listed in BS 4395-1. The use of these bolts should be approved by the designer and the relevant values for preload should be applied rather than the standard values given in BS EN 1090-2 and BS EN 1090-3.

4.5 Plastic redistribution [see BS EN 1999-1-1:2007, 7.1(4)]

Member capacities are generally based on ultimate limit states. Certain members might experience permanent strains from serviceability loadings if designed to maximum utilization at the ULS. This is particularly pertinent to members subjected to combined axial and bending loads where the plastic capacity of the member makes allowances for redistribution of stresses within the member. For certain alloys and section geometries, the stresses at edges of flanges or outer corners of sections might exceed proof stress at serviceability loads. It is recommended that extreme fibre stresses are checked at serviceability loads for all members subject to combined axial and bending effects. Where these exceed the proof stress, the effect on deflections and, where relevant, permanent deformations should be taken into account.

4.6 Serviceability limits for deflections in buildings – vertical and horizontal deflections [see BS EN 1999-1-1:2007, 7.2.1(1) and 7.2.2(1)]

Recommended limiting values for members in buildings are given in Table 5.

4.7 Serviceability limits for vibrations in buildings (see BS EN 1999-1-1:2007, 7.2.3)

The National Annex to BS EN 1995, which covers the design of timber structures, gives limiting values for residential floors. In the absence other guidance, these values may also be used for aluminium structures.

If vibration is thought to be a potential problem, the possibility of fatigue failure should also be considered.

Table 5 **Limiting deflections**

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

4.8 Other joining methods (see BS EN 1999-1-1:2007, 8.9)

4.8.1 Power beam welding processes

4.8.1.1 General

Many wrought aluminium alloys have been successfully welded using laser and electron beam processes for commercial applications. Their main advantages over the more widely used MIG and TIG (tungsten inert gas) processes are as follows:

a) higher welding speed and productivity;

b) lower distortion and more accurate dimensional control;

c) potentially more freedom from welding imperfections;

d) no consumables are required.

Laser and electron beam welding are fully mechanized processes which require greater capital outlay and are therefore most suited to mass production of similar components. They require accurate jigging and close fit-up tolerances. It is noted that welding needs to be carried out in protective enclosures.

Laser and electron beam welding processes can be used to produce butt welds in in-line, tee and corner joints. The narrow beam can also be used to produce "stake" welds, whereby tee joints are welded from the side opposite to that containing the joint. Conventional fillet welds cannot be produced.

The mechanical properties of joints are comparable with those produced by MIG welding.

Absence of a consumable results in minimal overfill, which can be readily ground or machined off, resulting in in-line butt welds with fatigue strength comparable to those of MIG-welded joints.

4.8.1.2 Laser beam welding

Laser beam welding is generally used for sheet, plate or extrusions up to approximately 6 mm thick. Speeds of several metres per minute are possible depending on the power and type of laser beam used. The welding heads can be gantry-mounted, an option which is most suitable for large built-up members or stiffened panels. For smaller, more complex geometries, an articulated robot arm employing fibre-optic delivery of this laser beam can be used.

For many laser beam welding applications, a filler wire consumable is necessary and this can be applied as cold wire or via the hybrid laser-arc welding process. The latter process is better able to accommodate variations in fit-up.

Joint faces are machined or laser cut prior to assembly, except where as-rolled or as-extruded.

Welding needs to be carried out in an enclosure, constructed to prevent the laser beam contacting personnel.

NOTE Some guidance on joint detailing and weldability of aluminium alloys by this process is given in BS EN 1011-6.

4.8.1.3 Electron beam welding

Electron beam welding is capable of welding aluminium alloys from less than 1 mm up to 200 mm thick in a single pass. It can be carried out in either a fully enclosed chamber with a high internal vacuum or a local chamber with a seal which moves along the joint and maintains a reduced pressure of helium background gas not exceeding 1 mbar.

Joint faces need to be machined and maintained in close contact during welding.

The chamber and seals need to be resistant to X-radiation.

NOTE Some guidance on joint detailing and weldability of aluminium alloys by this process is given in BS EN 1011-7.

4.8.2 Friction welding processes

4.8.2.1 General

In friction welding, the weld is solid state and the process does not involve fusion. The work piece metal is softened by frictional heat to a point where it becomes plastic. Relative movement of the parts then breaks up oxide layers and provides a sound metallic bond, resulting in joints with mechanical properties which can be as good as (and, in some cases, superior to) those of fusion welds. Absence of fusion eliminates the risk of imperfections, such as cracks, segregation and porosity. This commonly results in fatigue strengths well in excess of those for MIG-welded joints.

It is also possible to friction weld aluminium alloys to other metals, including ferritic and austenitic steels.

Conventional friction welding requires purpose-made machines which hold one side of the joint stationary whilst moving the other side relative to the first side and exerting a pressure between the two. This method is limited to joints of circular (for rotary friction welding) or rectangular (for linear friction welding) cross-section with dimensions not generally exceeding about 0.3 metres.

An important development in this field is the friction stir welding process which holds both parts of the joint together without motion (see **4.8.2.2**).

All friction welding processes share the same advantages, i.e. higher speed, lower distortion, fewer imperfections and no consumables, as for power beam welding (see **4.8.1**).

4.8.2.2 Friction stir welding

This process involves rotating a purpose-made tool which is plunged into and moved along a stationary joint line (which may be straight or curved). The action of the tool is to produce frictional heat which plasticizes the metal on both sides of the joint line to such an extent that it is spun in a vortex around the tool. The tool has a shoulder which retains the plasticized metal within the joint boundary, thus preventing voids in the wake of the tool as it traverses along the joint.

The process is fully mechanized and purpose-made machines are available for assembling large panels or members out of aluminium extrusions and/or plates. The machine bed size is potentially unlimited; 30 m long beds exist. Welding fixtures and supports should be stiff and strong enough to hold the parts in contact and react the tool forces.

Full penetration butt welds have been made in aluminium alloys up to 75 mm thick using one pass per side. Full penetration single sided butt welds up to 40 mm thick can be produced with sound roots in a single pass. Partial penetration butt welds and lap joints can also be produced, but not conventional fillet welds.

NOTE Guidance on terminology and joint detail design for friction stir welds in aluminium is given in BS EN ISO 25239-1 [1] *and BS EN ISO 25239-2* [1].

4.8.3 Design data

The use of the processes described in **4.8.1** and **4.8.2**, although increasing, is limited compared to MIG welding. As such, there is not yet a complete system of standards for design and execution, as exists for MIG-welded joints, covering mechanical properties for welds in all main alloys and tempers included in BS EN 1999, together with comprehensive welding and quality control standards.

If the potential advantages of these processes are to be explored at the conceptual design stage, it is recommended that organizations with the relevant expertise and equipment are consulted regarding their production capability and current experience. This consultation should include dimensional limits, alloys welded, quality standards and mechanical test data. In critical or high cost applications, it is recommended that relevant procedural trials are conducted to establish the level of quality which can be reliably achieved, where such data do not already exist.

NOTE Guidance on quality control for execution is given in PD 6705-3.

1) In preparation; due for publication in 2010.

4.9 Use of castings [see BS EN 1999-1-1:2007, 3.2.3(1), C.3.4.2(2), C.3.4.2(3) and C.3.4.2(4)]

4.9.1 Quality

The guidance given in PD 6705-3 should be followed.

4.9.2 γ_M factors

The values given in BS EN 1999-1-1:2007, **C.3.4.2**(2), **C.3.4.2**(3) and **C.3.4.2**(4), should be used.

5 Recommendations for the use of BS EN 1999-1-3

5.1 Use of damage tolerant design [see BS EN 1999-1-3:2007, 2.1(1) and A.3.1(1)]

Design should be based on safe life principles. However, there might be certain applications where achievement of minimum weight is a high priority and where a regime of routine removal from service for other maintenance or inspection reasons is already established. In these cases, the use of a damage tolerant approach might be justified.

It is essential before taking a decision on such a course of action to confirm that:

a) there are practical methods of repair or equipment replacement in the event that fatigue damage is detected;

b) the whole life costing of the design makes adequate allowance for loss of service, provision of access for inspection and the repair or replacement of the components at risk. The fact that, once repaired, the frequency of future repairs might increase should also be taken into account;

c) the future owner/maintaining authority has been made fully aware of the financial and operational commitments in item b) and has given the necessary approval.

5.2 Fatigue damage value [see BS EN 1999-1-3:2007, 2.2.1(3]

The use of D_{Lim} = 1,0 has been in widespread for many years. However, recent research has indicated that values less than unity can occur with certain stress histories. It is normal practice to assume that these uncertainties are covered by the existing margins of safety on resistance and loading.

In critical cases, and where there are a very high number of low stress cycles, it is recommended that the uncertainty in D_{Lim} is catered for by neglecting the cut-off limit and continuing the m_2 curve beyond 10^8 cycles (see BS EN 1999-1-3:2007, Figure 6).

5.3 Derivation of fatigue loading [see BS EN 1999-1-3:2007, 2.3.1(3)]

The guidance in BS EN 1999-1-3:2007, **C.2**, is recommended where no fatigue loading data exists.

5.4 Fatigue load factors [see BS EN 1999-1-3:2007, 2.3.2(6) and 2.4(1)]

In applications where Consequence Class 3 (CC3) is deemed to apply and Reliability Class 3 is selected, in accordance with BS EN 1990:2002+A1, Annex B, it is recommended that the amplitude of the factored fatigue loads are multiplied by factor K_{FI} = 1,1 as given in the same annex.

5.5 Fatigue strength data for low strength alloys [see BS EN 1999-1-3:2007, Clause 3(1)]

The data given in **5.8** for welded joints can be assumed to be applicable to the alloys and tempers listed as exceptions in BS EN 1999-1-3:2007, Clause **3**(1).

5.6 Effect of aggressive exposure [see BS EN 1999-1-3:2007, 4(2)]

Reference should be made to **5.13** regarding adhesive joints.

5.7 Damage equivalent factors [see BS EN 1999-1-3:2007, 5.8.2(1)]

Values of λ_i given in other Eurocodes might not be applicable for use with aluminium structures where they could have been based on different slopes of fatigue strength curve (m values) than recommended in this document. Where the fatigue check using such λ_i values shows D_{Lim} values in excess of 0,3, it is recommended that the details are checked using the actual load spectrum, rather than a single equivalent load.

5.8 Detail categories based on nominal stress [see BS EN 1999-1-3:2007, 6.1.3(1), 6.2.1(2) and 6.2.1(7)]

The following tables and figures give recommended detail categories and fatigue strength curves for use with nominal stresses, in lieu of BS EN 1999-1-3:2007, Annex J:

- plain material: Table 6, Table 7 and Figure 4;
- welded attachments (transverse weld toe): Table 8, Table 9 and Figure 5;
- welded attachments (longitudinal welds): Table 10, Table 11 and Figure 6;
- welded joints between members: Table 12, Table 13 and Figure 7;
- mechanically fastened joints: Table 14, Table 15 and Figure 8.

NOTE These tables and figures appear at the end of this document.

These fatigue strength curves are based on axial (membrane) stress ranges. Where bending stress components are present the fatigue strength values for certain detail types should be adjusted (see **5.10**).

In instances where two adjacent fatigue strength curves cross each other, the lower values of $\Delta\sigma$ should be used for endurances less than that at the crossing point.

5.9 Low stress cycles [see BS EN 1999-1-3:2007, 6.2.7(1) and Annex F]

The data in BS EN 1999-1-3:2007, Annex F, are related to the detail categories given in BS EN 1999-1-3:2007, Annex J, and are therefore not recommended (see **5.8**).

5.10 Effect of stress range gradient [see BS EN 1999-1-3:2007, 6.2.1(11)]

Where members containing transverse weld toe initiation sites are subject to stress gradients through their thickness, the value of the reference fatigue strength $\Delta\sigma_C$ obtained from **5.8** should be factored by k_b, where k_b is given by the following equations for the cases shown in Table 16:

Case 1: $k_b = 1 + \left\{\frac{0,7}{t^{0,2}} + 0,5\log_{10}\left(\frac{L}{t}\right)\right\}\left\{\frac{\Delta\sigma_b}{\Delta\sigma}\right\}^{1,4}$, but

$k_b \geqslant 1$ governs

Case 2: $k_b = \left[1 + \left\{\frac{0,7}{t^{0,2}} + 0,5\log_{10}\left(\frac{L}{t}\right)\right\}\left\{\frac{\Delta\sigma_b}{\Delta\sigma}\right\}^{1,4}\right]^{-1}$, but

$0 < k_b \leqslant 1$ governs

Case 3: See Case 1

Case 4: $k_b = 1 + \frac{0,7}{t^{0,2}} + 0,5\log_{10}\left(\frac{L}{t}\right)$, but

$k_b \geqslant 1$ governs (pure bending)

Case 5: $k_b = 1$ (pure axial)

where:

$\Delta\sigma_b$ is the bending stress range component of the nominal stress range. The absolute value (i.e. always positive) should be used;

$\Delta\sigma$ is the nominal stress range as defined in BS EN 1999-1-3. The absolute value (i.e. always positive) should be used;

L is the attachment length between weld toes in the stress direction in millimetres;

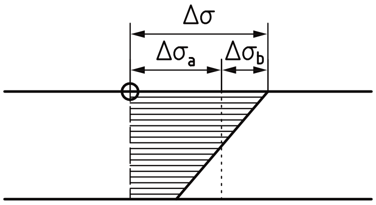
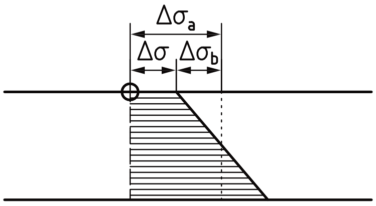
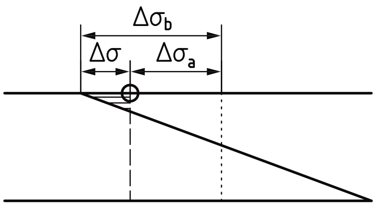
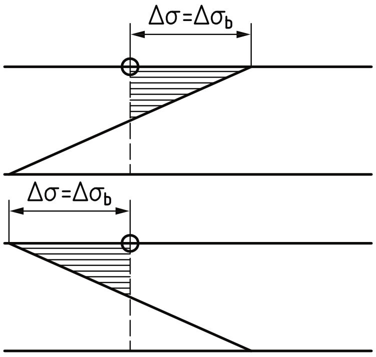
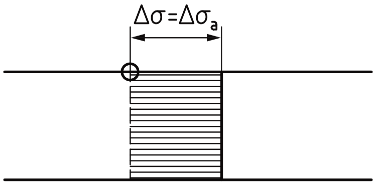
t is the thickness of the element over which the bending stress range is applied in millimetres.

For geometries where $L/t > 2$, the value of $L/t = 2$ should be used in these equations.

Values of k_b for selected values of t, L and $\Delta\sigma_b/\Delta\sigma$ derived from these equations are given in Table 17 and Table 18.

NOTE The equations given in this subclause have been derived using crack growth calculations based on the principles given in BS 7910. This included a parametric study comparing endurances obtained for pure axial stress ranges with those obtained for different ratios of axial and bending stress ranges, each for the same specific values of t and L. The equations were derived to give the best fit to the resulting adjustments to axial fatigue strength covering Case 1, Case 4, Case 5 and part of Case 2. The maximum deviation between the data points and the equation values was within ±5%. Values of $\Delta\sigma_b/\Delta\sigma$ for Case 3 and part of Case 2 which are outside the range of the calculated data points are indicated in Tables 17 and 18 as *showing indicative values of k_b. As they are obtained from extrapolations of the best fit equations, they are subject to a wider degree of uncertainty, but can be used as a guide to the expected trend in this region. Whilst there are very few comparative experimental test data relating to this subject, the limited data covering Case 4 tend to support the k_b values shown.*

Table 16 **Gradient adjustment factor, k_b (Case 1 to Case 5)**

Case no.	Stress range pattern	Bending range component $\Delta\sigma_b$		Gradient through thickness	Value of k_b
		Contribution to $\Delta\sigma$	Magnitude		
1		Adds to $\Delta\sigma_a$	No limit	Decreasing	>1
2		Subtracts from $\Delta\sigma_a$	$<\Delta\sigma_a$	Increasing	<1
3		Subtracts from $\Delta\sigma_a$	$>\Delta\sigma_a$	Decreasing	>1
4		Total ($\Delta\sigma_a = 0$)	No limit	Decreasing	>1
5		None ($\Delta\sigma_b = 0$)	Zero	Constant	1

Key

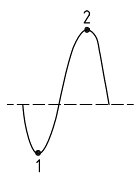
⊕ Initiation site

_ _ _ _ Axial stress gradient at turning point 1

.... Axial stress gradient at turning point 2

——— Total stress gradient at turning point 2 taking into account bending stress range change between 1 and 2

$\Delta\sigma_a$ Axial component of stress range



NOTE The stress change patterns shown are independent of the mean stress pattern and are applicable for both tensile and compressive changes of stress.

Attention is drawn to the extreme increasing and decreasing gradients in Case 2 and Case 3 respectively in Table 16. When the values of $\Delta\sigma_b$ and the axial component $\Delta\sigma_a$ are similar, but of opposite effect, the value of $\Delta\sigma$ is small. The relative accuracies of the value of $\Delta\sigma$, and consequently the value of k_b, will therefore be low when using normal structural analytical models. However, this is not critical in most designs as the value of $\Delta\sigma$ on the opposite surface is likely to be significantly higher and to govern fatigue design at this detail.

The detail type numbers where this factor is applicable are indicated in Table 8 and Table 12. Table 12 also shows that k_b is applicable to detail types **5.3**, **5.4** and **5.5** (root initiation sites). For these details, the effective value of *L* should be taken as equal to the value to *t*.

Table 17 **Values of k_b for Case 1, Case 3, Case 4 and Case 5**

Thickness mm	Length mm	k_b							
		$\Delta\sigma_b/\Delta\sigma$ = 0,00	$\Delta\sigma_b/\Delta\sigma$ = 0,20	$\Delta\sigma_b/\Delta\sigma$ = 0,40	$\Delta\sigma_b/\Delta\sigma$ = 0,60	$\Delta\sigma_b/\Delta\sigma$ = 0,80	$\Delta\sigma_b/\Delta\sigma$ = 1,00	$\Delta\sigma_b/\Delta\sigma$ = 1,50 [A)]	$\Delta\sigma_b/\Delta\sigma$ = 2,00 [A)]
		Case 5	**Case 1**				**Case 4**	**Case 3**	
5	2	1,00	1,03	1,09	1,15	1,23	1,31	1,54	1,81
	5	1,00	1,05	1,14	1,25	1,37	1,51	1,90	2,34
	10+	1,00	1,07	1,18	1,32	1,48	1,66	2,16	2,74
10	2	1,00	1,01	1,03	1,05	1,07	1,09	1,16	1,24
	5	1,00	1,03	1,08	1,14	1,21	1,29	1,51	1,77
	10	1,00	1,05	1,12	1,22	1,32	1,44	1,78	2,17
	20+	1,00	1,06	1,16	1,29	1,43	1,59	2,04	2,56
20	5	1,00	1,01	1,02	1,04	1,06	1,08	1,15	1,22
	10	1,00	1,02	1,06	1,11	1,17	1,23	1,41	1,62
	20	1,00	1,04	1,11	1,19	1,28	1,38	1,68	2,01
	40+	1,00	1,05	1,15	1,26	1,39	1,54	1,94	2,41
50	5	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00
	10	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00
	20	1,00	1,01	1,03	1,06	1,09	1,12	1,21	1,32
	50	1,00	1,03	1,09	1,16	1,23	1,32	1,56	1,84
	100+	1,00	1,05	1,13	1,23	1,34	1,47	1,83	2,24
100	5	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00
	10	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00
	20	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00
	50	1,00	1,01	1,04	1,06	1,09	1,13	1,23	1,34
	100	1,00	1,03	1,08	1,14	1,20	1,28	1,49	1,74
	200+	1,00	1,05	1,12	1,21	1,31	1,43	1,76	2,13

A) Indicative values of k_b (see **5.10**, Note).

Table 18 **Values of k_b for Case 2 and Case 5**

Thickness mm	Length mm	k_b							
		$\Delta\sigma_b/\Delta\sigma$ = 0,00	$\Delta\sigma_b/\Delta\sigma$ = 0,20	$\Delta\sigma_b/\Delta\sigma$ = 0,40	$\Delta\sigma_b/\Delta\sigma$ = 0,60 [A)]	$\Delta\sigma_b/\Delta\sigma$ = 0,80 [A)]	$\Delta\sigma_b/\Delta\sigma$ = 1,00 [A)]	$\Delta\sigma_b/\Delta\sigma$ = 1,50 [A)]	$\Delta\sigma_b/\Delta\sigma$ = 2,00 [A)]
		Case 5	**Case 2**						
5	2	1,00	0,97	0,92	0,87	0,82	0,76	0,65	0,55
	5	1,00	0,95	0,88	0,80	0,73	0,66	0,53	0,43
	10+	1,00	0,94	0,85	0,76	0,68	0,60	0,46	0,37
10	2	1,00	0,99	0,98	0,96	0,94	0,92	0,86	0,80
	5	1,00	0,97	0,93	0,88	0,82	0,77	0,66	0,57
	10	1,00	0,96	0,89	0,82	0,76	0,69	0,56	0,46
	20+	1,00	0,94	0,86	0,78	0,70	0,63	0,49	0,39
20	5	1,00	0,99	0,98	0,96	0,94	0,92	0,87	0,82
	10	1,00	0,98	0,94	0,90	0,85	0,81	0,71	0,62
	20	1,00	0,96	0,90	0,84	0,78	0,72	0,60	0,50
	40+	1,00	0,95	0,87	0,79	0,72	0,65	0,51	0,41
50	5	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00
	10	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00
	20	1,00	0,99	0,97	0,94	0,92	0,89	0,82	0,76
	50	1,00	0,97	0,92	0,86	0,81	0,76	0,64	0,54
	100+	1,00	0,95	0,88	0,81	0,74	0,68	0,55	0,45
100	5	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00
	10	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00
	20	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00
	50	1,00	0,99	0,97	0,94	0,91	0,89	0,82	0,75
	100	1,00	0,97	0,93	0,88	0,83	0,78	0,67	0,58
	200+	1,00	0,96	0,89	0,83	0,76	0,70	0,57	0,47

[A)] Indicative values of k_b (see **5.10**, Note).

5.11 Hot spot strength method [see BS EN 1999-1-3:2007, 6.2.4(1)]

5.11.1 Suitable applications

The hot spot strength method is recommended in lieu of the reference detail method given in BS EN 1999-1-3:2007, Annex K.

The hot spot strength method is used primarily for joints in which the weld toe orientation is transverse to the fluctuating stress component, and the crack is assumed to grow from the weld toe. The approach is not suitable for joints in which the crack would grow from embedded flaws or from the root of a fillet weld. Compared with the nominal stress approach, this approach is more suitable for use in the cases where:

a) there is no clearly defined nominal stress due to complicated geometric effects;

b) the structural discontinuity is not comparable with any classified details included in the design rules (nominal stress approach);

c) for the reasons given in items a) and b), the finite element method is in use with shell and/or solid element modelling;

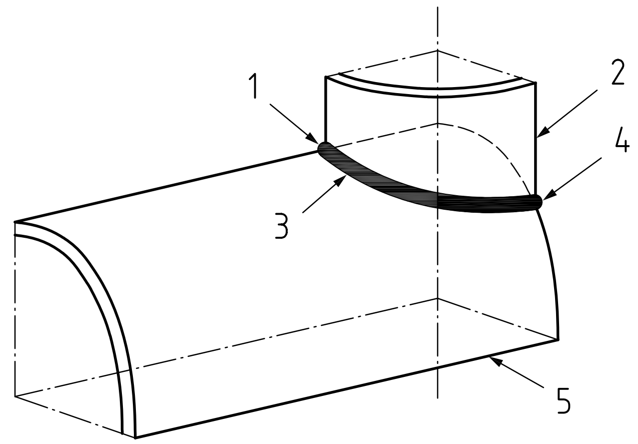
d) testing of prototype structures is performed using strain gauge measurements;

e) the offset or angular misalignments exceed any fabrication tolerances specified as being consistent with the design fatigue strength curves used in the nominal stress approach.

5.11.2 Definition of hot spot stress

Hot spot stress is defined as the greatest value of the direct stress around the joint, where the geometric stress on the surface of the member is extrapolated to the weld toe. This hot spot stress incorporates the effects of overall geometry, i.e. the relative sizes and shapes of the members, but omits the stress concentrating influence of the superimposed local stress at the toe, caused by the weld profile itself (see Figure 3).

Figure 3 **Example of hot spot stresses in a tubular lattice joint**

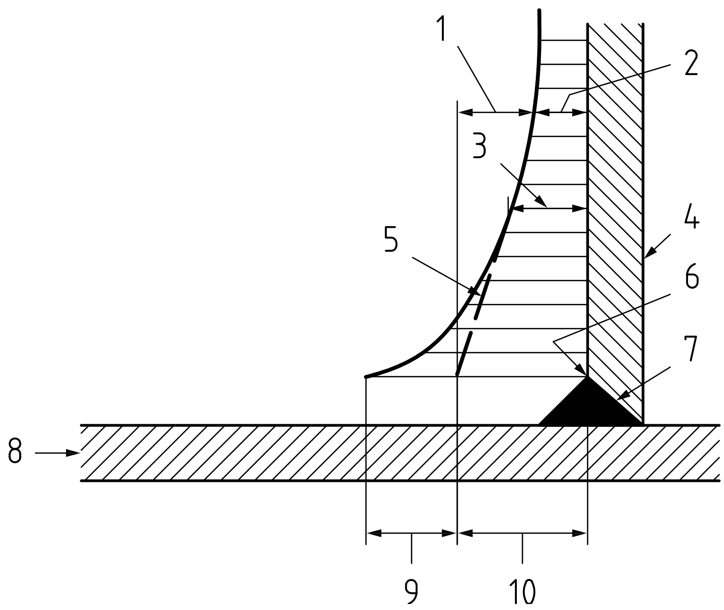


a) Nodal joint nomenclature

The load is applied in the brace.

Key

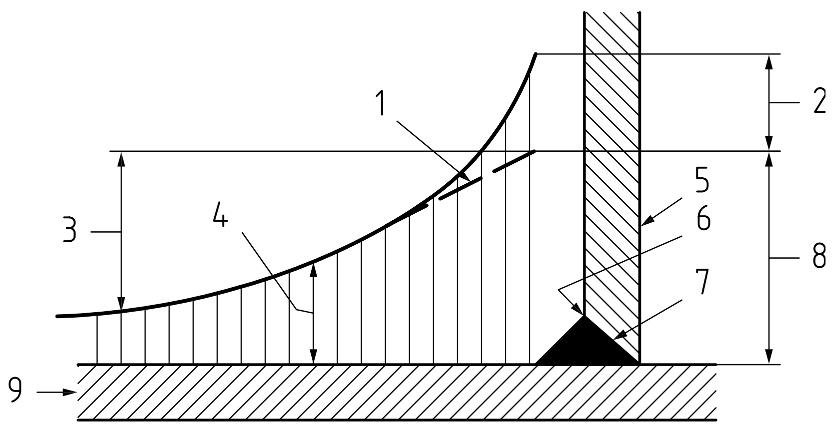
1 Crown point
2 Brace
3 Weld
4 Saddle point
5 Chord



b) Stress distribution in brace

Key

1 Increase in stress due to overall joint geometry
2 Nominal stress
3 Stress in brace
4 Brace wall
5 Extrapolation of geometric stress distribution to weld toe
6 Weld toe
7 Weld
8 Chord wall
9 Stress increase due to weld geometry
10 Brace hot spot stress = nominal stress × SCF_{brace}



c) Stress distribution in chord

Key

1 Extrapolation of geometric stress distribution to weld toe
2 Stress increase due to weld geometry
3 Increase in stress due to overall joint geometry
4 Stress in chord
5 Brace wall
6 Weld toe
7 Weld
8 Chord hot spot stress = nominal stress × SCF_{chord}
9 Chord wall

5.11.3 Hot spot initiation sites

For tubular nodal joints, the hot spot stress range should be evaluated at sufficient locations to characterize fully the fatigue performance of each joint. For example, in the case of a tubular set-on connection, at least four equally spaced points around the joint periphery would need to be considered. For any particular type of loading, e.g. axial loading, this hot spot stress range is the product of the nominal stress range in the brace and the appropriate stress concentration factor (SCF).

5.11.4 Derivation of hot spot stresses

The calculation of hot spot stress may be undertaken in a variety of ways, for example by physical model studies, by finite element analysis or by use of semi-empirical parametric formulae. The position of the "hot spot" in relation to the crown and saddle can be determined by the first two methods but not in all cases by parametric equations. When physical models are used, care should be taken in obtaining the geometric stress extrapolated to the weld toe (see **5.11.2**). When finite element calculations do not allow for any effect of weld geometry, the hot spot stress range at the weld toe can be estimated from the value obtained at the member intersection. Parametric formulae should be used with caution in view of their inherent limitations. In particular, they should only be used within the bounds of applicability relevant to the formula under consideration.

5.11.5 Hot spot strength curves

Values of $\Delta\sigma_C$-m_1 for hot spot stress assessment of weld toes are given in Table 19.

Table 19 **Values of $\Delta\sigma_C$-m_1 for hot spot stress assessment**

Thickness of stressed member t mm	$\Delta\sigma_C$-m_1
$0 < t \leqslant 4$	44-3,2
$4 < t \leqslant 10$	39-3,2
$10 < t \leqslant 15$	35-3,2
$15 < t \leqslant 25$	31-3,2
$25 < t \leqslant 40$	28-3,2
$t > 40$	25-3,2

The values in Table 19 might be conservative where small attachments occur at the weld toe. Where the fatigue strength curve in Table 15 is lower than that given when applying **5.8** and **5.10**, the latter subclauses may be used instead.

Subclause **5.10** should not be used in conjunction with the hot spot strength method.

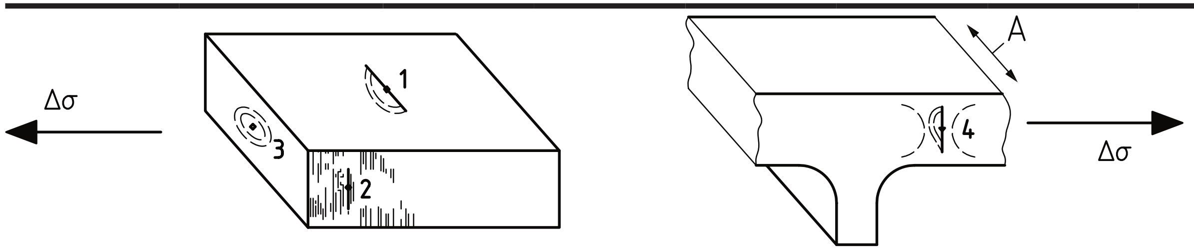
5.12 Fatigue strength of casting details [see BS EN 1999-1-3:2007, I.2.2(1) and I.2.3.2(1)]

Fatigue strength data for castings is given in Table 6.

5.13 Fatigue strength of adhesively bonded joints [see BS EN 1999-1-3:2007, I.2.4(1)]

It is recommended that the fatigue strength data in BS EN 1999-1-3:2007, Annex I, are only used where the adhesively bonded joints are exposed to a non-polluted dry environment where temperatures are normally above dew point. In other circumstances, it is recommended that data are based on fatigue tests which simulate the relevant environmental conditions. Sufficient adjustment should be made to the environmental conditions to take account of differences between the expected test duration and the required design life.

Table 6 **Detail categories for plain material**



Key

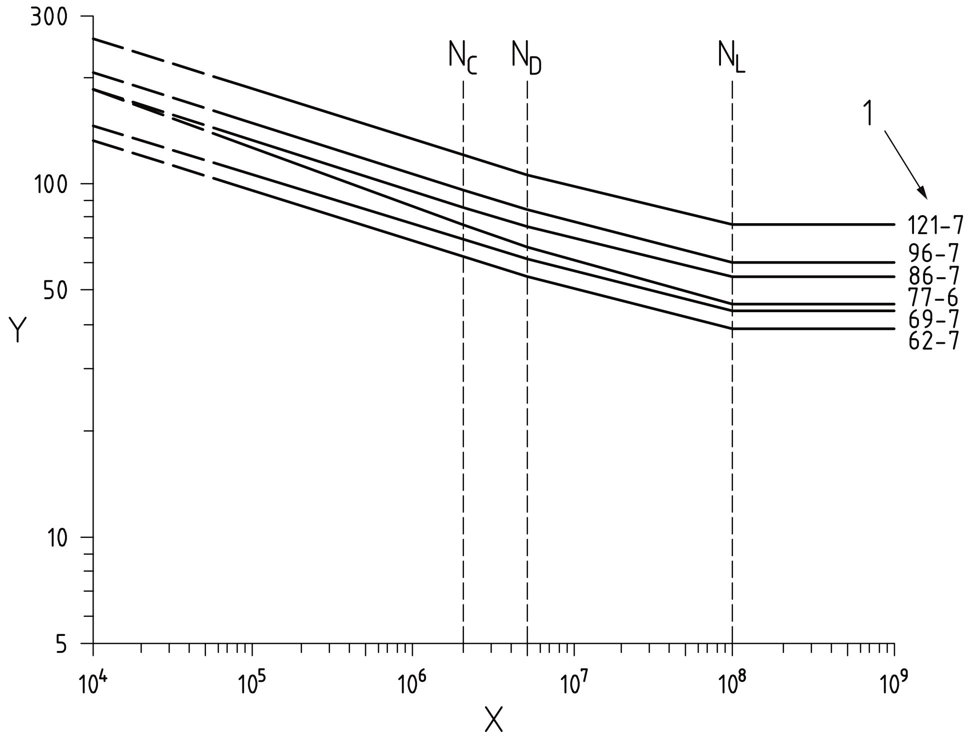
A Extrusion direction

1–4 Initiation sites **1** to **4** (see table row 2)

Product forms		Sheet, plate, simple extruded rod and bar		Shaped extrusions, tubes, forgings		Sheet, plate, solid extrusions, forgings		Hollow extrusions	→	Castings	→
Initiation site	Reference no.	**1, 2**	→	→	→	→	→	**4**	→	**1**	**3**
	Location	Small surface irregularity		→	→	→	→	Extrusion seam	Extrusion seam	Surface irregularity	Internal discontinuity
Stress orientation		Parallel to rolling or extrusion direction		→	→	Normal to rolling or extrusion direction		Normal to extrusion direction		—	—
Alloys (as per BS EN 1999-1-3:2007, Clause **3**(1))		7020 only	All except 7020	7020 only	All except 7020	7020 only	All except 7020	7020 only	6*** series only except 6060-T5	All	All
Particular requirements	Dimensional	Surfaces free of sharp corners unless parallel to stress direction		→	→	→	→	→	→	→	→
		No re-entrant corners in profile, no contact with other parts		—	—	—	—	—	—	—	—
	Fabrication	Machining only by high speed milling cutter		Hand grinding not permitted unless parallel to stress direction		→	→	Extruded by port hole or bridge die		Machining permitted if by high speed milling cutter	
	Inspection/ testing	Dye penetrant to PD 6705-3		→	→	→	→	Drift testing to PD 6705-3		Dye penetrant to PD 6705-3	Radiography to PD 6705-3
	Quality standard	Surface finish ($R_a < 0.5$ mm)		No score marks transverse to stress direction		→	→	No drift test fracture along weld seam		PD 6705-3	PD 6705-3
Stress analysis	Stress parameter	Principal structural stress range at initiation site		→	→	→	→	→	→	→	→
	Stress concen- trations already allowed for	Surface texture	→	→	→	→	→	→	→	→	Permitted internal porosity
Detail type number		1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	1.10
Detail Category $\Delta\sigma_C$-m_1		**121-7**	**86-7**	**96-7**	**69-7**	**96-7**	**69-7**	**86-7**	**62-7**	**77-6**	**77-6**

NOTE Where arrows (→) are shown in the table, the recommendation to the left of the arrow(s) applies.

Figure 4 **Fatigue strength curves for plain material** (see Table 6)



X Endurance N, cycles

Y Stress range $\Delta\sigma$, N/mm^2

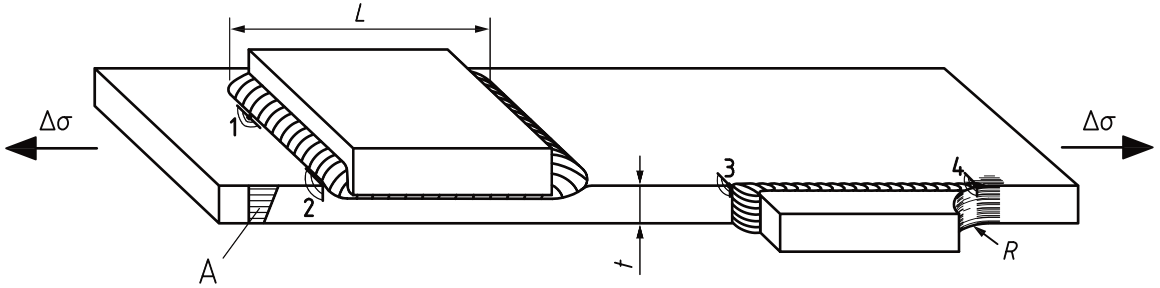
Key

1 Detail Category ($\Delta\sigma_C$-m_1)

Table 7 **Numerical values of $\Delta\sigma$ (N/mm^2) for plain material** (see Figure 4)

Detail Category values (N = 2 × 10^6)		**N = 10^5**	**N_D = 5 × 10^6**	**N_L = 10^8**
$\Delta\sigma_C$	m_1	$\Delta\sigma$	$\Delta\sigma_D$	$\Delta\sigma_L$
121	7	185,6	106,2	76,1
96	7	147,3	84,2	60,4
86	7	131,9	74,4	54,1
77	6	126,9	66,1	45,5
69	7	105,9	60,5	43,4
62	7	95,1	54,4	39,0

Table 8 **Members with welded attachments – transverse weld toe**



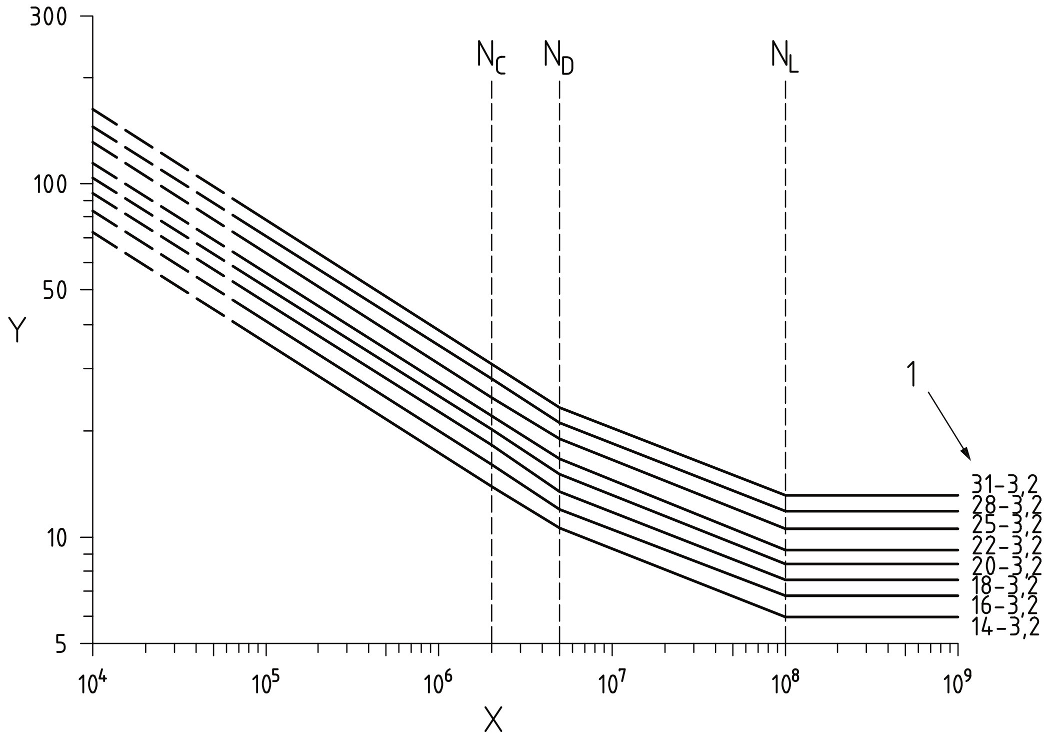
Key

L Attachment length between weld toes in stress direction
t Thickness
A Stress gradient
R Corner radius
1–4 Initiation sites **1** to **4** (see table row 2)

Product forms				Rolled, extruded and forged products						→	→	→	→	→	→	→
Initiation site	Reference no.			**1**	→	→	→	→	→	→	→	**2**	**3**	**4**	→	→
	Location			At transverse weld toe on stressed member							→	→	→	At longitudinal weld end		→
				On surface away from edge				→	→	→	→	At corner	→	In ground weld toe on edge		→
Stress orientation				Normal to transverse weld				→	→	→	→	→	→	Parallel to weld axis		→
Alloys (as per BS EN 1999-1-1:2007)				Table 3.1a		→	→	→	→	→	→	→	→	→	→	→
Particular requirements	Dimensional	Joint geometry		Attachment on member surface					→	→	→	→	Attachment on member edge		→	→
				Weld on surface away from corner						→	→	Welded round corner	Weld on edge	→	→	→
		Length *L* (mm) (toe to toe)	>	0	10	20	30	50	80	120	200	*L* and *t* as for Types 2.1 to 2.8	No radius	Corner radius *R* (mm)		→
			⩽	10	20	30	50	80	120	200						
		Thickness *t* (mm)		See Detail Category row				→	→	→	→	→	—	$10 < R \leqslant 20$	$20 \leqslant R \leqslant 40$	$R > 40$
	Fabrication			—	—	—	—	—	—	—	—	Grind undercut smooth	→	Grind radius in direction of Δσ[A)]		→
	Inspection/testing			See PD 6705-3			→	→	→	→	→	→	→	→	→	→
	Quality standard			See PD 6705-3			→	→	→	→	→	→	→	→	→	→
Stress analysis	Stress parameter			Nominal stress at initiation site					→	→	→	→	→	→	→	→
	Stress concentrations already allowed for			Weld profile permitted by PD 6705-3						→	→	→	→	→	→	→
				Stiffening effect of attachment					→	→	→	→	→	→	→	→
Applicability of k_b (see **5.10**)				✔	✔	✔	✔	✔	✔	✔	✔	✔	✘	✘	✘	✘
Detail type number				2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	2.10	2.11	2.12	2.13
Detail Category $\Delta\sigma_C$-m_1 (m_1 = 3,2 for all types; values omitted from table)		$t \leqslant 4$		**31**	**28**	**25**	**25**	**25**	**25**	**25**	**25**	As for Types 2.1 to 2.8 but reduced by one Detail Category	**18**	**25**	**28**	**31**
		$4 < t \leqslant 10$		**31**	**28**	**25**	**22**	**22**	**22**	**22**	**22**		**18**	**25**	**28**	**31**
		$10 < t \leqslant 15$		**31**	**28**	**25**	**22**	**20**	**20**	**20**	**20**		**18**	**25**	**28**	**31**
		$15 < t \leqslant 25$		**31**	**28**	**25**	**22**	**20**	**18**	**18**	**18**		**18**	**25**	**28**	**31**
		$25 < t \leqslant 40$		**31**	**28**	**25**	**22**	**20**	**18**	**16**	**16**		**18**	**25**	**28**	**31**
		$t > 40$		**31**	**28**	**25**	**22**	**20**	**18**	**16**	**14**		**18**	**25**	**28**	**31**

NOTE Where arrows (→) are shown in the table, the recommendation to the left of the arrow(s) applies. ✔ = applicable; ✘ = not applicable. [A)] Weld toe should be fully ground out.

Figure 5 **Fatigue strength curves for members with welded attachments – transverse weld toe** (see Table 8)



X Endurance N, cycles

Y Stress range $\Delta\sigma$, N/mm^2

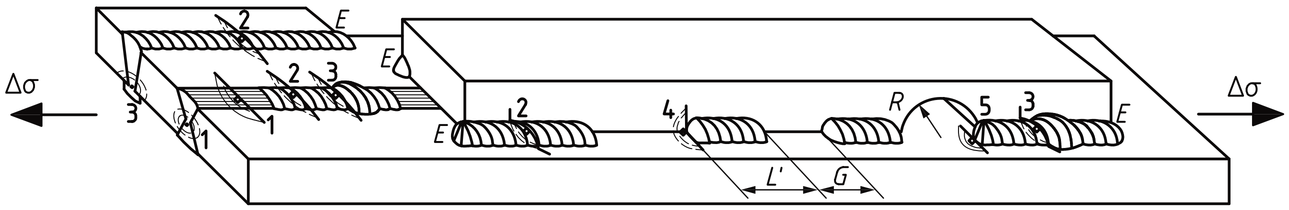
Key

1 Detail Category ($\Delta\sigma_C$-m_1)

Table 9 **Numerical values of $\Delta\sigma$ (N/mm^2) for members with welded attachments – transverse weld toe** (see Figure 5)

Detail Category values (N = 2 × 10^6)		**N = 10^5**	**N_D = 5 × 10^6**	**N_L = 10^8**
$\Delta\sigma_C$	m_1	$\Delta\sigma$	$\Delta\sigma_D$	$\Delta\sigma_L$
31	3,2	79,1	23,2	13,1
28	3,2	71,4	21,0	11,8
25	3,2	63,8	18,8	10,6
22	3,2	56,1	16,5	9,3
20	3,2	51,0	15,0	8,4
18	3,2	45,9	13,5	7,6
16	3,2	40,8	12,0	6,8
14	3,2	35,7	10,5	5,9

Table 10 **Detail categories for members with welded attachments – longitudinal welds**



Key

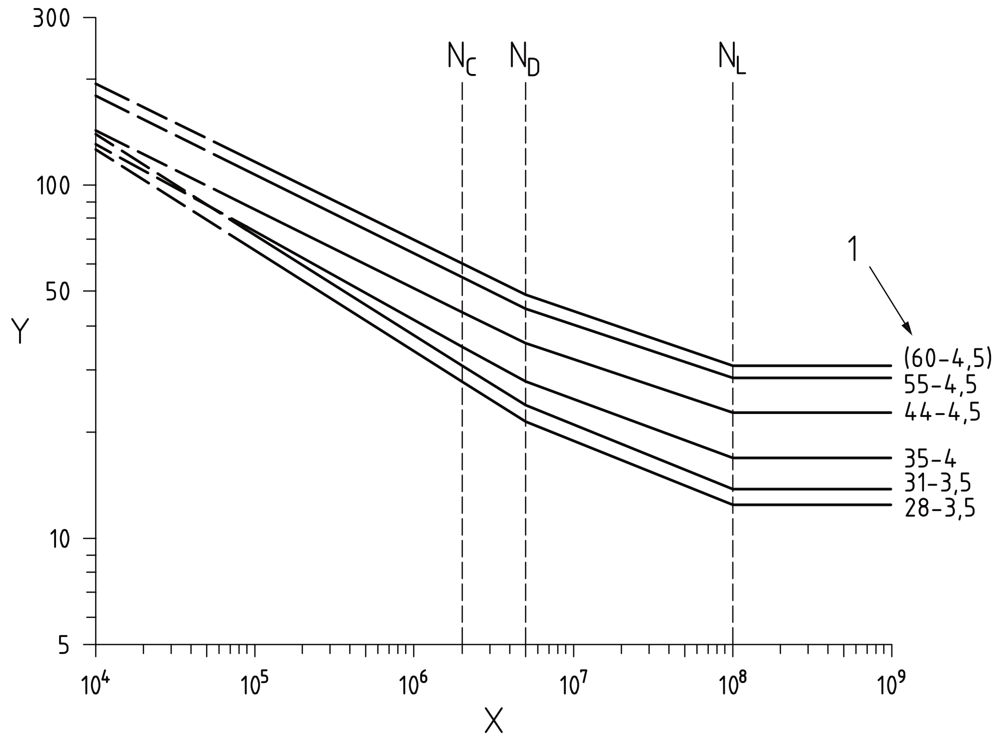
- *L′* Intermittent weld length between weld toes in stress direction
- *G* Gap between intermittent welds
- *R* Radius of cope hole
- **1–5** Initiation sites **1** to **5** (see table row 2)
- *E* Weld toe initiation sites at ends of attachments (see Table 8)

Product forms		Rolled, extruded and forged products	→	→	→	→
Initiation site	Reference no.	**1**	**2**	**3**	**4**	**5**
	Location	Weld discontinuity	Weld ripple	Stop-start	Weld toe or crater	Weld toe or crater
Stress orientation		Parallel to weld axis	→	→	→	→
Alloys (as per BS EN 1999-1-1:2007)		Table 3.1a	→	→	→	→
Particular requirements	Dimensional	Full penetration	—	—	Intermittent fillet weld	Cope hole centred on weld axis
		Double-sided butt weld	—	—	$G \leqslant 2.5\,L'$	$R \leqslant 25$ mm
	Manufacturing	Continuous automatic welding	→	—	—	—
		Weld caps ground flush in direction of Δσ	—	—	—	—
		Any backing bars (and attachment welds) to be continuous	→	→	—	—
	Inspection/testing	PD 6705-3	→	→	→	→
	Quality standard	PD 6705-3	→	→	→	→
Stress analysis	Stress parameters	Nominal stress range at initiation site	→	→	→	→
		Any attachment material to be included in section properties	→	→	→	→
	Stress concentrations already allowed for	Weld discontinuities permitted by PD 6705-3	→	→	→	→
		—	—	—	—	Presence of cope hole
Detail type number		2.14	2.15	2.16	2.17	2.18
Detail Category $\Delta\sigma_C$**-m**$_1$		**(60-4.5) 55-4,5**[A)]	**44-4,5**	**35-4**	**31-3,5**	**28-3,5**

NOTE Where arrows (→) are shown in the table, the recommendation to the left of the arrow(s) applies.

A) Value in brackets is attainable only with high weld quality levels which are not readily verifiable by normal non-destructive testing techniques. In order to meet the needs of quality assurance, the bracketed value should only be used where special inspection procedures are applied, which have been demonstrated to be capable of detecting and evaluating critical sizes of weld discontinuity that have been established by fracture mechanics for testing.

Figure 6 **Fatigue strength curves for members with welded attachments – longitudinal welds** (see Table 10)



X Endurance N, cycles

Y Stress range $\Delta\sigma$, N/mm^2

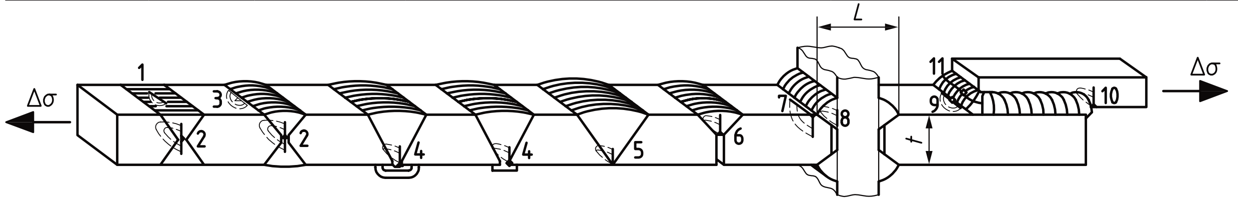
Key

1 Detail Category ($\Delta\sigma_C$-m_1)

Table 11 **Numerical values of $\Delta\sigma$ (N/mm^2) for members with welded attachments – longitudinal welds** (see Figure 6)

Detail Category values (N = 2 × 10^6)		**N = 10^5**	**N_D = 5 × 10^6**	**N_L = 10^8**
$\Delta\sigma_C$	m_1	$\Delta\sigma$	$\Delta\sigma_D$	$\Delta\sigma_L$
(60)	(4,5)	116,8	48,9	30,9
55	4,5	107,0	44,9	28,3
44	4,5	85,6	35,9	22,6
35	4	74,0	27,8	16,8
32	3,5	73,0	23,9	13,8
28	3,5	65,9	21,6	12,5

Table 12 **Detail categories for welded joints between members**



Key

L Joint length between weld toes in stress direction

t Thickness

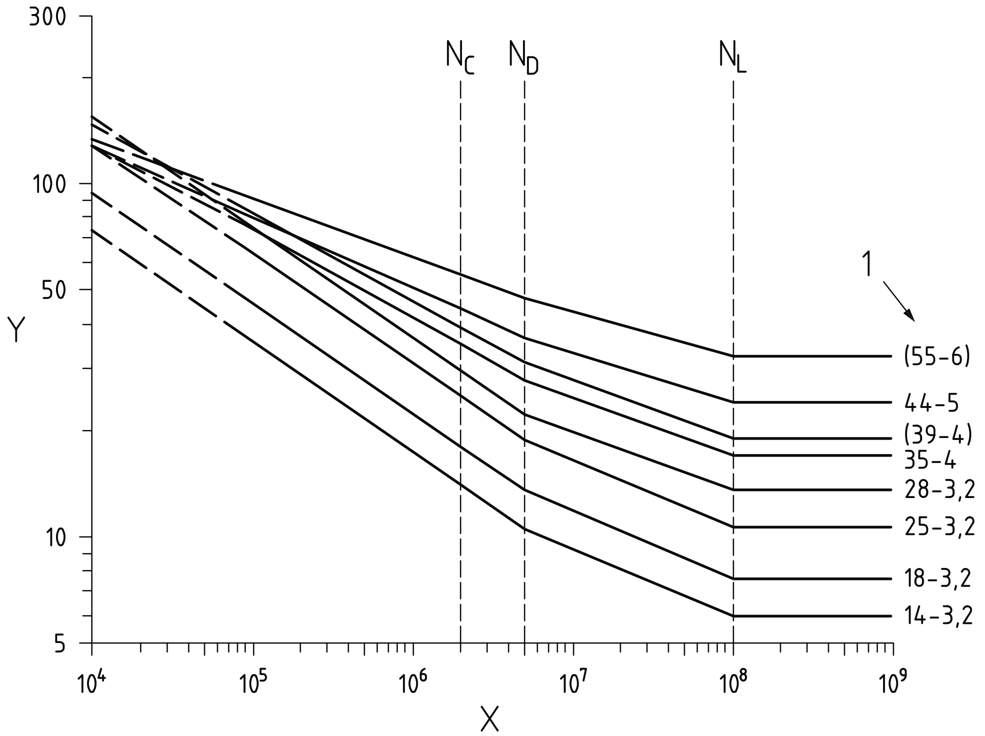
1–11 Initiation sites **1** to **11** (see table row 2)

Product forms			Rolled, extruded and forged products		→	→	→	→	→	→	→	→	Castings
Initiation site	Reference no.		**1, 2**	**3, 2**	**4**	**5**	**6**	**7**	→	**8**	**9, 10**	**11**	
Initiation site	Location		Surface or embedded discontinuity	Weld toe or embedded discontinuity	Weld root	Root discontinuity	Unfused root	Weld toe	Weld toe	Weld root	Weld toe	Weld root	As Types 3.1 to 3.10
Stress orientation			Normal to weld axis	→	→	→	→	→	→	→	→	→	
Alloys (as per BS EN 1999-1-1:2007)			Table 3.1a	→	→	→	→	→	→	→	→	→	Table 3.1b
Particular requirements	Dimensional	Joint type	In-line butt	→	→	→	→	Cruciform or tee		→	Lap	→	
		Weld type	Butt	→	→	→	→	Butt	→	→	Fillet	→	
		Preparation	Double sided	→	Single sided	→	→	—	—	—	—	—	
		Penetration	Full	→	→	→	Partial	Full	Partial	→	—	—	
		Transition	Taper slope 1 in 4 at width or thickness change			→	→	—	—	—	—	—	
	Manufacturing	Root	Ground	→	Backed	Unbacked	—	—	—	—	—	—	
		Cap	Ground flush	—	—	—	—	—	—	—	—	—	
		Ends	Extension plates used on ends, cut off and ground flush in direction of Δσ				→	→	→	→	—	—	As Types 3.1 to 3.10
	Inspection/testing		PD 6705-3	→	→	→	→	→	→	→	→	→	
	Quality standard		PD 6705-3	→	→	→	→	→	→	→	→	→	
Stress analysis	Stress parameters		Net throat + specified misalignment stress (no overfill)			→	→	Net section	→	Net throat	Net section	Net throat	
	Stress concentrations effects included in Detail Category		Profile, unspecified misalignment and discontinuities permitted by PD 6705-3				→	→ Stiffening effect of transverse element	→	→	→ Stress peaks at weld ends	→	
Applicability of k_b (see **5.10**)			✘	3 ✔, 2 ✘	✔	✔	✔	✔	✔	✘	9 ✔, 10 ✘	✘	✘
Detail type number			3.1	3.2	3.3	3.4	3.5	3.6	3.7	3.8	3.9	3.10	3.11 to 3.20
Detail Category $\Delta\sigma_C$-m_1		Flats, solid	**(55-6) 44-5**[A)]	**(39-4) 35-4**[A)]	**(35-4) 25-3,2**[A)]	**(28-3,2) 18-3,2**[A)]	**14-3,2**	As Table 8, Types 2.1 to 2.9		**18-3,2**	As Type 3.6 and Type 3.7	**14-3,2**	As Types 3.1 to 3.10 less one Detail Category
		Open shapes	**(44-5) 28-3,2**[A)]	**(35-4) 28-3,2**[A)]	**(35-4) 25-3,2**[A)]	**(28-3,2) 18-3,2**[A)]	**14-3,2**			**18-3,2**		**14-3,2**	
		Hollow	✘	✘	**(35-4) 25-3,2**[A)]	**(28-3,2) 18-3,2**[A)]	**14-3,2**			**18-3,2**		**14-3,2**	

NOTE *Where arrows (→) are shown in the table, the recommendation to the left of the arrow(s) applies. ✔ = applicable; ✘ = not applicable.*

A) Values in brackets are attainable only with high weld quality levels which are not readily verifiable by normal non-destructive testing techniques. In order to meet the needs of quality assurance, bracketed values should only be used where special inspection procedures are applied, which have been demonstrated to be capable of detecting and evaluating critical sizes of weld discontinuity that have been established by fracture mechanics for testing.

Figure 7 **Fatigue strength curves for welded joints between members** (see Table 12)



X Endurance N, cycles

Y Stress range $\Delta\sigma$, N/mm^2

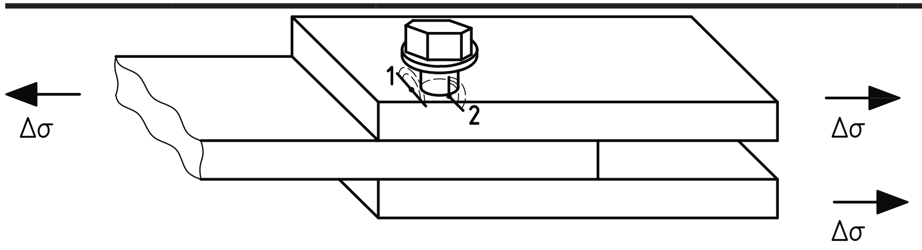
Key

1 Detail Category ($\Delta\sigma_C$-m_1)

Table 13 **Numerical values of $\Delta\sigma$ (N/mm^2) for welded joints between members** (see Figure 7)

Detail Category values (N = 2 × 10^6)		**N = 10^5**	**N_D = 5 × 10^6**	**N_L = 10^8**
$\Delta\sigma_C$	m_1	$\Delta\sigma$	$\Delta\sigma_D$	$\Delta\sigma_L$
(55)	(6)	90,6	47,2	32,5
44	5	80,1	36,6	23,9
(39)	(4)	82,5	31,0	18,8
35	4	74,0	27,8	16,8
28	3,2	71,4	21,0	11,8
25	3,2	63,8	18,8	10,6
18	3,2	45,9	13,5	7,6
14	3,2	35,7	10,5	5,9

Table 14 **Detail categories for mechanically fastened joints**



Key

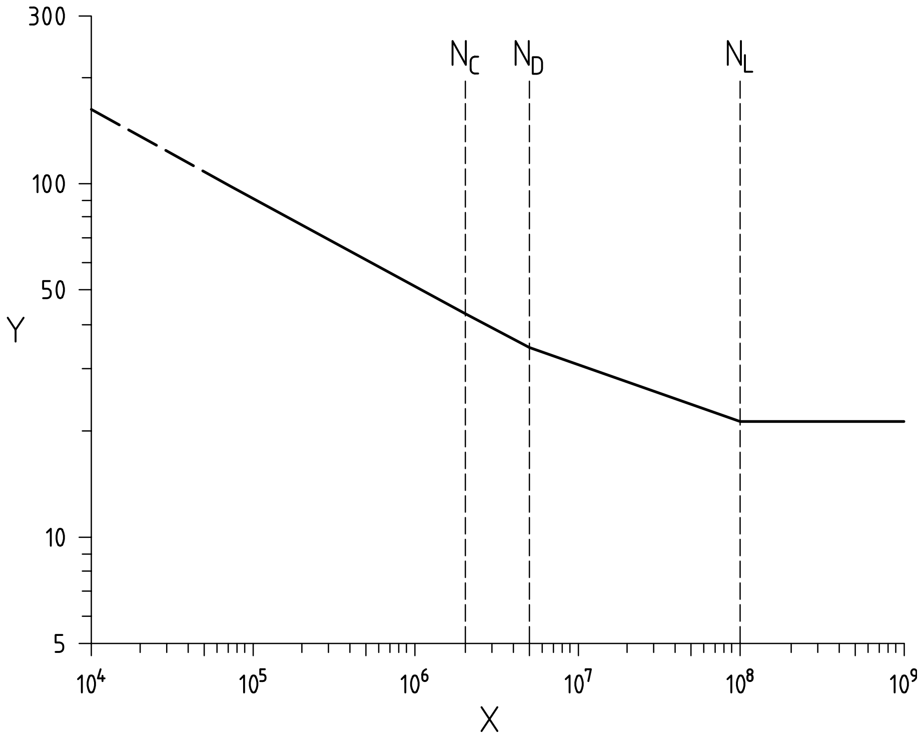
1–2 Initiation sites **1** to **2** (see table row 4) applicable to all plies

Fastener type		Preloaded (friction type)	→	Non-preloaded (bearing type)	→
		High strength bolt	Tensioned rivet	Bolt	Driven rivet
Product forms		Rolled, extruded and forged products	→	→	→
Initiation site (applies to all plies)	Reference no.	**1**, (**2**)	→	**2**	→
	Location	In front of hole (sometimes at edge of hole)	→	At edge of hole	→
Stress orientation		Parallel to rolling or extrusion direction	→	→	→
Alloys		Alloys with proof strength > 200 N/mm^2 A)	→	BS EN 1999-1-1:2007, Table 3.1a	→
Fastener materials		Steel, $R_{p0,2} \geqslant 640$ N/mm^2	→	As Part 1	→
Particular requirements	Dimensional	Lap joint with flat parallel surfaces	→	Lap joint	→
		Steel washer under bolt head and nut	—		
	Fabrication	Machining only by high speed milling cutter	→	→	→
		Holes drilled (with optional reaming) or punched (with compulsory reaming if thickness > 6 mm)			→
	Assembly	Degreased or shot blast faying surfaces to be in full contact with 30% pre-load in all bolts	Degreased or shot blast faying surfaces to be in full contact using temporary bolts	Holes in plies to be aligned within ±0.5 mm	→
	Fastening	Bolts to be torqued to a minimum of 85% of proof load	Rivet head to be swaged whilst rivet under a minimum 85% proof load	Bolts to be torqued to minimum 50% proof load unless lock nuts used	Rivets driven until faying surfaces in contact
	Inspection/ testing	Final torque/nut rotation checked after tightening complete	—	Final torque checked if lock nuts not used	—
Stress analysis	Stress parameter	Nominal stress range based on GROSS section properties	→	Nominal stress range based on NET section properties	→
	Stress concen-trations already allowed for	Surface texture, fastener hole geometry, unequal load distribution between rows of bolts, eccentricity of load path in SYMMETRICAL DOUBLE COVERED lap joints only. In other geometries the nominal stress should include the bending stress taking into account misalignment and relative out-of-plane stiffness of parts, together with the membrane stress.			
Detail type number		4.1	4.2	4.3	4.4
Detail Category $\Delta\sigma_C$-m_1		**45-4**	**45-4**	**45-4**	**45-4**

NOTE Where arrows (→) are shown in the table, the recommendation to the left of the arrow(s) applies.

A) See BS EN 1999-1-1:2007, **8.5.9.1**(1).

Figure 8 **Fatigue strength curve for mechanically fastened joints** (see Table 14)



X Endurance N, cycles

Y Stress range $\Delta\sigma$, N/mm²

Table 15 **Numerical values for $\Delta\sigma$ (N/mm²) for mechanically fastened joints** (see Figure 8)

Detail Category values (N = 2 × 10⁶)		**N = 10⁵**	**N_D = 5 × 10⁶**	**N_L = 10⁸**
$\Delta\sigma_C$	m_1	$\Delta\sigma$	$\Delta\sigma_D$	$\Delta\sigma_L$
45	4	95,2	35,8	21,7

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For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

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BS 1472, *Specification for wrought aluminium and aluminium alloys for general engineering purposes – forging stock and forgings* [2)]

BS 1474, *Specification for wrought aluminium and aluminium alloys for general engineering purposes: bars, extruded round tubes and sections* [2)]

BS 1490, *Specification for aluminium and aluminium alloy ingots for general engineering purposes* [2)]

BS 4300/1, *Specification for wrought aluminium and aluminium alloys for general engineering purposes (supplementary series) – Aluminium alloy longitudinally welded tube* [2)]

BS 4300/12, *Specification for wrought aluminium and aluminium alloys for general engineering purposes (supplementary series) – 5454 Bar, extruded round tube and sections* [2)]

BS 4300/14, *Specification for wrought aluminium and aluminium alloys for general engineering purposes (supplementary series) – 7020 Plate, sheet and strip* [2)]

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2) Superseded; withdrawn.

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BS EN ISO 25239-2, *Friction stir welding – Aluminium – Part 2: Design of weld joints* [3)]

ISO 10721-1, *Steel structures – Part 1: Materials and design*

ISO 10721-2, *Steel structures – Part 2: Fabrication and erection*

3) In preparation.

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BSI Group Headquarters

389 Chiswick High Road London W4 4AL UK

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