

Code of practice for

Fatigue design and assessment of steel structures

Committees responsible for this British Standard

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- Association of Consulting Engineers
- British Constructional Steelwork Association Ltd.
- British Railways Board
- Department of Transport
- Department of Transport (Transport Research Laboratory)
- ESDU International Ltd.
- Electricity Association
- Federation of Manufacturers of Construction Equipment and Cranes
- Institution of Civil Engineers
- Institution of Structural Engineers
- Ministry of Defence
- Process Plant Association
- Railway Industry Association of Great Britain
- Society of British Aerospace Companies Limited
- United Kingdom Offshore Operators Association
- Welding Institute

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Foreword

This British Standard has been prepared under the direction of the Welding Standards Policy Committee.

It has been produced with the objective of covering the general aspects of fatigue design of fabricated steel elements within the subject area regardless of the type of structure in which they are situated. It is anticipated that application standards for particular types of structure will in due course be modified to omit their own fatigue design rules and to cross refer to this code of practice, thereby achieving a co-ordinated approach to the subject. Such application standards will, however, still include fatigue loading and safety requirements for the structures to which they relate.

This code is based directly upon the recommendations of existing codes and other reference documents, such as the Department of Energy Publication *Offshore installations: Guidance on design, construction and certification*. At this stage no attempt has been made to update existing recommendations except in cases where they were found to be in need of clarification. Background notes on the sources of the data given in this code are provided in Annex G.

As a code of practice, this British Standard takes the form of guidance and recommendations. It should not be quoted as if it were a specification and particular care should be taken to ensure that claims of compliance are not misleading.

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.

NOTE The numbers in square brackets used throughout the text of this British Standard relate to the bibliographic references given in Annex H.

A British Standard does not purport to include all the necessary provisions of a contract. Users of British Standards are responsible for their correct application.

Compliance with a British Standard does not of itself confer immunity from legal obligations.

Summary of pages

This document comprises a front cover, an inside front cover, pages i to iv, pages 1 to 80, an inside back cover and a back cover.

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

Section 1. General

1.1 Scope

This British Standard gives recommendations for methods for the fatigue design and assessment of parts of steel structures which are subject to repeated fluctuations of stress. It is concerned with wrought structural steel with a specified minimum yield strength of up to 700 N/mm^2 operating in the sub-creep regime.

This British Standard is applicable to the following:

- a) parent material remote from joints;
- b) welded joints (in air or sea water) in such material¹⁾;
- c) bolted or rivetted joints in such material;
- d) shear connectors between concrete slabs and steel girders acting compositely in flexure.

Guidance on general fatigue design philosophy is given in Annex A, which also contains a brief description of the method of using this document.

The relevant application standard or other specification for the particular structure under consideration should specify the following:

- 1) the loading to be assumed for design purposes, including its magnitude and frequency;
- 2) the required life of the structure;
- 3) the environmental conditions;
- 4) the required nominal probability of failure (see 4.2).

This British Standard takes no account of the possible onset of unstable fracture from a fatigue crack. This possibility should be considered and guarded against by appropriate material selection.

This British Standard does not apply to the following:

- orthotropic decks;
- wire ropes;
- bonded connections;
- steel reinforcement in concrete;
- out of plane joints between hot rolled rectangular or square hollow sections;
- pressure vessels;
- castings;
- peening.

1.2 References

1.2.1 Normative references

This British Standard incorporates, by reference, provisions from specific editions of other publications. These normative references are cited at the appropriate points in the text and the publications are listed on the inside back cover. Subsequent amendments to, or revisions of, any of these publications apply to this British Standard only when incorporated in it by updating or revision.

1.2.2 Informative references

This British Standard refers to other publications that provide information or guidance. Editions of these publications current at the time of issue of this standard are listed on the inside back cover, but reference should be made to the latest editions.

1.3 Definitions

For the purposes of this British Standard the following definitions apply.

1.3.1 fatigue

the damage of a structural part by the initiation and gradual propagation of a crack or cracks caused by repeated applications of stress

1.3.2 stress cycle

a pattern of variation of stress at a point defined by the cycle counting method and consisting of a change in stress between defined minimum (trough) and maximum (peak) values and back again

NOTE 1 Also known as cycle of stress.

NOTE 2 One loading event may produce one or more stress cycles at any particular point.

1.3.3 stress range S_r

the algebraic difference between the two extremes (reversals) of a stress cycle

NOTE 1 Also known as range of stress.

NOTE 2 See 3.2 and 3.3 for parent metal and weld metal respectively.

1.3.4 initial non-propagating stress range S_0

the constant amplitude stress range below which (in the absence of any previous loading) a crack is assumed not to propagate

NOTE Its magnitude depends on the joint class and, for joints in air or adequately protected against corrosion, it is assumed to be the stress corresponding to a life of 10^7 cycles on the design $S-N$ curve. For unprotected joints in a corrosive environment it should be assumed that $S_0 = 0$.

¹⁾ For welded joints fatigue strength is same for all steels.

1.3.5**detail class**

the rating given to a particular structural detail to indicate which of the fatigue strength ($S-N$) curves should be used in the fatigue assessment

NOTE 1 Also known as joint class.

NOTE 2 The class is denoted by one of the following letters: A, B, C, D, E, F, F2, G, S, T, W or X. The categorization takes into consideration the local stress concentration at the detail, the size and shape of the maximum acceptable discontinuity, the stress direction, metallurgical effects, residual stresses, fatigue crack shape, and in some cases the welding process and a post-weld improvement method.

1.3.6**service life**

the intended operating life, which is the period in which a structure or component is required to perform safely with an acceptable probability that it will not require repair or withdrawal from service as a result of fatigue

1.3.7**design life**

the period within which there is a defined nominal probability that failure by fatigue cracking will not occur

NOTE This may be longer or shorter than the service life (see 1.6).

1.3.8**fatigue strength**

the constant amplitude stress range S_r causing failure in the appropriate number of cycles (N)

1.3.9 **$S-N$ curve**

the quantitative relationship between the fatigue strength S and the number of cycles N corresponding to a specific probability of failure for a detail, derived from test data

1.3.10**basic $S-N$ curve**

the $S-N$ curve, for the required probability of failure, for a detail of basic thickness (see 4.3.2) tested in air without the application of any fatigue strength improvement method apart from those given in Table 1 to Table 12

1.3.11 standard basic $S-N$ curve

the basic $S-N$ curve for two standard deviations below the mean ($d = 2$) assuming that the test data are represented by a normal distribution of log life

1.3.12**design $S-N$ curve**

the $S-N$ curve adopted for design purposes for the detail under consideration

NOTE It is derived from the relevant basic $S-N$ curve modified, if necessary, to allow for the influence of material thickness, environment, fatigue strength improvement techniques (additional to those given in Table 1 to Table 12), stress relief (see 4.3.5) or workmanship (see 2.4).

1.3.13**fatigue loading**

the loading on a structure which is liable to cause fatigue cracking

NOTE It may be composed of several different types and magnitudes of loading events (see 1.7).

1.3.14**loading event**

a defined loading sequence on the structure which may be characterized by its relative frequency of occurrence as well as its magnitude and geometrical arrangement

NOTE In the case of a crane this could involve the lifting, movement and depositing of a load. With respect to a bridge it could be the approach, passage and departure of a train or, for short lengths, a bogie or axle, over a railway bridge or one vehicle over a highway bridge. For design purposes each loading event is assumed to repeat a given number of times in the design life of the structure.

1.3.15**load spectrum**

a tabulation showing the relative number of occurrences of all the loading events of different types and intensities expected to be experienced by the structure in its design life

1.3.16**cycle counting method**

a particular method of counting the numbers of stress cycles of different magnitudes which occur in a service stress history

NOTE The loads applied to the structure, considered in sequence, generate a particular stress history at each detail of interest. This stress history can be broken down into equivalent numbers of stress ranges of different magnitudes by the operation of cycle counting. The particular method of counting recommended in this code is the rainflow or reservoir method (see 3.9).

1.3.17**design spectrum**

a tabulation of the number of occurrences of all the stress ranges S_r of different magnitudes produced by the load spectrum in the design life of the structure or component, to be used in the fatigue assessment

NOTE 1 Also known as stress spectrum.

NOTE 2 Different components of a structure may have different design spectra.

1.3.18**Miner's summation**

a cumulative damage summation based on the rule devised by Palmgren and Miner

1.4 Symbols and units

For the purposes of this British Standard, the following symbols and units are used.

A	Net area of cross section (in mm^2)
C_0	Parameter defining the mean line S_r - N relationship
C_2	Parameter defining the S_r - N relationship for two standard deviations below the mean line
C_d	Parameter defining the S_r - N relationship for d standard deviations below the mean line
K_f	Stress concentration factor under fatigue loading
M, M^1	Applied bending moments (in N mm)
$N_1, N_2 \dots$	Number of cycles to failure under constant amplitude loading with stress ranges $S_{r1}, S_{r2} \dots$, etc., corresponding to n_1, n_2 etc. (in cycles)
P, P^1	Applied axial forces (in N)
S	Fatigue strength of the joint under consideration, including any required thickness correction (in N/mm^2)
S_B	Fatigue strength of the joint using the basic S_r - N curve (in N/mm^2)
S_0	Constant amplitude initial non-propagating stress range (in air $S_0 = S_r$ at $N = 10^7$ cycles) (in N/mm^2)
S_r	Stress range in any one cycle (in N/mm^2)
$S_{r1}, S_{r2} \dots$	Individual stress ranges (S_r) in a design spectrum (in N/mm^2)
Z	Elastic modulus of section (in mm^3)
d	Number of standard deviations below the mean S_r - N curve
m	Inverse slope of $\log S_r$ $\log N$ curve (i.e. $S_r^m N = \text{constant}$)
$n_1, n_2 \dots$	Number of cycles of damaging stress ranges $S_{r1}, S_{r2} \dots$, etc in a design spectrum (in cycles)
t	Plate thickness of the member under consideration (in mm)
t_B	Thickness relevant to the basic S_r - N curve for the joint (in mm)
w	Weld throat thickness (in mm)

$\sum \frac{n}{N}$	Miner's summation
γ_{fL}	Load factor for fatigue
σ	Standard deviation of $\log N$
σ_Y	Nominal tensile yield stress (in N/mm^2)

1.5 Assessment

Any structure which is exposed to loads which may cause cyclic stress variations in its structural members, and is therefore liable to suffer fatigue cracking in those members, should be assessed in accordance with this British Standard. A summary of the fatigue assessment procedure is given in A.5.

1.6 Design life

The design life is the period for which it is assumed, for purposes of calculation, that a structure or component will be required to perform safely, and within which there is a defined probability that failure will not occur by fatigue cracking. The structure should, whenever possible, be designed to be damage tolerant (see A.3).

In some circumstances it may be decided to make the design life either longer or shorter than the service life. If the design life is made longer (see A.4), then the result is the introduction of an arbitrary factor of safety on life, but if it is shorter there is a greater probability that failure may occur during the service life. The latter approach should only be considered if the structure, or the relevant part of it, can safely and economically be inspected and any cracks be detected and repaired before any crack reaches a length which causes failure under static loading; this requires a conscious decision with the strength of the structure, the need for inspection and the feasibility of repair in mind. It is also necessary that the strength of the structure in the presence of any cracks should have been evaluated at the time of the design.

1.7 Fatigue loading

In assessing fatigue performance a realistic estimate of the fatigue loading is crucial to the calculation of life, and all types of cyclic loading should be considered. Cyclic loading from different sources may be significant at different phases of the life of a structure, e.g. construction, transport, installation, in-service, and may involve different frequencies.

The design load spectrum should be selected on the basis that it is an upper bound estimate of the accumulated service conditions over the full design life of the structure. Account should be taken of all likely operational and environmental effects arising from the foreseeable usage of the structure during that period. The loading should not, however, be factored (i.e. $\gamma_{FL} = 1.0$).

The following are some important sources of cyclic loading that should be considered, any or all of which may be relevant in particular applications:

- a) fluctuating loads;
- b) acceleration forces in moving structures;
- c) pressure changes;
- d) temperature fluctuations;
- e) mechanical vibrations;
- f) environmental loading (wind, currents and waves, especially when vortex shedding is induced, e.g. on slender members).

Particular care should be taken to assess dynamic magnification effects where loading frequencies are close to one of the natural frequencies of the structure.

In some instances the loading to be assumed for fatigue design purposes will be specified in the relevant application standard. Where such information is not available reasonable assumptions as to the loading to be expected in service should be made, and it may be useful to obtain data from existing structures subjected to similar effects. In particular, in assessing an existing structure, a design spectrum may be able to be compiled from strain readings or loading records obtained from continuous monitoring.

In any case the objective is to define the spectrum in terms of the numbers of cycles of each of the individual stress ranges expected in the life of the structure. Where a non-standard loading is used the design spectrum should be divided into a sufficient number of intervals of stress and the use of stress ranges in each interval should be such as to represent adequately the damage effect over the whole spectrum.

1.8 Basis of fatigue analysis

It should be recognized that uncertainties exist in assessing both the stresses resulting from applied loads and the response of a particular joint, which together control fatigue performance. The basis of the fatigue analysis should be to use a best estimate of these stresses, noting the uncertainties involved, with $S-N$ curves derived from experimental data. In this way, uncertainties associated with the life of a particular joint, e.g. size, weld detail, local environment, can be separated from those associated with applied stress.

In order to evaluate fatigue lives it is necessary to establish the long term distribution of stress range taking into consideration all stress variations which can reasonably be expected during the life of the structure which have magnitudes and numbers large enough to cause fatigue effects.

Using the calculated long term distribution of stress range, the method of assessment described in this code is based on the Palmgren-Miner rule for damage calculation (see 4.7). The resulting calculated fatigue lives, which enable critical parts to be ranked in terms of fatigue sensitivity, should be used, in conjunction with an assessment of the consequences of failure of specific members, to establish a priority basis for developing a selective inspection programme to be followed during the service life of the structure.

1.9 Factors on fatigue life

The standard basic $S-N$ curves (see 4.2) are based on the mean minus two standard deviation curves for relevant experimental data. Their use therefore implies a finite probability of failure for the calculated life. Thus, an additional factor on life, i.e. the use of $S-N$ curves based on the mean minus more than two standard deviations, should be considered for cases of inadequate structural redundancy. In defining this factor on life, account should be taken of the accessibility of the joint and the proposed degree of inspection as well as the consequence of failure. As a crack grows in one part of a structure, the load may be shed to other members and lead to further fatigue cracks in those members. Because of the sensitivity of calculated life to the accuracy of estimates of stress, particular care should be taken to ensure that stresses are not underestimated.

1.10 Features influencing fatigue behaviour

For both welded and bolted steel structures it has been established that the fatigue life is normally governed by the fatigue behaviour of the joints, including both main and secondary joints. The best fatigue behaviour will be obtained by ensuring that the structure is so detailed and constructed that stress concentrations are kept to a minimum and that where possible the elements are able to deform in their intended ways without introducing secondary deformations and stresses due to local restraints. Stresses may also be reduced by increasing the thickness of parent metal which should improve fatigue life although with some types of joint fatigue strength tends to decrease with increasing thickness (see 4.3.2).

The best joint performance is achieved by avoiding joint eccentricity and misalignment and welds near free edges and by other controls over the quality of the joints. Performance is adversely affected by concentrations of stress at holes, openings and re-entrant corners. Guidance in these aspects is given in Table 1 to Table 12 and Annex B and Annex C.

The magnitude and nature of stresses that will cause propagation of a crack, and consequently reduce the number of stress repetitions to cause failure, are affected by the presence of residual stress, inherent flaws in welds and adjacent parent metal, surface flaws and any other stress raisers interfering with the flow of stress. These are taken into account in the classifications given in Table 1 to Table 12.

1.11 Fracture mechanics

In some situations the normal fatigue assessment procedures may be inappropriate, but fracture mechanics methods may be helpful. Guidance on the use of fracture mechanics is given in Annex D.

Section 2. Classification of details

2.1 General

For the purposes of fatigue design, joints are divided into several classes, each with a corresponding design *S-N* curve (see 4.2). This classification depends upon the following:

- a) the geometrical arrangement and proportions of the detail;
- b) the direction of the fluctuating stress relative to the detail;
- c) the location of possible crack initiation at the detail;
- d) the methods of manufacture and inspection.

In any structure or component, which is liable to be subjected to repeated applications of stress, every welded joint or other form of stress concentration, such as a bolt hole, is potentially a source of fatigue cracking. Hence, each part of each constructional detail should be considered individually and should, where possible, be placed in its relevant joint class in accordance with the criteria given in Table 1 to Table 12. Otherwise the detail should be dealt with in accordance with 2.3.

In bolted or rivetted joints fatigue cracks will normally initiate from the bolt or rivet hole. However, in welded details there are several locations at which fatigue cracks may, potentially, initiate; these are as follows:

- 1) in the parent metal of either part joined adjacent to:
 - i) the end of the weld;
 - ii) a weld toe;
 - iii) a change of direction of the weld;
- 2) in the weld metal starting from:
 - i) the weld root;
 - ii) the weld surface;
 - iii) an internal flaw.

In the case of members or elements connected at their ends by fillet welds or partial penetration butt welds and flanges with shear connectors, the crack initiation may occur either in the parent metal or in the weld throat; both possibilities should be checked by taking into account the appropriate classification and stress range. For other details, the classifications given in Table 1 to Table 12 cover crack initiation at any possible location in the detail. Notes on the potential modes of failure for each detail are given in Annex B.

2.2 Classification of details

Table 1 to Table 12 correspond to the following basic types of details:

- 1) plain material;
- 2) lapped or spliced, rivetted or bolted joints;
- 3) fasteners;
- 4) continuous longitudinal welded attachments;
- 5) other welded attachments;
- 6) transverse butt welds in plates;
- 7) transverse butt welds in sections and tubes;
- 8) load-carrying fillet and T-butt joints;
- 9) slotted connections and penetrations through stressed members;
- 10) details relating to tubular members;
- 11) seam welds in vessels;
- 12) branch connections to vessels.

Each classified detail is illustrated and given a type number. Table 1 to Table 12 also give various associated criteria and the diagrams illustrate the geometrical features and potential crack locations which determine the class of each detail. This information should be used to assist with initial selection of the appropriate type number.

A detail should only be designated a particular classification if it conforms in every respect to the tabulated criteria appropriate to its type number. Class A is generally inappropriate for structural work and the special inspection standards relevant to classes B and C cannot normally be achieved in the vicinity of welds in structural work.

Table 1 — Classification of details: plain material free from welding

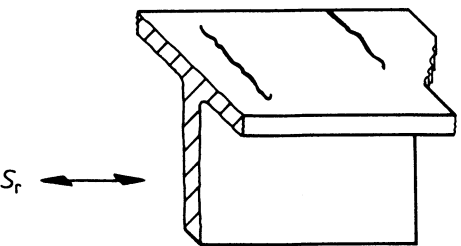
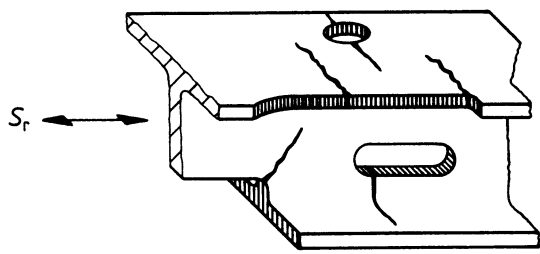
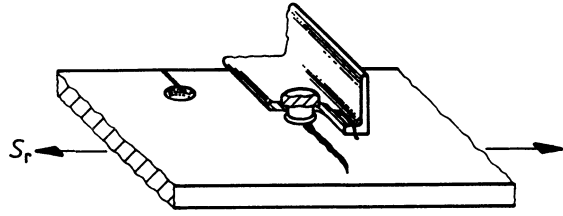
Product form	Location of potential crack initiation	Dimensional requirements	Manufacturing requirements	Special inspection requirements	Design stress area	Type number	Class	Notes	Sketch
Rolled steel structural plates and sections	Away from all welds or structural connections	Member of constant or smoothly varying cross section with no holes or re-entrant corners	All surfaces fully machined and polished. No flame cutting			1.1	A	See B.2.2	
			Edges as rolled or machined smooth. No flame cutting			1.2	B		
	At any external or internal edge	Member with or without apertures, re-entrant corners or other discontinuities	Any flame cut edges subsequently machined or ground smooth		Net cross section	1.3	B	All visible signs of drag lines should be removed from the flame cut edge by grinding or machining. See also note for type 1.4.	
			Any cutting of edges by planing or machine flame cutting with controlled procedure		Net cross section	1.4	C	The controlled flame cutting procedure should ensure that the resulting surface hardness is not sufficient to cause cracking. Types 1.3 and 1.4. The presence of an aperture, re-entrant corner or other discontinuity implies the existence of a stress concentration and the design stress should be the stress on the net section multiplied by the relevant stress concentration factor (see Annex C).	
	At a small hole (may contain bolt for minor fixtures)		Hole drilled or reamed		Net cross section	1.5	D	This type may be deemed to include bolt holes for attaching light bracing members where there is negligible transference of stress from the main member in the direction S_r . The classification includes allowance for the stress concentration created by the hole.	

Table 2 — Classification of details: bolted or rivetted, spliced or lapped connections

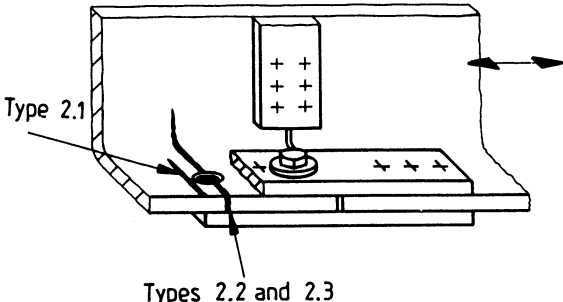
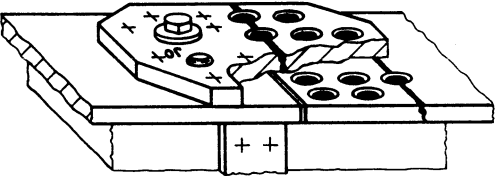
Product form	Location of potential crack initiation	Dimensional requirements	Manufacturing requirements	Special inspection requirements	Design stress area	Type number	Class	Notes	Sketch
Rolled steel structural plates and sections	At joint made with high strength friction grip bolts, away from the hole	Double covered symmetrical joint	Holes drilled or reamed		Gross	2.1	C	This covers connections designed for slip resistance at the ultimate limit state and where secondary out-of-plane bending of the joint is restrained or does not occur i.e. double-covered symmetrical joints. Failure initiates by fretting in front of the hole. Failure initiates at edge of hole. See B.2.3 regarding the tightening of bolt groups. The classifications include allowance for the stress concentrations created by the bolt hole.	 Type 2.1 Types 2.2 and 2.3
	At joint made with high strength friction grip bolts, at the hole		Bolts tightened in accordance with BS 4604-1:1970 or BS 4604-2:1970			2.2	C		
	At joint made with rivets or precision bolts, at the hole					2.3	D		
	At joint made with high strength friction grip bolts, at the hole				Net section	2.4	D		
	Joint made with rivets, at the hole					2.5	D		
	Joint made with precision bolts, at the hole	Close tolerance hole	Torque to at least $0.7 \times$ proof load or use lock nuts			2.6	E		
	Joint made with black bolts, at the hole					2.7	G		

Table 3 — Classification of details: fasteners and shear connectors

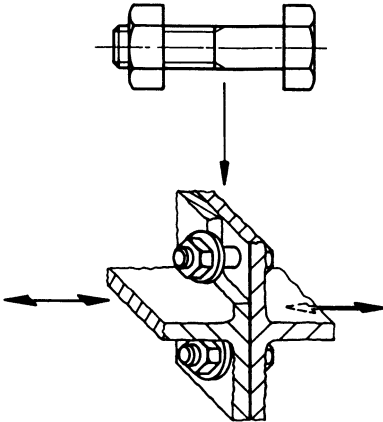
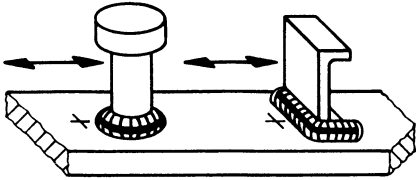
Product form	Location of potential crack initiation	Dimensional requirements	Manufacturing requirements	Special inspection requirements	Design stress area	Type number	Class	Notes	Sketch
Threaded fasteners	At thread root. Fastener in a butt joint with fastener axis parallel to S_r		Bolts conforming to BS 3692:1967, BS 4395-1:1969 BS 4395-2:1969 Screw threads conforming to BS 3643-2:1981		Tensile stress area	3.1	X (see 3.8 and Figure 10)	This classification applies to failure at the root of the thread in normal commercial quality threaded components. Attention should be paid to the details of head fillets, waisted shanks and thread run-out in components, not covered by an appropriate British Standard, to ensure that they have satisfactory fatigue resistance. A higher fatigue resistance (see 3.8) can be obtained with a rolled thread on material which has previously been fully heat-treated, but such components should be subject to special test and inspection procedures. For the use of black bolts conforming to BS 4190:1967 and subjected to fluctuating tensile loads, see 3.8. Where bolts or screwed rods are pre-tensioned to a value in excess of an applied external load, including any prying forces, stress fluctuations will be governed by the elasticity of the pre-compressed elements. The increase in tension will rarely exceed 10 % of an external load applied concentrically with the bolt axis, but where the load is eccentric, e.g. as in the sketch, a further increase will result from prying action.	
Shear connectors in concrete	In weld throat between encased connector and any member			All regions stressed in through thickness direction to be free from lamellar flaws and tears	Effective weld throat area (see 3.7)	3.2	S	This type covers embedded shear connectors at any position along a girder. The fatigue strength of the member adjacent to the shear connector is covered by type 5.1.	

Table 4 — Classification of details: continuous welded attachments essentially parallel to the direction of applied stress

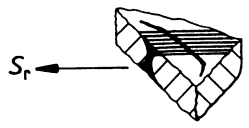
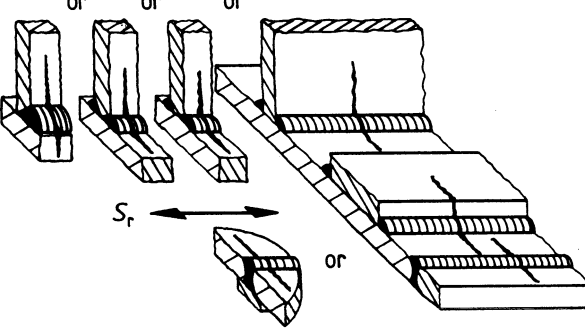
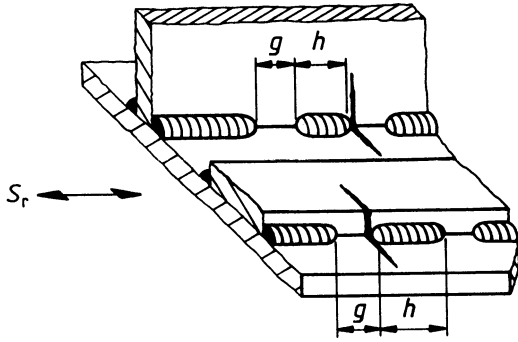
Product form	Location of potential crack initiation	Dimensional requirements	Manufacturing requirements	Special inspection requirements	Design stress area	Type number	Class	Notes	Sketch
Rolled steel structural plates, sections and built-up members	At a long welded attachment (in the direction of S_r), away from the weld end	Butt weld with full penetration and no backing strip	Weld reinforcement dressed flush	Proved free of all flaws which are likely to degrade the joint below its stated classification (see 2.4.3)	Minimum transverse cross section of member at location of potential crack initiation	4.1	B	Finish machining should be in the direction of S_r . The significance of flaws should be determined with the aid of specialist advice and/or by the use of a fracture mechanics analysis. The non-destructive testing (NDT) technique should be selected with a view to ensuring the detection of such significant flaws. This type is only recommended for use in exceptional circumstances.	
		Butt or fillet welded web or attachment with width not greater than 50 mm	Automatic weld with no stop/starts			4.2	C	Accidental stop/starts are not uncommon in automatic processes. Repair to the standard of a C classification should be the subject of specialist advice and inspection and as a result, the use of this type is not recommended.	
			Welds with stop/starts			4.3	D	For situation at the ends of flange cover plates see joint type 5.4. Backing strips, if used, need to be continuous and either not attached or attached by continuous fillet welds. If the backing strip is attached by discontinuous fillet welds see type 4.6.	
	At an intermediate gap in a longitudinal weld	Intermittent fillet weld with $\frac{g}{h} \leq 2.5$				4.4	E	The limiting gap ratio g/h applies even though adjacent welds may be on opposite sides of a narrow attachment (as in the case of a longitudinal stiffener with staggered fillet welds). Long gaps between intermittent fillet welds are not recommended as they increase the risk of corrosion and, in the case of compression members, may cause local buckling. If intermediate gaps longer than $2.5h$ are required the class should be reduced to F.	

Table 4 — Classification of details: continuous welded attachments essentially parallel to the direction of applied stress

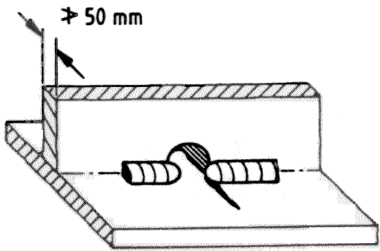
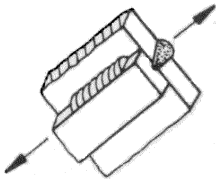
Product form	Location of potential crack initiation	Dimensional requirements	Manufacturing requirements	Special inspection requirements	Design stress area	Type number	Class	Notes	Sketch
Rolled steel structural plates, sections and built-up members	At a cope hole		Weld may or may not continue round plate ends		Minimum transverse cross section of member at location of potential crack initiation	4.5	F	The existence of the cope hole is allowed for in the joint classification: It should not be regarded as an additional stress concentration in relation to cracking in the flange. With regard to the web see notes for type 7.1.	
	At the ends of a discontinuous fillet weld attaching a backing strip		The backing strip to be continuous			4.6	E	This type includes tack welds to the edges of continuous longitudinal backing strips irrespective of spacing, provided that the welds conform in all respects to the workmanship requirements for permanent welds and that any undercut on the backing strip is ground smooth. The effects of tack welds which are subsequently fully ground out or incorporated into the butt weld by fusion, need not be considered. If the backing strip is either not attached or is attached by a continuous fillet weld, see type 4.3.	

Table 5 — Classification of details: welded attachments on the surface or edge of a stressed member

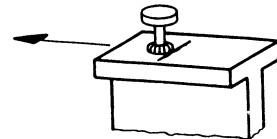
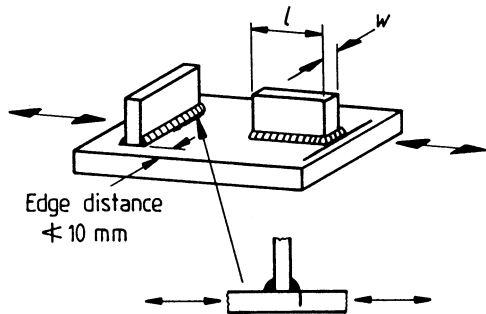
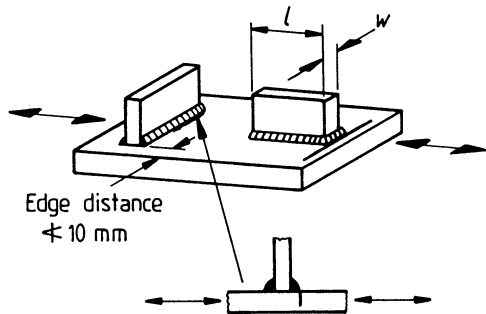
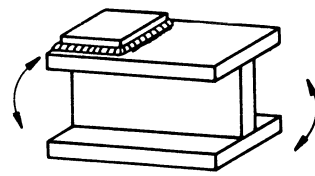
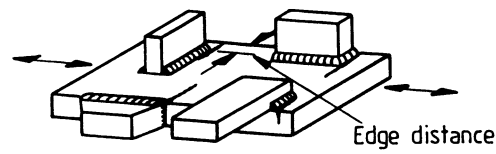
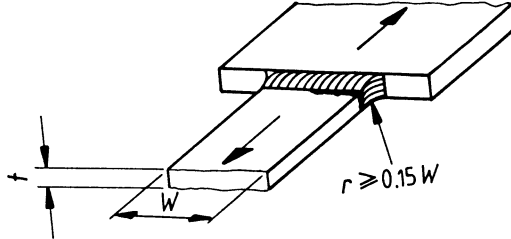
Product form	Location of potential crack initiation	Dimensional requirements	Manufacturing requirements	Special inspection requirements	Design stress area	Type number	Class	Notes	Sketch
Rolled steel structural plates, sections, tubes, and built-up members	At weld toe of stud shear connector				Minimum transverse cross section of member at location of potential crack initiation	5.1	F		
	At weld toe or end of a short attachment (in direction of S_p)	Weld length (parallel to S_p) $l \leq 150$ mm				5.2	F	Butt welded joints should be made with an additional reinforcing fillet so as to provide a similar toe profile to that which would exist in a fillet welded joint.	
	At weld toe or end of a long, narrow attachment	$l \leq 150$ mm $w \leq 50$ mm Weld not within 10 mm of member edge				5.3	F2	The decrease in fatigue strength with increasing attachment length is because more load is transferred into the longer gusset, giving an increase in stress concentration.	
	At weld toe or end of a long, wide attachment	$l > 150$ mm $w > 50$ mm				5.4	G	The classification may be deemed to include stress concentrations arising from normal eccentricities in the thickness direction. This type includes parent metal adjacent to the ends of flange cover plates regardless of the shape of the ends.	
	At weld toe or end of any attachment close to edge of stressed member	Weld within 10 mm of member edge	Grind out undercut			5.5	G	This type applies regardless of the shape of the end of the attachment. In all cases, care should be taken to avoid undercut on element corners or to grind it out to a smooth profile should it occur. In particular, weld returns across a corner should be avoided and the use of cover plates wider than the flange, to which they are attached, is not recommended. The classification applies to all sizes of attachment. It would therefore include, for example, the junction of two flanges at right angles. In such situations a low fatigue classification can often be avoided by the use of a transition plate (see also joint type 6.5).	

Table 6 — Classification of details: full penetration butt welds between co-planar plates^a

Product form	Location of potential crack initiation	Dimensional requirements	Manufacturing requirements	Special inspection requirements	Design stress area	Type number	Class	Notes	Sketch
Rolled steel plates only	At transverse butt weld joining two single plates end to end	Plates of equal width and thickness	Misalignment slope ≤ 1 in 4	Proved free of all flaws which are likely to degrade the joint below its stated classification (see 4.3)	Minimum transverse cross section of member at location of crack initiation	6.1	C	The significance of flaws should be determined with the aid of specialist advice and/or by the use of a fracture mechanics analysis. The NDT technique should be selected with a view to ensuring the detection of such significant flaws. This class should not normally be used in structural work. (See B.2.2 and B.6.2.6.)	
		Longitudinal axes in line	Dress flush reinforcement			6.2	D	Shop welds made entirely in the flat position, either manually or by an automatic process other than submerged arc, tend to have a better reinforcement shape from the point of view of fatigue than positional, site or submerged arc welds, i.e. larger re-entrant angles at the toes.	
		Longitudinal axes in line	Flat position shop welds, not submerged arc. Grind smooth any undercut			6.3	E	This category can be raised to class D provided that the reinforcement is ground smooth until flush with the plate surface on both sides, in addition to grinding smooth any undercut. Any NDT should be carried out after grinding.	
		Any width or thickness change ≤ 1 in 4 slope	Other weld processes and positions than those in type 6.2. Grind smooth any undercut			6.4	F	If the backing strip is fillet or tack welded to the plate (type 5.2) the detail class will not be reduced below class F unless permanently tacked within 10 mm of the member edge, in which case it will be class G (type 5.5).	

^a The joints covered by this table may also fail from internal weld flaws if they are more severe than the external geometrical discontinuity. Weld quality is therefore pertinent to the various classifications (see 2.4.3).

Table 6 — Classification of details: full penetration butt welds between co-planar plates^a

Product form	Location of potential crack initiation	Dimensional requirements	Manufacturing requirements	Special inspection requirements	Design stress area	Type number	Class	Notes	Sketch
Rolled steel plates only	At transverse butt weld joining two single plates end to end	Longitudinal axes in line Abrupt width change	Build up corners to radius $\leq 0.15W$ Corner reinforcement ground flush for $2t$. Grind smooth any undercut	Proved free of all flaws which are likely to degrade the joint below its stated classification (see 4.3)	Minimum transverse cross section of member at location of crack initiation	6.5	F2	The effect of the stress concentration at the corner of the joint between two individual plates of different widths in line is included in the classification. Where the end of one plate is butt welded to the surface of another refer to types 8.1 and 8.3. Stress concentrations due to abrupt changes of width can often be avoided by tapering the wider plate (see types 6.2, 6.3 and 6.4). Where the end of one plate is butt welded to the surface of another, refer types 8.1 and 8.2.	

^a The joints covered by this table may also fail from internal weld flaws if they are more severe than the external geometrical discontinuity. Weld quality is therefore pertinent to the various classifications (see 2.4.3).

Table 7 — Classification of details: transverse butt welds in sections and tubes

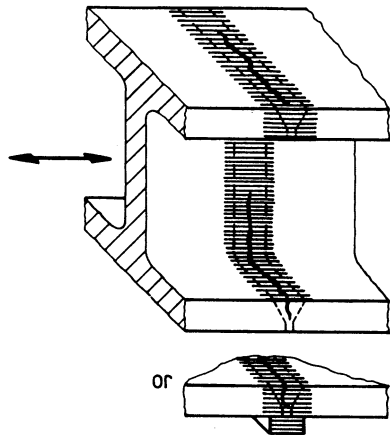
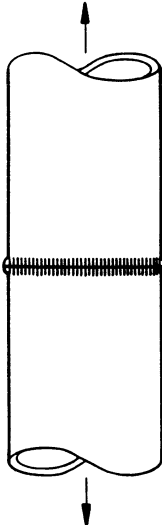
Product form	Location of potential crack initiation	Dimensional requirements	Manufacturing requirements	Special inspection requirements	Design stress area	Type number	Class	Notes	Sketch
Rolled steel sections and built-up members	At transverse butt weld joining two sections of similar profile end to end.	Full penetration butt weld with longitudinal axes in line.	Misalignment slope ≤ 1 in 4.		Minimum transverse cross section of member at location of crack initiation.	7.1	F2	Butt welds between rolled sections or between built-up sections are prone to weld flaws, which are difficult to detect, in the region of the web/flange junction. Special preparations, procedures and inspection may be undertaken in exceptional circumstances and type 6.3 may then be applied unless the weld is made on a permanent backing (type 6.4). Dressing of the weld reinforcement is advised to overcome poor reinforcement shape resulting from the greater misalignments which may occur in the jointing of sections. This joint is frequently made using a cope hole. This gives improved access to the flange butt welds when webs or longitudinal stiffeners have already been attached. The end of the web butt weld at the cope hole can be considered to be equivalent to class D with the appropriate stress concentration factor provided that the end of the butt weld and the reinforcement within a distance equal to the radius r are ground flush (see Figure B.8). If there is no grinding class E with the appropriate stress concentration factor should be used. Cope holes of triangular shape are not recommended.	
Steel tubes	At the toes of circumferential butt welds in tubes		Weld made from both sides with overfill dressed flush	Proved free of all flaws which are likely to degrade the joint below its stated classification (see 2.4.3)		7.2	C	The significance of flaws should be determined with the aid of specialist advice and/or by the use of a fracture mechanics analysis. The NDT technique should be selected with a view to ensuring the detection of such significant flaws. Use of this type is not recommended.	
			Weld made from both sides			7.3	E		
			Weld made from one side on permanent backing strip			7.4	F		
			Weld made from one side with no backing strip	Weld to be checked for full penetration		7.5	F2		

Table 7 — Classification of details: transverse butt welds in sections and tubes

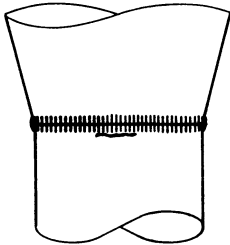
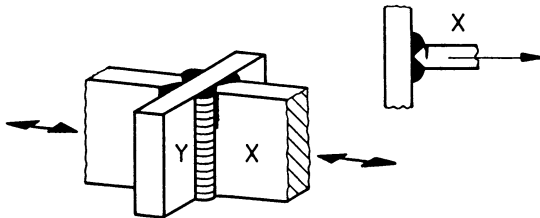
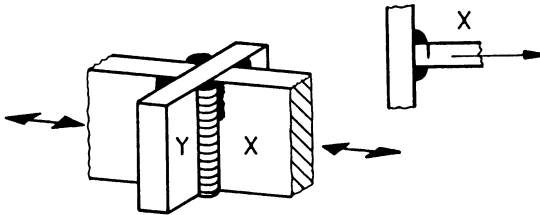
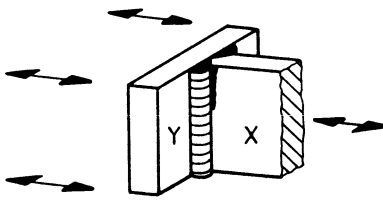
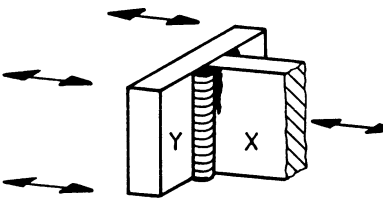
Product form	Location of potential crack initiation	Dimensional requirements	Manufacturing requirements	Special inspection requirements	Design stress area	Type number	Class	Notes	Sketch
Steel tubes	At the toes of circumferential butt welds between tubes and conical sections		See types 7.2 to 7.5, as appropriate	See types 7.2 to 7.5 as appropriate		7.6	C E F F2	Class and stress should be those corresponding to the joint type as indicated in types 7.2 to 7.5, but the stress has also to include the stress concentration factor due to overall form of the joint. If a stiffener or diaphragm is situated adjacent to the joint, see also type 10.3	

Table 8 — Classification of details: load carrying fillet and T-butt joints between plates in different planes

Product form	Location of potential crack initiation	Dimensional requirements	Manufacturing requirements	Special inspection requirements	Design stress area	Type number	Class	Notes	Sketch
Rolled steel structural plates, sections and built-up members	At toe of weld joining two members end to end with third member transverse through joint	Full penetration butt weld with longitudinal axes in line	Any undercut should be ground smooth particularly on the corners of member X If width permits make weld continuous around the joint; otherwise grind ends flush with edge of member X.	All regions of plate Y stressed in the through thickness direction to be free from lamellar defects and tears.	Cross section of member X	8.1	F	Weld metal failure will not govern with full penetration welds. Member Y can be regarded as one with a non-load-carrying weld (see joint types 5.2 and 5.5). In this instance the edge distance limitation applies. Misalignment between the two plates X shall be kept to be a minimum. It may be necessary to include a stress concentration factor in the design calculation (see B.8.2).	
		Partial penetration butt or fillet weld				8.2	F2	In this type of joint failure is likely to occur in the weld throat unless the weld is made sufficiently large. (See joint type 8.5). Misalignment between the two plates X shall be kept to be a minimum. It may be necessary to include a stress concentration factor in the design calculation (see B.8.2).	
	At toe of weld joining the end of one member to the surface of another	Full penetration butt weld				8.3	F	See joint type 8.1.	
		Partial penetration butt or fillet weld				8.4	F2	See joint type 8.2.	

NOTE Butt welded joints should be made with an additional reinforcing fillet so as to provide a similar toe profile to that which would exist in a fillet welded joint (see B.5.2.2).

Table 8 — Classification of details: load carrying fillet and T-butt joints between plates in different planes

Product form	Location of potential crack initiation	Dimensional requirements	Manufacturing requirements	Special inspection requirements	Design stress area	Type number	Class	Notes	Sketch
Rolled steel structural plates, sections and built-up members	In weld throat of any incompletely fused joint				Effective weld throat area	8.5	W	This includes joints in which a pulsating load may be carried in bearing, such as the connection of bearing stiffeners to flanges. In such examples the welds should be designed on the assumption that none of the load is carried in bearing.	
	At toe of transverse load carrying fillet weld in lap joint on both sides of plate symmetrically	Weld toe not less than 10 mm from edge of member			See notes	8.6	F2	The classification may be deemed to include stress concentrations arising from normal eccentricities in the thickness direction. Where a narrow attachment, Y, is transferring the entire load out of a wide member, X, as in the case of a welded lap type connection between, for example, a cross brace and a gusset, the stress in the gusset at the end of the cross brace will vary substantially across the section. For assessing the stress in the gusset X the effective width should be taken as shown below: Minimum weld length 150 mm	
	At toe of transverse load carrying fillet weld in lap joint on one surface only					8.7	G	 For failure in the cross brace at Z the cross brace, Y, is the "member" and the gusset is the "attachment". (See type 8.8.) Minimum weld length 150 mm	

NOTE Butt welded joints should be made with an additional reinforcing fillet so as to provide a similar toe profile to that which would exist in a fillet welded joint (see B.5.2.2).

Table 8 — Classification of details: load carrying fillet and T-butt joints between plates in different planes

Product form	Location of potential crack initiation	Dimensional requirements	Manufacturing requirements	Special inspection requirements	Design stress area	Type number	Class	Notes	Sketch
Rolled steel structural plates, sections and built-up members	At the ends of longitudinal load carrying fillet welds, with the weld end on a plate edge	Weld toe within 10 mm of edge of member	Grind any undercut Avoid weld returns round laps		Cross section of member Y	8.8	G	This type applies regardless of the shape of the end of the attachment. In all cases, care should be taken to avoid undercut on element corners or to grind it out to a smooth profile should it occur. In particular, weld returns across a corner should be avoided and the use of cover plates wider than the flange, to which they are attached, is not recommended.	
NOTE But welded joints should be made with an additional reinforcing fillet so as to provide a similar toe profile to that which would exist in a fillet welded joint (see B.5.2.2).									

Table 9 — Classification of details: slotted connections and penetration through stressed members

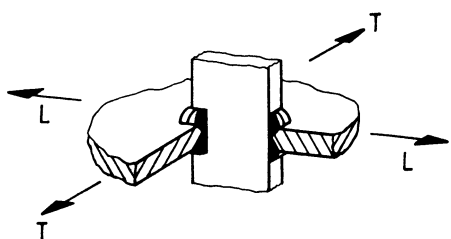
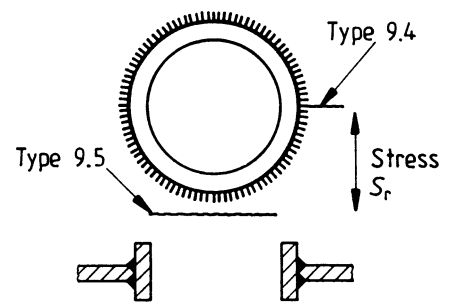
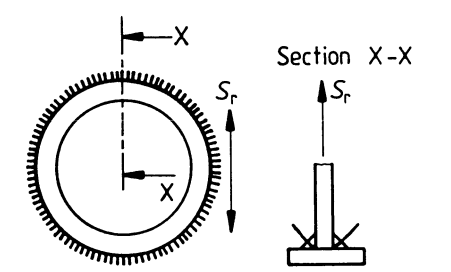
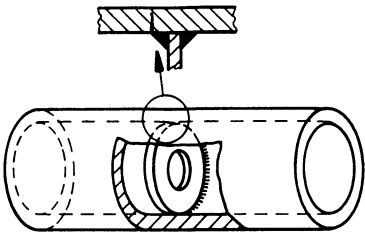
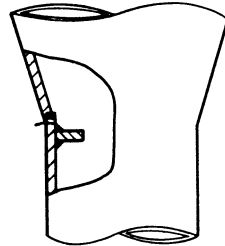
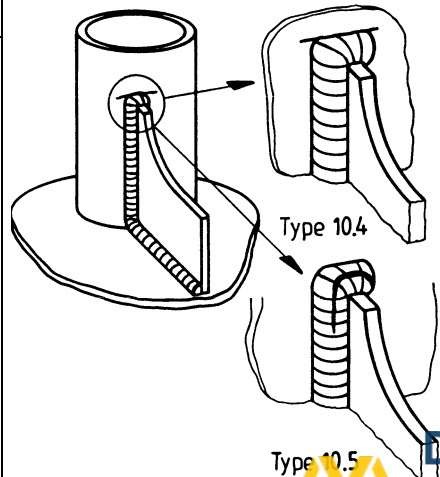
Product form	Location of potential crack initiation	Dimensional requirements	Manufacturing requirements	Special inspection requirements	Design stress area	Type number	Class	Notes	Sketch
Steel plates, sections or tubes	In stressed member at toe of butt weld connecting slotted through member	Length of slotted through member, parallel to S_r , ≤ 150 mm and edge distance ≥ 10 mm				9.1	F	This classification does not apply to fillet welded joints (see joint type 8.2). However it does apply to loading in either direction (L or T in the sketch).	
		Length > 150 mm and edge distance > 10 mm				9.2	F2		
		Any length and edge distance < 10 mm				9.3	G		
	In parent or weld metal adjacent to a penetration, on a plane essentially perpendicular to S_r					9.4	D	In this situation the relevant stress should include the stress concentration factor due to the overall geometry of the detail. Full penetration welds are normally required in this situation. If they are not used, the possibility of failure through the weld has to be considered (see type 9.6).	
						9.5	F	For failure at weld toe (see sketch).	
	In weld metal of fillet or partial penetration welds around a penetration, on a plane essentially parallel to S_r					9.6	W	The stress in the weld should include an appropriate stress concentration factor to allow for the overall joint geometry. This type of failure could subsequently lead to failure of type 9.4. Weld metal failure does not govern with full penetration welds.	

Table 10 — Classification of details: circular tubular members

Product form	Location of potential crack initiation	Dimensional requirements	Manufacturing requirements	Special inspection requirements	Design stress area	Type number	Class	Notes	Sketch
Steel tubes	Adjacent to the toes of full penetration welds in nodal joints					10.1	T	In this situation design should be based on the hot spot stress as given in 3.6.2.	
	At toe of weld attaching diaphragm or stiffener to tubular member					10.2	F	Stress should include the stress concentration factor due to overall shape of adjoining structure.	
	In the stressed member at the toes of bevel butt or fillet welded attachment in a region of stress concentration					10.3	F or F2 or G	Class depends on attachment length (see types 5.2 to 5.4) but stress should include the stress concentration factor due to overall shape of adjoining structure.	
	In the tube at the toe of full penetration or fillet welded gusseted connections					10.4	F	The design stress has to include any local bending stress adjacent to the weld end.	
	Weld throat failure in fillet welded gusseted connections				Effective weld throat	10.5	W	For failure in the weld throat of fillet welded joints.	

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