

BS 7608:2014+A1:2015



BSI Standards Publication

Guide to fatigue design and assessment of steel products

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Summary of pages

This document comprises a front cover, an inside front cover, pages i to vi, pages 1 to 142, an inside back cover and a back cover.

Foreword

Publishing information

This British Standard is published by BSI Standards Limited, under licence from The British Standards Institution, and came into effect on 31 March 2014. It was prepared by Technical Committee WEE/37, *Acceptance levels for flaws in welds*. A list of organizations represented on this committee can be obtained on request to its secretary.

Supersession

BS 7608:2014+A1:2015 supersedes BS 7608:2014, which is withdrawn.

Information about this document

Guidance on general fatigue design philosophy is given in Annex A, which also contains a brief description of the method of using this British Standard. A more general method for assessing welded joints using the hot-spot stress, only included previously for assessing tubular joints, is also included.

The relevant application standard or specification for the particular product being assessed specifies the following:

- a) the loading to be assumed for design purposes, including its magnitude and frequency;
- b) the required life of the structure;
- c) the environmental conditions;
- d) the required nominal probability of failure.

BS 7608:2014 was a full revision of the standard, and introduced the following principal changes [1]:

- Introduction of the hot-spot stress method with guidance on finite element stress analysis (FEA).
- New correction for both plate thickness and applied bending with allowance for welded joint proportions.
- Additional weld details; some have been reclassified.
- Weld quality requirements based on fitness for purpose.
- Revised sea water corrosion fatigue data.
- New rules for bolts.
- Design data to resist shear fatigue failure.
- Guidance on stress calculation for combined loading.
- Revised cumulative damage rules.
- Comprehensive guidance on use of weld toe improvement methods.
- New guidance on acceptance fatigue testing and statistical analysis of results.

European standards containing fatigue rules for steel structures and pressure vessels have been published since the 1993 edition of this British Standard. It is therefore not applicable to product areas covered by them. It is applicable to a wide range of other steel product areas that do not have specific fatigue rules.

Text introduced or altered by Amendment No. 1 is indicated in the text by tags **A1** **A1**. Minor editorial changes are not tagged. The principal changes are to Table 4 to Table 10, Clause 14, Clause 16, Table 18, new Table 21, Annex C and Annex F.

Use of this document

As a guide, this British Standard takes the form of guidance and recommendations. It should not be quoted as if it were a specification or a code of practice and claims of compliance cannot be made to it.

Presentational conventions

The guidance in this standard is presented in roman (i.e. upright) type. Any 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 British Standard cannot confer immunity from legal obligations.

1 Scope

1.1 General

This British Standard gives methods for assessing the fatigue life of parts of steel products that are subject to repeated fluctuations of stress. It is applicable to all areas of industrial application that are not covered by other British Standards containing fatigue assessment rules.

NOTE Some British Standards have specific product acceptance tests for fatigue life, but do not have assessment rules. In such cases the guidance in this British Standard might be applicable for product development purposes.

1.2 Applications not covered

This British Standard is not applicable to the following application areas;

- a) lighting columns (see BS EN 40);
- b) concrete building and civil engineering structures (see BS EN 1992);
- c) steel building and civil engineering structures [see BS EN 1993 (all parts)];
- d) composite steel and concrete building and civil engineering structures [see BS EN 1994 (all parts)];
- e) unfired pressure vessels (see BS EN 13445); and
- f) fixed offshore structures (see BS EN ISO 19902).

1.3 Materials

This British Standard covers:

- a) wrought steel material products;
- b) welds in fully machined areas of steel casting;
- c) ferritic alloy and low alloy steels;
- d) austenitic and duplex stainless steels;
- e) unprotected weathering steels; and
- f) threaded fasteners.

It is applicable to yield strengths in the range 200 N/mm² to 960 N/mm² and ultimate tensile strengths in the range 360 to 1 200 N/mm² for material thicknesses 3 mm and greater.

This British Standard is not applicable to the following:

- 1) proprietary fasteners;
- 2) steel castings;
- 3) cold drawn products;
- 4) wire ropes; and
- 5) steel for reinforcement in concrete.

1.4 Manufacturing processes

This British Standard is applicable to machined products with the following exceptions:

- a) rough sawn surfaces;
- b) surfaces requiring high quality surface finish (e.g. lapping, polishing, honing, fine grinding); and

- c) machined details with sharp corners (e.g. key ways, un-radiused shoulders).

The following manufacturing processes are also covered:

- 1) cold formed wrought products;
- 2) weld toe improvement methods;
- 3) arc welded joints, with the exclusion of joints between rectangular and square hollow sections;
- 4) in-line butt welds made by power beam A_1 or A_1 friction welding;
- 5) tensioned and un-tensioned bolted joints and hot-driven riveted lap joints loaded in shear; and
- 6) thermal cutting.

This British Standard is not applicable to the following manufacturing processes:

- i) resistance welding processes and brazing;
- ii) contact joints under pressure where fretting occurs;
- iii) adhesively bonded joints;
- iv) shearing and punching; and
- v) surface hardening.

1.5 Environment

The fatigue design data in this British Standard are applicable to internal and external air environments. They are applicable to structural steel products exposed to sea water.

They are not applicable to unprotected stainless or weathering steel products in sea water or aggressive corroding environments (e.g. chloride, sulphide, strong acid or alkali).

The data are applicable to products operating at temperatures below the creep range of the steel.

This British Standard is not applicable to products operating in the creep regime.

2 Normative references

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

BS 3643-2, *ISO metric screw threads – Part 2: Specification for selected limits of size*

BS 3692, *ISO metric precision hexagon bolts, screws and nuts – Specification*

BS 4190, *ISO metric black hexagon bolts, screws and nuts – Specification*

BS 4395 (all parts), *Specification for high strength friction grip bolts and associated nuts and washers for structural engineering*

BS 7910, *Guide to methods for assessing the acceptability of flaws in metallic structures*

BS EN 1011-1, *Welding – Recommendations for welding of metallic materials – Part 1: General guidance for arc welding*

BS EN 1011-2, *Welding – Recommendations for welding of metallic materials – Part 2: Arc welding of ferritic steels*

BS EN 1011-3, *Welding – Recommendations for welding of metallic materials – Part 3: Arc welding of stainless steels*

BS EN 10163 (all parts), *Delivery requirements for surface condition of hot-rolled steel plates, wide flats and sections*

BS EN 1993-1-8, *Eurocode 3 – Design of steel structures – Design of joint*

BS EN ISO 3506, *Mechanical properties of corrosion-resistant stainless steel fasteners – Bolts, screws*

BS EN ISO 4014, *Hexagon head bolts – Product grades A and B*

BS EN ISO 4017, *Hexagon head screws – Product grades A and B*

BS EN ISO 4762, *Hexagon socket head cap screws*

BS EN ISO 9013, *Thermal cutting – Classification of thermal cuts – Geometrical product specification and quality tolerance*

BS ISO 12108, *Metallic materials – Fatigue testing – Fatigue crack growth method*

3 Terms and definitions

For the purposes of this British Standard, the following terms and definitions apply.

3.1 cycle counting method

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 stress ranges by the operation of cycle counting.

3.2 detail class

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, G2, S_1 , S_2 , TJ, W1 or X. The categorization takes into account the stress being used in the assessment (e.g. nominal, hot-spot or shear stress), the local stress concentration at the detail, the size and shape of the maximum acceptable discontinuity, the stress direction, metallurgical effects, residual stresses and a post-weld improvement method.

3.3 design life

period within which there is a defined nominal probability that failure by fatigue cracking is unlikely to occur

NOTE This can be longer or shorter than the service life (see Annex A).

3.4 design spectrum

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 product can have different design spectra.

3.5 fatigue

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

3.6 fatigue failure

achievement of a through-section fatigue crack or a sufficiently large fatigue crack to cause static failure or excessive deformation

NOTE See Annex A.

3.7 fatigue life, N

number of stress cycles that produce a given probability of fatigue failure

3.8 fatigue loading

loading on a structure which is liable to cause fatigue cracking

NOTE It can be composed of several different types and magnitudes of loading events (see Clause 7).

3.9 fatigue strength

constant amplitude stress range, S_r , causing failure in a specified number of cycles (N)

3.10 hot-spot stress, S_H

structural stress at a weld toe or weld end

3.11 initial non-propagating stress range, S_{oc}

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

NOTE 1 Also known as constant amplitude fatigue limit, CAFL.

NOTE 2 Its magnitude depends on the structural detail being assessed. For parts in air or adequately protected against corrosion, it is assumed to be the stress range corresponding to a life of 10^7 cycles on the design S-N curve for all detail classes except S_1 and S_2 , for which it corresponds to 10^8 cycles. For unprotected joints in a corrosive environment it should be assumed that $S_{oc} = 0$ for all classes.

3.12 load spectrum

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

3.13 loading event

defined loading sequence on the structure

NOTE 1 This can be characterized by its relative frequency of occurrence as well as its magnitude and geometrical arrangement.

NOTE 2 For example, in the case of handling equipment this could involve the lifting, movement and depositing of a load. For design purposes each loading event is assumed to repeat a given number of times in the design life of the structure.

3.14 Miner's summation

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

3.15 nominal stress

structural stress that would exist in the absence of the structural discontinuity being considered

NOTE Nominal stress is a reference stress that can be calculated using elementary theory of structures. It excludes the effects of structural discontinuities (e.g. welds, openings, thickness changes) and secondary bending due to a local weld detail.

3.16 **S-N curve**

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

3.16.1 **basic S-N curve**

S - N curve, for the required probability of failure, for a detail of basic thickness (see 16.3.2) operating in air without the application of any fatigue strength improvement method apart from those given in Table 3 to Table 10

3.16.2 **design S-N curve**

S - N curve adopted for design purposes for the detail being assessed

NOTE It is derived from the relevant basic S - N curve modified, if necessary, to allow for the influence of material thickness, bending, environment, fatigue strength improvement techniques (additional to those given in Table 3 to Table 10), stress relief (see 16.3.6) or workmanship (see Clause 14).

3.16.3 **standard basic S-N curve**

basic S - N curve for 97.7% probability of survival [two standard deviations of $\log N$ below the mean ($d = 2$)] assuming that the test data are represented by a normal distribution of log life

3.17 **service life**

period in which a structure or component is required to perform safely with an acceptable probability (see A.2) that it is unlikely to require repair or withdrawal from service as a result of fatigue cracking

3.18 **slope transition point**

point on the S - N curve beyond which it is extrapolated at a shallower slope for use in cumulative damage calculations of fatigue under variable amplitude loading

3.19 **stress cycle**

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 can produce one or more stress cycles at any particular point.

3.20 **stress range S_r**

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

NOTE 1 Also known as range of stress.

NOTE 2 See 15.2 for parent metal.

NOTE 3 See 15.3 for weld metal.

3.21 **structural stress**

surface value of the linearly distributed stress across the section thickness arising from applied loads (forces, moments, pressure, etc.) and the corresponding reaction forces on the particular structural part

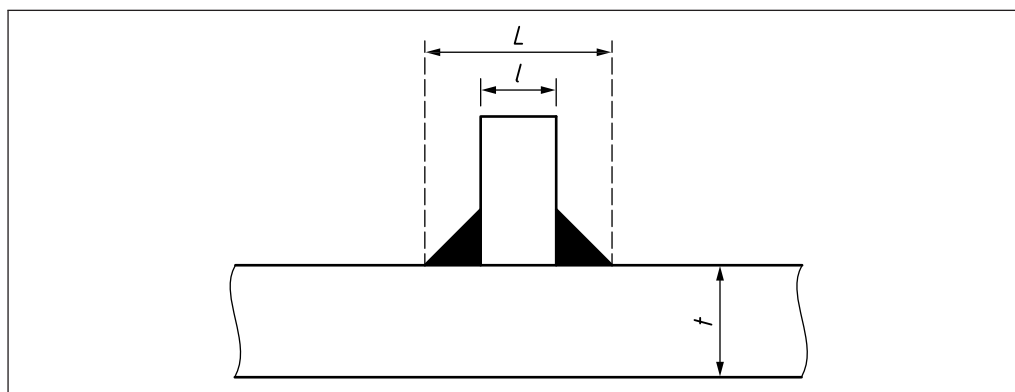
NOTE The linear stress distribution includes the effects of gross structural discontinuities (e.g. presence of an attachment, aperture, change of cross-section, misalignment, intersection of members) and distortion-induced bending moments. However, it excludes the notch effects of local structural discontinuities (e.g. weld toe, weld end) which give rise to non-linear stress distributions across the section thickness.

4 Symbols and units

Unless otherwise indicated, for the purposes of this British Standard, the following symbols and units apply.

A	Net area of cross section (in mm ²)
a	Weld throat thickness (in mm)
b	Exponent in correction term for thickness and bending
C_o	Parameter defining the mean line S_r - N relationship
C_2	Parameter defining the S_r - N relationship for two standard deviations of log N below the mean line
C_d	Parameter defining the S_r - N relationship for d standard deviations of log N from the mean line
D	Miner's summation $\sum \frac{n}{N}$
d	Number of standard deviations of log N from the mean S_r - N curve
$\boxed{A_1} E_B$	Reference elastic modulus at temperatures $T \leq 150$ °C (in N/mm ²) $\boxed{A_1}$
E_T	Elastic modulus at temperature T (in N/mm ²)
e	Axial misalignment (eccentricity or centre-line mismatch) (in mm)
F	Fatigue test factor
g	Gap between welds in intermittently welded joint (in mm)
h	Weld length (in mm)
K_b	Bolt stiffness (in N/mm)
K_c	Summation of clamped components stiffness (in N/mm)
K_f	Stress concentration factor under fatigue loading
k_m	Stress magnification factor due to misalignment
k_{tb}	Correction factor for plate thickness and bending
L	Overall attachment length, including welds (see Figure 1) (in mm)
l	Attachment length parallel to direction of loading considered (in mm)
M, M^1	Applied bending moments (in N·mm)
m	Inverse slope of log S_r -log N curve (i.e. $S_r^m \cdot N = \text{constant}$)
$N_1, N_2 \dots$	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)
N_{oc}	Constant amplitude endurance corresponding to S_{oc} (in cycles)
N_{ov}	Endurance at slope transition point, S_{ov} , on S - N curve (in cycles)
n	Number of fatigue test results

$n_1, n_2 \dots$	Number of cycles of damaging stress ranges $S_{r1}, S_{r2} \dots$, etc. in a design spectrum
P, P^1, P_N, P_L	Applied axial forces (in N)
P_r	Applied force range (in N)
R	Stress ratio (ratio of minimum to maximum algebraic value of applied stress) or chord radius in mm (see Annex G)
r	Radius (in mm)
S	Fatigue strength of the structural detail under consideration, including any required thickness correction (in N/mm ²)
S_B	Fatigue strength obtained from the basic S_r - N curve (in N/mm ²)
S_H	Hot-spot stress (in N/mm ²)
S_{Hr}	Hot-spot stress range (in N/mm ²)
S_{oc}	Constant amplitude initial non-propagating stress range (in air $S_o = S_r$ at $N = 10^7$ cycles for all design classes except S_1 and S_2 when it coincides with $N = 10^8$ cycles) (in N/mm ²)
	<i>NOTE Also known as constant amplitude fatigue limit (CAFL).</i>
S_{ov}	Stress range at slope transition point (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)
S_w	Resultant stress range on weld throat (in N/mm ²)
SD	Standard deviation of log N
W	Plate width or thickness of longitudinal attachment (in mm)
T	Applied torque (in N.mm)
t	Plate thickness of the member under consideration (in mm)
t_B	Thickness relevant to the basic S_r - N curve for the detail (in mm)
t_c	Cover plate thickness (in mm)
t_{eff}	Effective plate thickness (in mm)
w	Combined size of effective weld throats (in mm)
Z	Section modulus (in mm ³)
σ_x, σ_y	Direct stresses acting in the x- and y-directions (in N/mm ²)
$\Delta\sigma_b$	Applied bending stress range (in N/mm ²)
$\Delta\sigma_m$	Applied membrane stress range (in N/mm ²)
$\Delta\sigma_{\perp}$	Direct stress range on weld throat (in N/mm ²)
$\Delta\sigma_w$	Engineering shear stress range on weld throat (in N/mm ²)
σ_Y	Nominal tensile yield strength (in N/mm ²)
τ	Shear stress (in N/mm ²)
$\Delta\tau$	Shear stress range (in N/mm ²)
$\Delta\tau_{\perp}$	Transverse shear stress range on weld throat (in N/mm ²)
$\Delta\tau_{//}$	Longitudinal shear stress range on weld throat (in N/mm ²)
Ω	Degree of bending ($\Delta\sigma_b/(\Delta\sigma_m + \Delta\sigma_b)$)

Figure 1 Definition of length L for use in thickness-bending correction

5 Fatigue assessment procedure

A stressed element can contain a number of potential fatigue crack initiation sites. All of these should be checked (see 12.1). The regions subjected to the highest stress fluctuations and/or containing the severest stress concentrations should normally be given the highest priority. The design procedure in this British Standard involves calculation of the fatigue damage accumulation during the design life or comparison of the maximum applied stress range with the relevant constant amplitude fatigue limit. It is primarily intended for use in "safe life" design (see A.3.1). It might also be suitable for "damage-tolerant" design (see A.3.2).

The steps that should be followed are:

- a) establish the required design life of the product (see Clause 6);
- b) establish a conservative estimate of the loading expected in the life of the product (see Clause 7);
- c) estimate the resulting stress history at the detail under consideration (see Clause 15);
- d) reduce the stress history to an equivalent number of cycles n_i of different stress ranges S_{ri} using a cycle counting technique (see 15.9);
- e) classify the detail in accordance with Table 1 to Table 10;
- f) use this classification to define the basic design S_r - N curve (see 16.2);
- g) calculate the resulting fatigue life on the basis of comparison of the maximum applied stress range and the relevant CAFL (see 16.6) or a cumulative damage calculation (see 16.7);
- h) if all applied stress ranges are below the relevant CAFL (see 16.6), the detail can be assumed to have a life exceeding the specified design life in a) (see Clause 6);
- i) if some of the applied stress ranges exceed the relevant CAFL and that the life calculated using the full design stress spectrum and the cumulative damage method (see 16.7) exceeds the specified design life in a), the requirement for safe life design is met; and
- j) if the procedure in i) results in a calculated life less than the specified design life in a), the requirement for safe life design is not met. The following measures should be taken:
 - 1) adjust the detail design so that a higher S_r - N curve can be used;
 - 2) if 1) is not adequate, increase the cross-section at the potential fatigue crack initiation site to reduce the stress ranges.

- 3) if measures 1) and 2) result in severe economic consequences, use of a damage-tolerant approach involving periodic in-service non-destructive testing (NDT) for the detection of fatigue cracking may be employed to ensure that the overall probability of failure without warning during the design life is no less than that assumed for safe life design. For further guidance see **A.3.2**.

6 Design life

The design life of a product is usually pre-determined by factors such as market expectations, planned service life or obsolescence, contract or warranty requirements and uncontrollable deterioration by mechanisms other than fatigue, such as wear and tear or corrosion. Where a design life has not already been specified for a product in which fatigue is a potential failure mode, it should be selected on the basis of the period of service over which the probability of failure by fatigue is required to be low. This is achieved in design by the use of lower-bound fatigue strength data (see Clause 16) and upper-bound loading data (see Clause 7).

7 Fatigue loading

When 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 taken into account. Cyclic loading from different sources might be significant at different phases of the life of a structure, e.g. manufacture, transport, storage, installation service, and can involve different loading modes and frequencies.

Uncertainties exist in assessing both the stresses resulting from applied loads and the response of a particular joint, which control fatigue performance. The basis of the fatigue analysis should be the use of an upper bound estimate of these stresses, recording the uncertainties involved, combined 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.

Uncertainties can also exist in the number of applications of the load expected to occur during the product's design life. The design load spectrum should be selected on the basis that it is an upper bound estimate of the accumulated service conditions, including both loading and number of cycles, over the full design life of the product. The adoption of mean plus two standard deviations data for applied loads levels or an upper bound estimate based on knowledge of the actual or predicted loading environment and applied numbers of cycles, when used with the design (i.e. mean minus two standard deviations of $\log N$) S_r-N data in Clause 16, usually results in an acceptably low probability of failure during the design life, commensurate with safe-life design principles.

Because of the sensitivity of calculated life to the accuracy of estimates of stress, stress ranges should not be underestimated. Account should be taken of all likely operational and environmental loads arising from the foreseeable usage of the product during that period. Use of this approach compensates for the use of design $S-N$ curves that correspond to a finite probability of failure and means that load factors are not required.

The following are some important sources of cyclic loading that should be taken into account, any or all of which can be relevant in particular applications:

- a) fluctuating loads;
- b) acceleration forces in moving structures;
- c) pressure changes;

- d) temperature fluctuations;
- e) mechanical vibrations; and
- f) environmental loading (wind, currents and waves, especially when vortex shedding is induced, e.g. on slender members).

It is particularly important to assess dynamic magnification effects where loading frequencies are close to one of the natural frequencies of the component or structure. In some instances the loading to be assumed for fatigue design purposes is specified in the design specification. Where such information is not available, assumptions as to the loading to be expected in service should be made, and it might be useful to obtain data from existing products subjected to similar effects. In particular, in assessing an existing product, it might be possible to compile a design spectrum from strain readings or loading records obtained from continuous monitoring.

In all cases, 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 product. If it is required to convert the spectrum into a series of constant amplitude blocks, the resulting simplified spectrum should be equivalent in terms of fatigue damage to the actual spectrum. To achieve this, a sufficient number of intervals of stress should be selected to avoid discretion errors due to insufficient resolution in the stress spectrum.

8 Environmental considerations

The fatigue assessment should take into account the environmental conditions that the product is exposed to during all phases of its anticipated service life. For example, products designed to operate in seawater might be constructed and transported in an air environment, installed and commissioned in a freely corroding marine environment, and operated in seawater with cathodic protection. This British Standard provides *S-N* curves for three environmental conditions and the most appropriate curve should be used for each segment of the anticipated service life. Periods of free corrosion should be avoided, for example during temporary storage of products awaiting installation in seawater or following commissioning hydro-tests of pressurized components, as this can cause pitting and an associated reduction in the expected fatigue life.

It might be necessary to take the operating temperature into account (see **16.3.3**). The fatigue strength of steel products in air varies with temperature, in accordance with the corresponding change in elastic modulus. Therefore it is improved at subzero temperatures. However, in the case of ferritic steels, as the fracture toughness is reduced, it is possible that overall fatigue life would be reduced if the product suffers premature failure by brittle fracture from a small fatigue crack. Consequently, no allowance should be made for the beneficial effect of sub-zero temperature on fatigue strength but, where such operation is expected, for consistency with the fatigue design data provided in this British Standard, the steel used should be capable of tolerating the presence of through-section fatigue cracking at the minimum anticipated temperature. This is achieved with steels that have minimum low temperature impact properties specified in the material standard and are operated at or above the stated temperature.

There are no particular recommendations for austenitic stainless steels operating at low temperature, as they are not susceptible to brittle fracture. For elevated temperatures, no effect is assumed for temperatures up to 150 °C, but at temperatures higher than this fatigue strength decreases in line with the decrease in elastic modulus for temperatures below the creep range of the steel concerned. No guidance is provided for combined creep and fatigue.

9 Factors on fatigue life

The reliability of a product's fatigue life is dependent on the following factors:

- a) selection of a safe level of fatigue loading (see Clause 7);
- b) correct calculation of stress ranges (see Clause 15);
- c) correct detail classification (see Clause 12);
- d) application of appropriate controls during manufacture (see Clause 14);
- e) in some cases, fatigue testing might be appropriate (see Annex E).

The fatigue design data provided in this British Standard are in the form of mean $S-N$ curves and the corresponding standard deviations of $\log N$ to enable different probabilities of survival to be adopted. The standard basic $S-N$ curves (see 16.2) represent 97.7% probability of survival, as they are based on the mean minus at least two standard deviations of $\log N$ curves for relevant experimental data. Their use therefore indicates a finite probability of failure (up to 2.3%) for the calculated life. In some circumstances, for example in a failure investigation of a part that has experienced fatigue cracking in service, it might be more appropriate to assume a higher probability of failure and make use of an $S-N$ curve less than two standard deviations of $\log N$ below the mean. Conversely, it might be appropriate to use $S-N$ curves based on the mean minus more than two standard deviations of $\log N$ for components with inadequate structural redundancy or difficult access for inspection. In selecting the number of standard deviations to be used to define the design $S-N$ curve, account should be taken of the accessibility of the joint and the proposed degree of manufacture and in-service inspections, as well as the consequences of failure. As a crack grows in one part of a structure, the load might be shed to other members and lead to further fatigue cracks in those members.

10 Features influencing fatigue behaviour

For both welded and bolted steel products the fatigue life is normally governed by the fatigue behaviour of the joints, including both main and secondary joints [2, 3]. Even fabrication or handling aids, such as welded brackets or lifting lugs, that remain in the completed product could provide sites for fatigue cracking and should therefore be assessed. Optimum fatigue behaviour is obtained when the product is detailed and constructed such that stress concentrations are kept to a minimum and, where possible, the elements are able to deform in their intended ways without introducing secondary deformations and stresses due to local restraints. Stresses can also be reduced by increasing the thickness of parent metal or the weld throat, depending on the potential failure mode. In the case of the former, allowance might need to be made for the fact that fatigue strength tends to decrease with increasing plate thickness for some types of joint when assessing the resulting benefit (see 16.3.2).

Optimum joint performance is achieved by avoiding joint eccentricity and misalignment, welds at free edges, and by other controls over the quality of the joints.

In the specific case of pipe-to-pipe joints made from seamless pipe, the accumulation of maximum allowable manufacturing tolerances for thickness, ovality and diameter leads to a large potential for girth weld misalignment and associated penalty on fatigue life. Apart from the resulting introduction of secondary bending stresses, such misalignment can also intensify the stress concentration due to the geometry of the weld root bead in welds made from one side. It is therefore advantageous to record the actual range of tolerances achieved for each batch of pipe supplied and use this information to calculate the maximum potential misalignment. Performance is also adversely affected by concentrations of stress at holes, openings and re-entrant corners. Guidance in these aspects is given in Table 1 to Table 10, Annex B, Annex C and Annex G.

The magnitude and nature of stresses that cause propagation of a crack and therefore 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 10.

11 Fracture mechanics

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

12 Classification of details

12.1 General

For the purposes of fatigue design, joints are divided into several classes, each with a corresponding design *S-N* curve (see 16.2). This classification depends upon the following:

- a) the type of stress being used to assess the detail (nominal or hot-spot stress);
- b) the geometrical arrangement and proportions of the detail;
- c) the direction of the fluctuating stress relative to the detail;

NOTE Any reference to transverse or longitudinal welds, welded joints or welded attachments refers to their orientation with respect to the direction of stressing.

- d) the location of possible fatigue crack initiation at the detail; and
- e) the methods of manufacture and inspection.

In any product or component that is liable to be subjected to repeated applications of stress, every welded joint, including non-structural attachments, lifting lugs and temporary fabrication aids left in place, or other forms of stress concentration, such as a bolt hole or cut edge, is potentially a source of fatigue cracking. Each part of every constructional detail should be assessed individually and should, where possible, be placed in its relevant joint class in accordance with Table 1 to Table 10. Where this is not possible, the detail should be classified in accordance with Clause 13.

In bolted or riveted joints, fatigue cracks normally initiate from the bolt or rivet hole or, in the case of friction-grip bolted joints, in the plate by fretting or in the bolt itself. In plate with cut edges or welded details fatigue cracks can potentially initiate in the following places:

- 1) from any point on the plate edge or plate surface;

- 2) 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;
- 3) 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, crack initiation can occur in the parent metal or in the weld throat. Both possibilities should be assessed by taking into account the appropriate classification and stress range. Similarly, fatigue crack initiation can occur from a weld toe on either the outside or inside of a full-penetration girth weld between pipes or tubes. The most critical location depends on the relevant classification and stress range, both of which can differ between the outside and inside. For other details, the classifications given in Table 1 to Table 10 cover crack initiation at the location indicated. Notes on the potential modes of failure for each detail are given in Annex B.

12.2 Classification of details

Table 1 to Table 10 correspond to the following basic types of details:

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

Detail classifications are given for assessments based on applied nominal stresses and, where appropriate, hot-spot stresses. Where relevant, the need to apply a correction for thickness and bending (see 16.3.2) and the applicability of a weld toe improvement technique (see 16.3.5) are included. Each classified detail is illustrated and given a type number. Table 1 to Table 10 also give associated criteria and diagrams that illustrate the geometrical features and potential crack locations for the direction of loading shown which determine the class of each detail. They 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 to all criteria in Table 1 to Table 10 appropriate to its type number or if a suitable classification can be justified on the basis of relevant published fatigue data or the results of specific fatigue tests in accordance with Annex E. Class A is generally inappropriate for structural work and therefore no design data are provided. The practical difficulty of achieving the special inspection standards relevant to classes B and C might limit the feasibility of adopting these classifications in structural work.

Table 1 Classification of details: plain material free from welding

Type no.	Product form	Location of potential crack initiation	Detail	Manufacturing requirements	Special requirements	Design stress area	Class ^{a)}	Notes	Sketch
1.1	Rolled steel plates and sections	Away from all welds or 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			A	See B.2.2	
1.2				Edges as rolled or machined smooth. No flame cutting. The surface condition should be in accordance with BS EN 10163 as a minimum.			B ^{b)}		
1.3		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. The surface condition should be in accordance with BS EN 10163 as a minimum.	Flame-cut edges in steel sheets cold formed after cutting should be checked for cracking and any such cracks ground out to leave a smooth edge surface	Net cross section	B ^{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.	
1.4				Any cutting of edges by planning or machine flame cutting with controlled procedure Thermal cut quality in accordance with BS EN ISO 9013 with mean height of the profile range 2. No visible gouges greater than 0.5 mm deep. Any deburring or rectification by grinding should be longitudinal to the plate edge. No repair of gouges by welding.		Net cross section	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 Q).	
1.5		At a small hole (may contain bolt for minor fixtures)		Hole drilled or reamed. Minimum distance between centre of hole and plate edge = 1.5 x hole diameter		Net cross section	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.	
1.6						Gross cross section	B ^{b)}	The classification does not include allowance for the stress concentration created by the hole.	

^{a)} One class lower in the case of unprotected weathering steels.^{b)} For unprotected steel exposed to sea water or other corrosive environments the class is reduced to C.

Table 2 Classification of details: bolted and riveted connections

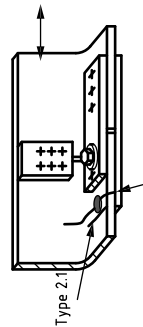
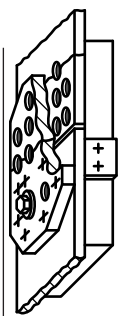
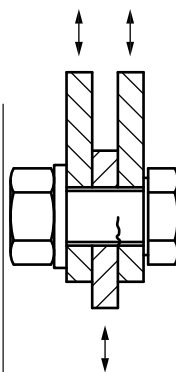
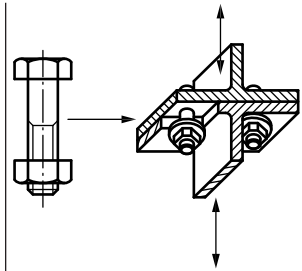
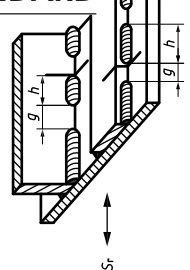
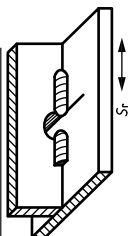
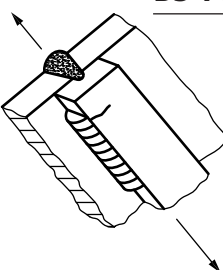
Type no.	Product form	Location of potential crack initiation	Detail	Manufacturing requirements	Special requirements	Design stress area	Class	Thickness and bending correction (see 16.3.2)	Notes	Sketch
2.1	Rolled steel plates and sections	At joint, in plate away from the hole	Double covered symmetrical joint made with high strength friction grip bolts	Holes drilled or reamed. Bolts should be tightened in accordance with BS EN 1993-1-8.		Gross section of plate	C	Not applicable	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.	 Type 2.1 Types 2.2 and 2.3
2.2		At joint, in plate from the edge of a hole	Double covered symmetrical joint made with rivets or precision bolts	Hot-driven	Faced under head and turned on shank in accordance with BS 4190	Net section of plate	C		See B.2.2.2 regarding the tightening of bolt groups. The classifications include allowance for the stress concentrations created by the bolt hole.	
2.3			Single covered joint made with high strength friction grip bolts				D			
2.4			Joint made with rivets				D			
2.5			Joint made with precision bolts and close tolerance holes.				D			
2.6		Anywhere in shank for bolts loaded in shear	Joint made with black bolts.	Torque tightened using a controlled procedure.		Cross-sectional area of shank	E	Not applicable	Shear failure of the bolt itself	
2.7			Any bolted lap joint but thread not in shear plane	Type 2.3 or 2.4 apply as long as bolt torque-tightened using controlled procedure that is designed to carry entire shear load in friction grip throughout its design life, taking into account any relaxation that might occur.			G			
2.8							S_1			
2.9	Threaded fasteners	At thread root.		Fastener in a butt joint with fastener axis parallel to S_1 . Bolts conforming to BS 3692, BS 4395 (all parts). Screw threads conforming to BS 3643-2. BS EN ISO 4014, BS EN ISO 4017, BS EN ISO 4762. BS EN ISO 3506	See 14.3.3 This classification is not applicable to bolts that have been welded.	Tensile stress area (see 15.8)	X	Applicable assuming $\Delta b = 0$ and $b = 0.25$.	This classification applies to failure at the thread root in normal commercial quality threaded fasteners. See 15.8 and 16.2.2 for type limitations and enhancements.	

Table 3 Classification of details: butt welds and continuous welded attachments essentially parallel^(A) to the direction of applied stress

Type no.	Product form	Location of potential crack initiation	Detail	Manufacturing requirements	Special treatments or requirements	Design stress area	Class		Thickness and bending correction (see 16.3.2)	Notes	Sketch
							Nominal stress	Hot-spot stress			
3.1	Rolled steel plates, sections and built-up members	Weld surface or embedded flaw	Butt weld with full penetration and no permanent backing strip.	Weld reinforcement dressed flush.	Proved free of all flaws which are likely to degrade the joint below its stated classification (see 14.3.4)	Minimum transverse cross section of member at location of potential crack initiation	B ^(B)	Not applicable	Not applicable	Finish machining should be in the direction of S_r . In view of the difficulty of ensuring freedom from significant flaws (see 14.3.4), this class is only recommended for use in exceptional circumstances (see B.2.2.1 and B.3.1)	
3.2		Fillet weld root or ripples on weld surface away from the weld end.	Butt weld with full penetration or butt or fillet welded web or attachment (in the direction of S_r), including lap joints.	All welds continuous with no stop/starts. Butt welds with full penetration. If used, backing should be incorporated (e.g. joggle joint), continuous and either not attached or attached by continuous fillet welds.	Weld toe improvement techniques not relevant.		C	Not applicable	Not applicable	Accidental stop/starts are not uncommon even 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.	
3.3		Stop / start position on weld surface away from the weld end.		As type 3.2 but with stop/starts.			D	Not applicable	Not applicable	For the situation at the ends of flange cover plates see joint type 4.5. 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 3.6.	

Table 3 Classification of details: butt welds and continuous welded attachments essentially parallel^{a)} to the direction of applied stress

Type no.	Product form	Location of potential crack initiation	Detail	Manufacturing requirements	Special treatments or requirements	Design stress area	Class		Thickness and bending correction (see 16.3.2)	Notes	Sketch
							Nominal stress	Hot-spot stress			
3.4		Weld end at an intermediate gap in a longitudinal weld	Intermittent fillet weld with $g/h \leq 2.5$		Weld toe improvement techniques not suitable.	Minimum transverse cross section of member at location of potential crack initiation	E	Not applicable	Not applicable	The limiting gap ratio g/h applies even though adjacent welds can 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 is reduced to F.	
3.5		At end of longitudinal weld in flange at cope hole	Web to flange joint at cope hole.	Cope hole no higher than 40% of web height Weld might or might not continue round plate ends.		Minimum transverse cross section of member at location of potential crack initiation. Based on normal stress range in flange S_f and shear stress range in web $\Delta\tau$ at weld ends, with design curve being used in conjunction with normal stress range	F if $\Delta\tau \leq 0.15S_r$, otherwise with class F allowable stress ranges multiplied by the greater of $1.74(\Delta\tau/S_f)$ or 0.5.	D	Applicable assuming $t_{w,r} =$ flange thickness and $b = 0.25$	The existence of the cope hole is allowed for in the nominal stress classification. It should not be regarded as an additional stress concentration in relation to cracking in the flange. With regard to a butt weld in the web, see types 6.2 and 6.3.	
3.6		At weld end in backing strip	Discontinuous fillet weld attaching backing strip	Backing strip to be continuous.		Minimum transverse cross section of member at location of potential crack initiation.	E	D	Not applicable	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 3.3.	

^{a)} The classifications apply for stresses acting within $\pm 15^\circ$ of the stressing direction shown. For greater angles see 15.2.^{b)} For unprotected steel exposed to sea water or other corrosive environments the class is reduced to C.

Table 4 Classification of details: welded attachments on the surface or edge of a stressed member^{A)}

Type no.	Product form	Location of potential crack initiation	Detail	Manufacturing requirements	Special treatments or requirements	Design stress area	Class		Thickness and bending correction (see 16.3.2)	Notes	Sketch
							Nominal stress	Hot-spot stress			
4.1	Rolled steel plates, sections, tubes, and built-up members	At weld toe	Fillet welded shear connector. Stud diameter or bracket thickness ≤ 15 mm. For larger values treat as type 4.3 equating diameter or thickness to l .		Weld toe improvement techniques applicable but whole toe should be treated	Minimum transverse cross section of member at location of potential crack initiation	E	D	Applicable assuming $b = 0.25$		
4.2		At weld toe or end	Small transverse (thickness $l \leq 15$ mm) or longitudinal (length $l \leq 15$ mm) attachment ⁴⁾	Fillet or butt welds with welds continued around ends or not. Care needed to avoid undercutting plate edge if weld ends at or close to plate edge. Any such undercutting should be ground out.	Weld toe improvement techniques applicable but only if weld continued around ends in the case of longitudinal attachments. Weld toe improvement might lead to fatigue failure from weld root but the stated benefit still applies.		E	D	Applicable assuming $b = 0.25$	Butt welded joints require an additional reinforcing fillet so as to provide a toe profile transverse to S_y similar to that which would exist in a fillet welded joint (see B.4.2.2)	
4.3		At weld toe or end	Transverse attachment with $15 \text{ mm} < l \leq 150 \text{ mm}$, or longitudinal attachment with $15 \text{ mm} < l \leq 150 \text{ mm}$ and $W \leq 50 \text{ mm}$ ⁴⁾				F	D		The decrease in nominal stress class with increasing attachment length is because more load is transferred into the longer gusset, giving an increase in stress concentration.	
4.4		At weld toe or end	Long, narrow attachment with $l > 150 \text{ mm}$, $W \leq 50 \text{ mm}$				F2	D			
4.5		At weld toe or end	Long, wide attachment with $l > 150 \text{ mm}$, $W > 50 \text{ mm}$, $t_c \leq 32 \text{ mm}$				G	D	Applicable assuming $b = 0.25$ ⁴⁾	The nominal stress 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. The use of cover plates wider than the flange, to which they are attached, is not recommended.	
4.6			$l > 150 \text{ mm}$, $W > 50 \text{ mm}$, $t_c > 32 \text{ mm}$				G2	D			Cover plate length l , width W and thickness t_c

Table 4 Classification of details: welded attachments on the surface or edge of a stressed member^{A)}

Type no.	Product form	Location of potential crack initiation	Detail	Manufacturing requirements	Special treatments or requirements	Design stress area	Class		Thickness and bending correction (see 16.3.2)	Notes	Sketch
							Nominal stress	Hot-spot stress			
4.7	Rolled steel plates, sections, tubes, and built-up members	At weld toe or end	Any attachment fillet or butt welded to plate edge	Care needed to avoid undercut on plate corners or to grind it out to a smooth profile should it occur. In particular, weld returns across a corner should be avoided.	Weld toe improvement techniques only applicable with weld continued around ends of attachment.	Minimum transverse cross section of member at location of potential crack initiation	G	D	Not applicable	This type applies regardless of the shape of the end of the attachment. The classification applies to all sizes of attachment both in-plane and out-of-plane with respect to the loaded member. 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 5.6).	

^{A)} The classifications apply for stresses acting within $\pm 15^\circ$ of the stressing direction shown. For greater angles see 15.2.

Table 5 Classification of details: full penetration butt welds between co-planar plates A), B)

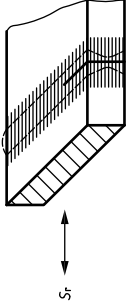
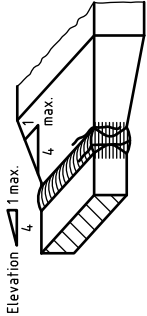
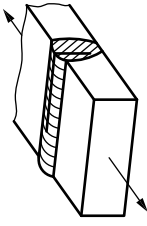
Type no.	Product form	Location of potential crack initiation	Detail	Manufacturing requirements	Special treatments or requirements	Design stress area	Class		Thickness and bending correction (see 16.3.2)	Notes	Sketch
							Nominal stress	Hot-spot stress			
5.1	Rolled steel plates only	Weld surface or embedded flaw	Transverse butt weld between plates of equal width and thickness Longitudinal axes in line	Full penetration weld. Misalignment slope ≤ 1 in 4. Weld reinforcement dressed flush with all traces of the original weld toe removed.	Proved free of all flaws which are likely to degrade the joint below its stated classification (see 14.3.4)	Minimum transverse cross section of member at location of crack initiation. These classifications do not include allowance for any misalignment of the joint (see B.5.2.1)	C	Not applicable	Not applicable	In view of view of the difficulty of ensuring freedom from significant flaws (see 14.3.4), this class should not normally be used in structural work (see B.2.2.1 and B.5.2.6).	
		At weld toe	Transverse butt welds made from both sides by any arc welding process in any position. Longitudinal axes in line Any width or thickness change ≤ 1 in 4 slope	Full penetration weld. Grind smooth any undercut.	Proved free of all flaws which are likely to degrade the joint below its stated classification (see 14.3.4) Weld toe improvement techniques applicable		D	D			
5.3		At root or toe of weld root bead (Note: classification for weld cap toe same as that for welds made from both sides)	Transverse butt weld made from one side either with temporary non-fusible backing or without backing.	Plate surfaces in contact with temporary backing should be aligned within ± 1 mm to justify Class E. Grind smooth undercut on weld face.	Proved free of all flaws which are likely to degrade the joint below its stated classification especially at the weld root where there should be full weld penetration but freedom from excess penetration and significant undercut (see 14.3.4). Weld toe improvement techniques applicable with access to root.	Weld root condition assessed by appropriate NDT. Without direct access to root inspection by automated ultrasonic testing (AUT) is recommended (see B.5.2.4). Weld root condition not assessed directly by NDT	E	E		Weld root condition assessed by appropriate NDT. Without direct access to root inspection by automated ultrasonic testing (AUT) is recommended (see B.5.2.4).	
							F2	F2			Weld root condition not assessed directly by NDT

Table 5 Classification of details: full penetration butt welds between co-planar plates^{A)}, B)

Type no.	Product form	Location of potential crack initiation	Detail	Manufacturing requirements	Special treatments or requirements	Design stress area	Class		Thickness and bending correction (see 16.3.2)	Notes	Sketch
							Nominal stress	Hot-spot stress			
5.5		At weld root	Transverse butt weld made from one side onto permanent backing strip, whether fillet or tack welded in position or integral (e.g. joggle joint)	Full penetration weld.	Weld toe improvement techniques not applicable to weld root.	Minimum transverse cross section of member at location of crack initiation. These classifications do not include allowance for any misalignment of the joint (see B.5.2.1).	F	F			
5.6	Rolled steel plates only	At weld toe	Transverse butt weld between plates of different width. Longitudinal axes in line. Abrupt width change.	Full penetration weld. Corner welds should be built up to radius $\geq 0.15W$ and corner reinforcement ground flush for $2t$.	Proved free of all flaws which are likely to degrade the joint below its stated classification (see 14.3.4). As-welded toes suitable for application of weld toe improvement technique.	Minimum transverse cross section of member at location of crack initiation	F2	D	 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 nominal stress classification. Stress concentrations due to abrupt changes of width can often be avoided by tapering the wider plate (see type 5.2) Where the end of one plate is butt welded to the surface of another, refer types 7.1 and 7.2.		

^{a)} The joints covered by this table might 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 14.3.4).

^{b)} The classifications apply for stresses acting within $\pm 15^\circ$ of the stressing direction shown. For greater angles see 15.2.

^{A)} The joints covered by this table might 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 14.3.4).

^{B)} The classifications apply for stresses acting within $\pm 15^\circ$ of the stressing direction shown. For greater angles see 15.2.

Table 6 Classification of details: transverse butt welds in sections, tubes and pipes ^{A)}

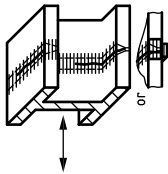
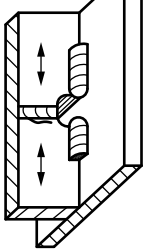
Type no.	Product form	Location of potential crack initiation	Detail	Manufacturing requirements	Special treatments or requirements	Design stress area	Class		Thickness and bending correction (see 16.3.2)	Notes	Sketch
							Nominal stress	Hot-spot stress			
6.1	Rolled steel sections and built-up members	Embedded flaw in weld.	Butt weld joining two sections of similar profile end to end with longitudinal axes in line.	Full penetration weld. Misalignment slope ≤ 1 in 4. Dressing of the weld overfill advised to overcome poor profile resulting from the greater misalignments which can occur in the jointing of sections.	Proved free of all flaws which are likely to degrade the joint below its stated classification (see 14.3.4).	Minimum transverse cross section of member at location of crack initiation.	F2	Not applicable	Not applicable	This joint is prone to weld flaws, which are difficult to detect, in the region of the web/flange junction. A higher class may be justifiable in exceptional circumstances (see B.6).	
6.2		Web butt weld toe at cope hole		End of butt weld and reinforcement within a distance equal to cope hole radius to be ground flush (see Figure B.8). Weld not ground.		Minimum transverse cross section of member at web butt weld toe. This classification does not include allowance for stress concentration due to cope hole.	D	D	 Applicable assuming $b = 0.2 \sqrt{a}$	Triangular shaped cope holes are not recommended.	
							E	E			

Table 6 Classification of details: transverse butt welds in sections, tubes and pipes A)

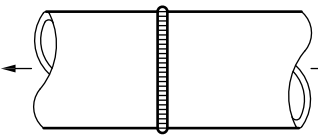
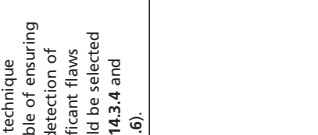
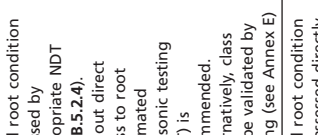
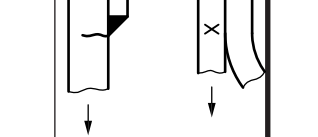
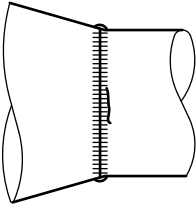
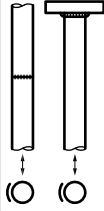
Type no.	Product form	Location of potential crack initiation	Detail	Manufacturing requirements	Special treatments or requirements	Design stress area	Class		Thickness and bending correction (see 16.3.2)	Notes	Sketch
							Nominal stress	Hot-spot stress			
6.4	Steel pipes or tubes	Weld surface or embedded flaw	Circumferential butt weld in tube	Weld made from one or both sides with overfill on both outside and inside dressed flush	Proved free of all flaws which are likely to degrade the joint below its stated classification (see 14.3.4)	Minimum transverse cross section of member at location of crack initiation.	C	Not applicable	Not applicable	NDT technique capable of ensuring the detection of significant flaws should be selected (see 14.3.4 and B.5.2.6).	
		Toe of weld cap or root bead, or toe of weld cap in welds made from one side		Weld made from one or both sides. Weld toe improvement techniques applicable.		This classification does not include allowance for any misalignment of the joint or a thickness change (see B.5.2.1)	D		Applicable assuming $b = 0.2 \sqrt{a}$		
6.6		At weld root bead toe on inside	Circumferential butt weld made from one side either with temporary non-fusible backing or without backing.	Full penetration weld. Pipe surfaces in contact with temporary backing should be aligned within ± 1 mm to justify Class E.	As type 5.3. Weld toe improvement techniques only applicable if access to root.		E		Applicable assuming $b = 0.2 \sqrt{a}$	Weld root condition assessed by appropriate NDT (see B.5.2.4). Without direct access to root automated ultrasonic testing (AUT) is recommended. Alternatively, class can be validated by testing (see Annex E)	
							F2	F2		Weld root condition not assessed directly by appropriate NDT	
6.8		At butt weld root or toe of fillet weld if used	Circumferential butt weld made from one side onto permanent backing strip whether fillet or tack welded in position or integral (e.g. joggle joint)	Full penetration weld.			F	F	Applicable assuming $b = 0.2$, related to member X in joggle joint $\sqrt{a}$		
											

Table 6 Classification of details: transverse butt welds in sections, tubes and pipes A)

Type no.	Product form	Location of potential crack initiation	Detail	Manufacturing requirements	Special treatments or requirements	Design stress area	Class		Thickness and bending correction (see 16.3.2)	Notes	Sketch
							Nominal stress	Hot-spot stress			
6.9	Steel tubes	At weld toe on inside or outside of tube	Circumferential butt weld between tubes and conical sections.	See types 6.4 to 6.8, as appropriate.	See types 6.4 to 6.8 as appropriate	Minimum transverse cross-section of member at location of potential crack initiation.	C	C	See type 6.4 to 6.8, as appropriate	Class and stress should be those corresponding to the joint type as indicated in types 6.4 to 6.8, but the nominal stress has also to include the stress concentration factor due to overall form of the joint, including any thickness change. If a stiffener or diaphragm is situated adjacent to the joint, see also type 9.3.	
							D	D			
6.10	Solid or hollow tubular members	At weld toe in tube	Fillet or butt weld between solid or hollow tube and any member		Weld toe improvement techniques not applicable.	Minimum transverse cross-section of tubular member at weld toe.	S ₁	Not applicable	Not applicable	Shear failure in tubular member under applied shear stress. For combined loading see 15.2 and Table 17.	
		At weld root				Effective weld throat area (see 15.3)	S ₂	Not applicable			

A) The classifications apply for stresses acting within $\pm 15^\circ$ of the stressing direction shown. For greater angles see 15.2.

Table 7 Classification of details: load carrying fillet and T-butt joints ^{A)} between plates ^{B)}

Type no.	Product form	Location of potential crack initiation	Detail	Manufacturing requirements	Special treatments or requirements	Design stress area	Class	Thickness and bending correction (see 16.3.2)	Notes	Sketch
							Nominal stress	Hot-spot stress		
7.1	Rolled steel plates, sections and built-up members	At weld toe in member X	Weld joining two members end to end with third member transverse through joint. Member Y can be regarded as one with a non-load-carrying weld (see joint type 4.2 or 4.3).	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. Weld toe improvement techniques applicable but note need to assess partial penetration welded joints with respect to potential failure through the weld throat (see type 7.8).	Cross section of member X at weld toe. Allowance should be made for any misalignment of the joint exceeding that already allowed for in the classification (see B.7.2 and B.5.2.1). In some circumstances (see B.7.2) it might be necessary to include a stress concentration factor in the nominal stress design calculation.	F	D	Weld metal failure does not govern with full penetration welds.	
7.2				Partial penetration butt or fillet weld with longitudinal axes in line.			F2	D	In this type of joint failure is likely to occur in the weld throat unless the weld is made sufficiently large. (See joint type 7.8).	
7.3			Weld joining the end of one member to the surface of another.	Full penetration butt weld made from one or both sides.		Cross section of member X at weld toe	F	D	See joint type 7.1.	
7.4			Member Y can be regarded as one with a non-load-carrying weld (see joint type 4.2 or 4.3).	Partial penetration butt or fillet welds made from both sides			F2	D	See joint type 7.2.	

Table 7 Classification of details: load carrying fillet and T-butt joints A) between plates B)

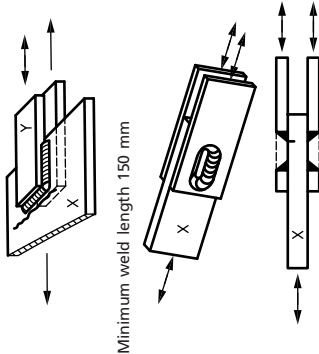
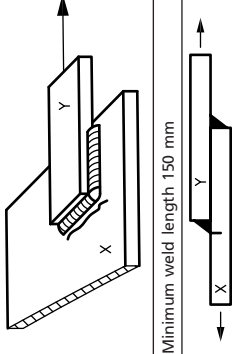
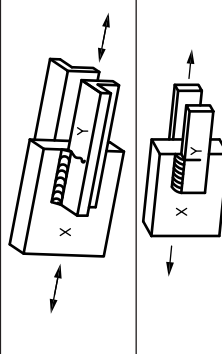
Type no.	Product form	Location of potential crack initiation	Detail	Manufacturing requirements	Special treatments or requirements	Design stress area	Class		Thickness and bending correction (see 16.3.2)	Notes	Sketch
7.5	Rolled steel plates, sections and built-up members	At weld toe in member X	Transverse load carrying fillet weld in lap joint on both sides of plate symmetrically.	Care needed to avoid undercutting plate edge if weld ends at or close to edge. Any such undercutting should be ground out.	Weld toe improvement techniques applicable but note need to assess joints with respect to potential failure through the weld throat (see type 7.8 or 7.10)	Cross section of member X at weld toe.	F2	D	Applicable assuming $b = 0.25$; related to plate X (4)	The nominal stress 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 nominal stress in the gusset at the end of the cross brace varies substantially across the section. For assessing the nominal stress in the gusset X the effective width (W) should be taken as shown for type 7.6.	
7.6		At weld toe in member X	Transverse load carrying fillet weld in lap joint on one surface only			These classifications do not include allowance for bending due to misalignment of the applied forces (see B.5.2.1)	G	D		For failure in the cross brace at Z, the cross brace, Y, is the "member" and the gusset is the "attachment" (See type 7.7)	
7.7		At weld end in member Y	Longitudinal load carrying fillet welds, with the weld end on a plate edge. Weld length $\geq$ cover plate width	Welds on both edges of member Y. Any undercutting of plate edge should be ground out.	Weld toe improvement techniques not suitable.	Cross section of member Y	G	D	Not applicable	W= effective width for nominal stress calculation This type applies regardless of the shape of the end of the attachment. 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. For fatigue cracking in member X see types 7.5 or 7.6.	

Table 7 Classification of details: load carrying fillet and T-butt joints ^{a)} between plates ^{b)}

Type no.	Product form	Location of potential crack initiation	Detail	Manufacturing requirements	Special treatments or requirements	Design stress area	Class	Thinness and bending correction (see 16.3.2)	Notes	Sketch
							Nominal stress	Hot-spot stress		
7.8	Rolled steel plates, sections and built-up members	At weld root	Cruciform, lap or T-joint	Fillet or partial penetration weld made from both sides	Weld toe improvement techniques not applicable	Effective weld throat area (see 15.3) Allowance to be made for any misalignment of cruciform joints exceeding that already allowed for in the classification and for that in a single lap joint (see B.5.2.1)	W1 if $\Delta\tau_{xy} < 0.3\Delta\sigma_w$ (see 15.3) S ₂ if $\Delta\tau_{xy} \geq 0.3\Delta\sigma_w$ (see 15.3)	Not applicable	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.	
7.9		At weld root	Corner or T-joint	Fillet, partial or full penetration weld made from one side		Effective weld throat area (see 15.3)	G	Not applicable		
7.10		At fillet weld root	Lap joints	Fillet welded		Effective weld throat area (see 15.3)	S ₂	-	Refers to fatigue failure by shear across weld throat	

^{a)} 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.4.2.2).

^{b)} The classifications apply for stresses acting within $\pm 15^\circ$ of the stressing direction shown. For greater angles see 15.2.

Table 8 Classification of details: slotted connections and penetrations through stressed members

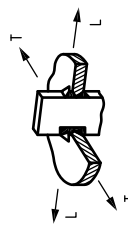
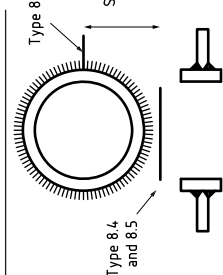
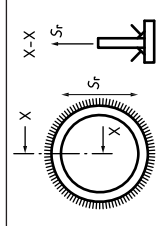
Type no.	Product form	Location of potential crack initiation	Detail	Manufacturing requirements	Special treatments or requirements	Design stress area	Class		Thickness and bending correction (see 16.3.2)	Notes	Sketch	
							Nominal stress	Hot-spot stress				
8.1	Steel plates, sections or tubes	At weld toe in stressed member	Full penetration butt weld connecting slotted through member	Length of slotted through member, parallel to S_r , ≤ 150 mm Length > 150 mm	Weld toe improvement techniques applicable	Minimum transverse cross-section of member at location of potential crack initiation	F	D	Applicable assuming $b = 0.25$	These classifications do not apply to fillet welded joints (see joint type 7.2). However they do apply to loading in either direction (L or T in the sketch).		
8.2							F2	D				
8.3	Steel plates, sections or tubes	Weld surface	Welded penetration, on a plane essentially perpendicular to S_r	Full penetration butt weld			D	Not applicable	Not applicable	In this situation the relevant nominal 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 8.6).		
8.4		At weld toe adjacent to penetration		Full penetration welds	Weld toe improvement techniques applicable but the possibility of failure through a partial penetration weld should be considered (see type 8.6).		F	D	Applicable assuming $b = 0.25$ (a)			For failure at weld toe (see sketch).
8.5							F2	D				
8.6	Steel plates, sections or tubes	At weld root	Welded penetration, on a plane essentially perpendicular to S_r	Fillet or partial penetration welds	Weld toe improvement techniques not applicable	Effective weld throat area (see 15.3)	W1 if $\Delta\sigma_{\parallel} < 0.3\Delta\sigma_w$ (see 15.3) S_2 if $\Delta\sigma_{\parallel} \geq 0.3\Delta\sigma_w$ (see 15.3)		Not applicable	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 8.3. Weld metal failure does not govern with full penetration welds.		

Table 9 Classification of details: circular tubular members A)

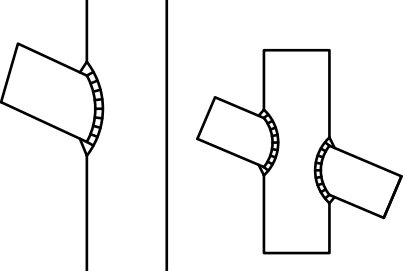
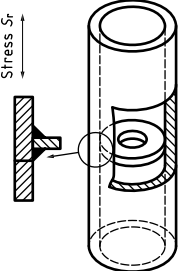
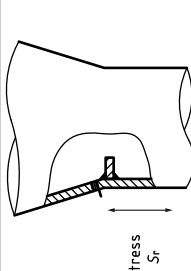
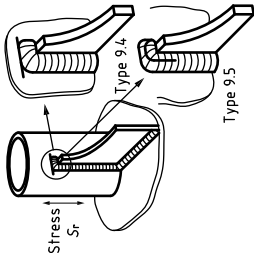
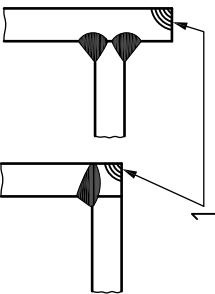
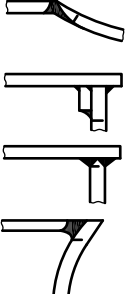
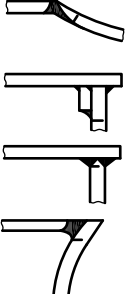
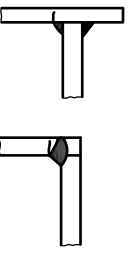
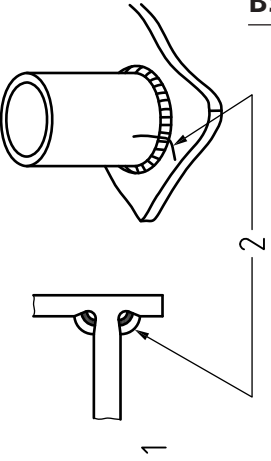
Type no.	Product form	Location of potential crack initiation	Detail	Manufacturing requirements	Special treatments or requirements	Design stress area	Class		Thickness and bending correction (see 16.3.2)	Notes	Sketch
							Nominal stress	Hot-spot stress			
9.1	Steel tubes	Weld toe in chord or brace	Tubular nodal joint	Full penetration welds	Weld toe improvement techniques applicable	Minimum transverse cross-section of tube at weld toe	-	TJ	Applicable assuming $b = 0.25$ and $\Delta\sigma_b = 0$ (4)	This type of detail is not classified on the basis of nominal stress. Consequently, design should be based on the hot-spot stress range (see Annex G)	
9.2		At weld toe in tube	Weld attaching diaphragm or stiffener to tubular member				F	D	Applicable assuming $b = 0.25$	S_r might be intensified as a result of the presence of the attachment, particularly if it is large. Nominal stress should include the stress	
9.3			Bevel butt or fillet welded attachment in a region of stress concentration				E, F or F2 depending on attachment size (see types 4.2 to 4.5)	D	Applicable assuming $b = 0.25$	concentration factor due to overall shape of adjoining structure.	

Table 9 Classification of details: circular tubular members A)

Type no.	Product form	Location of potential crack initiation	Detail	Manufacturing requirements	Special treatments or requirements	Design stress area	Class		Thickness and bending correction (see 16.3.2)	Notes	Sketch
							Nominal stress	Hot-spot stress			
9.4	Steel tubes	At weld toe in tube	Welded gusseted connections	Butt or fillet welded	Weld toe improvement techniques applicable but gusset shape should also be tapered to provide smooth transition from gusset edge to tube surface.	Minimum transverse cross-section of tube at weld toe	F	D	Applicable assuming $b = 0.25 \sqrt{a}$	The design stress has to include any local bending stress adjacent to the weld end.	
9.5		At weld root		Fillet welded	Weld toe improvement techniques not applicable	Effective weld throat area. (see 15.3)	W1 if $\Delta\sigma_w < 0.3\Delta\sigma_w$ (see 15.3) S ₁ if $\Delta\sigma_w \geq 0.3\Delta\sigma_w$ (see 15.3)	Not applicable	Not applicable	For failure in the weld throat of fillet welded joints.	

^{A)} The classifications apply for stresses acting within $\pm 15^\circ$ of the stressing direction shown. For greater angles see 15.2.

Table 10 Classification of details: branch connections in pressurized containers

Type no.	Product form	Location of potential crack initiation	Detail	Manufacturing requirements	Special treatments or requirements	Design stress area	Detail class		Thickness and bending correction (see 16.3.2)	Notes	Sketch
							Nominal stress	Hot-spot stress			
10.1	Steel plates	At crotch corner	Nozzle to shell joint		Fatigue strength improved with generous radius on nozzle corner	Nozzle section normal to plane of cracking	D	Not applicable	Not applicable	Nominal stress has to include the relevant stress concentration factor.	 1 = Cracks radiate from corner into plate – sketches show plane of crack
10.2		At weld toe in shell			Weld toe improvement techniques applicable	Minimum transverse cross-section of member at location of potential crack initiation	F	D	 Applicable assuming $b = 0.25 \sqrt{a}$	Nominal stress has to include the relevant stress concentration factor.	
10.3		At weld toe in branch					F	D		Note that the possibility of failure through the weld throat under stresses acting normal to weld length should be assessed as for joint type 7.8	
10.4		At weld root			Weld toe improvement techniques not applicable	Minimum transverse cross-section of weld	D	Not applicable	Not applicable		 1 = Plane of crack 2 = Cracks radiate from root
				Full-penetration weld							
				Fillet or partial penetration weld			F				

13 Unclassified details

13.1 General

Details that are not expressly classified should be treated as class G2, or class W1 for load-carrying weld metal, unless a higher classification can be justified either by reference to published experimental work or by carrying out special tests. Such tests should be sufficiently extensive to allow the basic or design *S-N* curve to be determined in the manner used for the standard classes (see Annex E).

13.2 Post-welding treatments

Where the classification of Table 4 to Table 10 does not give adequate fatigue resistance, the performance of weld details may be improved by post-welding treatments, as detailed in 16.3.5 and Annex F. The detail types that are suitable for application of the techniques described in Annex F are indicated in Table 4 to Table 10. When improved fatigue performance is required, and the proposed improvement method is not covered by Annex F, or the improvement stipulated therein is insufficient, the detail should be classified by testing (see 13.1).

14 Workmanship and Inspection

14.1 General

The classifications for structural details in Table 1 to Table 10 refer to specific modes of fatigue failure. However, the details concerned can contain features that could provide alternative sites for fatigue crack initiation or increase the severity of those covered by the classification scheme, in both cases possibly resulting in lower fatigue performance. Therefore, in fatigue-loaded steel products there should be adequate control and inspection of manufacturing quality, together with acceptance limits related specifically to fatigue resistance. Where the classification of a detail is dependent on particular manufacturing or inspection requirements, the necessary standards of workmanship and inspection should be indicated on the relevant drawings.

In practice, the overall quality requirements for a product are determined by a number of performance requirements, depending on its application. These might or might not be sufficient to cover the quality requirements needed for fatigue performance.

Typical performance requirements other than fatigue can include one or more of the following:

- a) static strength (resistance to fatigue or buckling);
- b) resistance to deformation or deflection;
- c) energy absorption (ductility);
- d) geometrical precision (dimensional tolerances);
- e) clearance to moving parts;
- f) fit-up to adjacent parts;
- g) resistance to corrosion;
- h) lack of obstruction to fluid flow;
- i) aesthetic appearance; and
- j) hygiene (elimination of crevices).

Some of the recommendations in the sub-clause can impose very high requirements for specific aspects of quality.

The existing product specification requirements should therefore be adequate for fatigue performance purposes. If not, then the non-conforming aspects should be enhanced.

It should not be assumed that the quality requirements needed for fatigue performance alone adequately cover those required for other performance requirements. In some cases they might not.

Quality aspects which are detrimental to fatigue performance are described in **14.2**.

Guidance on quality levels needed to ensure that the various detail classes are achieved is given in **14.3**.

14.2 Quality aspects detrimental to fatigue

14.2.1 General

The presence of unspecified notches in a new product can have the same effect on the remaining fatigue life as a fatigue crack of the same size. Such notches can therefore significantly shorten the fatigue life of the product, by eliminating the period of early crack growth.

The most severe notches are those that exhibit the following characteristics:

- a) planar with a sharp tip;
- b) orientated normal to the direction of fluctuating stress;
- c) located at or close to a surface; and
- d) located at or close to one of the classified initiation sites.

Other quality aspects which can adversely affect fatigue life are those which result in an increase in cyclic stress at one of the classified initiation sites. These are usually caused by unspecified variations in product geometry.

The most common types of quality aspects important to fatigue are listed in **14.2.2** to **14.2.4**.

Some quality restrictions are given in Table 1 to Table 10. Guidance on others is given in **14.3**.

14.2.2 Parent materials

Particular material quality aspects that should be controlled for fatigue purposes are:

- a) surface imperfections (rolling flaws and their repairs, corrosion pitting, accidental damage such as arc strike and weld spatter);
- b) internal laminations and inclusions;
- c) incorrect geometry (e.g. deviations in shape, flatness or thickness at the limits of tolerances, see Note).
- d) cracks due to inadequate removal of hydrogen (e.g. heat treatment or plating processes, bolts of Grade 10.9 and above).
- e) liquid metal assisted cracking (LMAC) in heavy galvanized products.

NOTE Design stresses calculated using nominal thickness are applicable to plates manufactured to the thickness tolerance requirements of BS EN 10051 and BS EN 10029:2010 Classes A, B and C.

14.2.3 Bolted joints

Particular quality aspects that should be controlled for fatigue purposes are:

- a) correct alignment of holes (in un-tensioned lap joints in particular);

- b) correct fit-up between faying surfaces prior to tightening (most important with pre-tensioned tensile joints);
- c) correct bolt tightening procedure and sequence; and, in cases where a torque measure method is applied;
- d) correct friction coefficients in threads and under washer faces and the correct lubrication required by the torque tightening specification.

14.2.4 Welded joints

Particular quality aspects that should be controlled for fatigue purposes are:

- a) cracks (usually a sign of serious material or process problems);
- b) lack of fusion or penetration (surface and embedded);
- c) undercut at weld toes (transverse to stress direction);
- d) volumetric flaws (e.g. porosity, slag);
- e) excess weld cap or root profiles;
- f) loss of weld throat (butt and fillet welds); and
- g) linear or angular misalignment in cruciform or in-line butt welds.

No unauthorized attachments, introduced as fabrication aids or later in service, should be welded to the product in regions where such attachments would reduce the classification assumed for design. Unless allowance is made for them at the design stage, they should be removed and the area ground out and checked by NDT to ensure that no unacceptable flaws remain.

14.3 Control of quality for fatigue

14.3.1 General

Table 1 to Table 10 provide limited information on manufacturing requirements for certain type numbers. In general, most of the necessary controls on fatigue-related quality aspects described in 14.2 are not provided in the tables. Guidance on control of these quality aspects is given in 14.3.2 to 14.3.4.

The detail classes given in Table 1 to Table 10 denote the highest recommended *S-N* curves for each detail type. Any manufacturing recommendations in the Table 1 to Table 10 assume that the detail is to be stressed up to the limit allowed by that *S-N* without a shortfall in fatigue life. In practice there might be a number of details in a product that are stressed to similar levels, but have different detail classes. On the assumption that all details have been assessed to have a satisfactory fatigue life, details with the higher classes are not stressed to the maximum limit permitted by the classification. For example if a component has a long wide welded attachment on its surface (detail type 4.5, nominal stress class G) and there is a transverse double sided butt weld (detail type 5.3, class D) close by and stressed to the same level then the butt weld cannot be stressed to its maximum permissible limit (e.g. 90 N/mm² at 2×10^6) because the class G detail would be limited to 50 N/mm² at 2×10^6 cycles. Thus, in the case of the butt weld the required class for this product is G, i.e. 45% lower in stress terms than the maximum permitted detail class D according to the table. The required class is therefore a function of the stress spectrum only and is the lowest *S-N* curve which just provides an acceptable fatigue life.

[A1] It is therefore possible to select the fatigue quality control requirements for a particular product on a fitness-for-purpose basis, using the assessment methods in BS 7910. **[A1]** For products with medium or low cyclic stressing this is likely to result in significant quality control savings compared to those required for meeting the maximum permitted class for all the details in the product. The required class at any location in the product can be readily determined by repeating the calculation procedures in Clause 15 and Clause 16 for various S-N curves until the lowest acceptable curve is found for that location. The required class, as in the case of the detail class in Table 1 to Table 10, depends on the direction of stress fluctuation and is likely to be different in the two orthogonal directions.

14.3.2 Parent material

14.3.2.1 Material quality

Where material is to be welded, selection of a suitable carbon equivalent value (CEV) is important for prevention of cracks.

Where material is to be used for transverse elements in welded cruciform or T-joints (see element "Y" in Table 7, types 7.1 to 7.4) and there is the risk of lamellar tearing, the following testing should be carried out:

- a) through-thickness deformation (Z) testing; and
- b) ultrasonic inspection to ensure that it is free from laminations and inclusion cluster.

14.3.2.2 Surface condition

The following should be carried out to ensure the surface is in an acceptable condition.

- a) Visual inspection should be carried out to ensure that the surfaces are free from damage for required classes D and above (corrosion pits, arc strikes and spatter, mechanical damage).
- b) NDT of any areas where temporary welding has been carried out for required classes F and above (repair of rolling flaws, removed temporary attachments) should be undertaken to ensure freedom from cracks.
- c) Excessive irregularities (see Type 1.4, Table 1) in thermally cut edges should be ground smooth for required classes G and above.
- d) Cold formed radiused edges should be checked for cracks by NDT where the class requirement is G or above in the transverse direction and E or above in the longitudinal direction.
- e) Bolts of Grade 10.9 and above which are to be coated or galvanized should preferably not be subject to acid or electro-deposition processes. If this is unavoidable, heat treatment to remove hydrogen should be carried out effectively (otherwise stress corrosion cracking might occur).

14.3.3 Bolted joints

Groups of holes in lap joints, (e.g. detail types 2.6 and 2.7), with bolts carrying load in bearing should be jig, Computer Numerically Controlled (CNC) or match drilled to ensure uniform bearing between all bolts in the group. Appropriate tolerances on diameter, position and alignment of parts should be specified.

When the fatigue design of a bolted joint is based on bolts being pre-tensioned to a nominated or minimum value, it should be ensured that the required pre-tension is achieved. Bolt tightening, (and therefore bolt pre-tension), can be obtained using torque, angle or bolt-stretch measurements. The bolt pre-loading method and hence pre-load accuracy should be selected after assessing the criticality of the joint. For all pre-loading methods, the correct measurements, torque sequences and torque-checking data should be defined. Calibration tests should be carried out to confirm that the required pre-tension is achieved. Established data on similar fasteners may be used if allowance is made for variation between batches and products. A system of monitoring and recording should be implemented to ensure that procedures are followed correctly.

Fit-up between parts with flat contact surfaces should be designed to ensure uniform contact at the initial hand-tight stage prior to final tensioning.

The required bolt pre-load should be obtained by the following procedure.

- a) Using a torque control method apply, in a defined sequence, sufficient torque to bring the components into full face to face contact.
- b) Using a torque measurement, bolt or nut part-turn or bolt-stretch method, that is appropriate for the criticality of the joint, apply the final pre-load.

This procedure does not preclude the use of a final stage of tightening using other methods.

Where a hollow jack might be used to tension long studs or bolts, tests should be carried out to measure the pre-load loss, due to the applied dynamic loads. This should be taken into account when determining the minimum pre-tension to be used as the basis of design.

14.3.4 Welded joints

Welding is a process where notch-like imperfections and deviations in geometry are difficult to eliminate entirely, particularly in arc welds. The degree of severity depends primarily on the level of control of the process, but also on other factors such as the type of process, the materials, the joint geometry and access.

The size of imperfection that can be tolerated without compromising the fatigue life based on the details classified in Table 3 to Table 10 becomes smaller as the required class (defined in 14.3.1) increases and the choice of viable details becomes more limited. For example, if the required class is C and a transverse butt weld in a plate is required, only detail type 5.1 is acceptable. This detail involves removal of all local geometrical stress raisers such as weld toes, welding access from both sides and a high level of NDT. If the component cross-section is a more complex shape than a flat plate then the access for welding is reduced and the likelihood of producing larger imperfections and also not detecting them by NDT increases significantly. For this reason the maximum detail class for a butt weld in this case is reduced to F2 (see detail type 6.1), a reduction of four classes.

In contrast, if the required class is only W1 or less, a very wide choice of joints is available. This includes transverse load-carrying fillet welded joints where the design allows major areas of the joint to remain unfused with severe notches at the weld roots (see detail types 7.2 and 7.4). Whilst these cruciform and T-joints can be stressed in the parent metal to the level of nominal stress class F2 as far as failure from the toe is concerned, failure from the root through the weld metal is limited to W1 (detail type 7.8).

Direction of stress fluctuation with respect to weld axis is a further important factor. Weld imperfections with more notch-like features (cracks, lack of fusion, lack of penetration, undercut, slag inclusions) are generally orientated parallel to the weld axis and are therefore much more severe in terms of fatigue performance when the stress direction is transverse to the weld axis. Local stress raisers such as weld toes are similarly more unfavourably orientated with respect to transverse stresses. This is reflected in the detail classifications where, for example, a continuously fillet welded T-joint stressed longitudinally is acceptable for a required class of C (or D if it contains stop-starts, see detail types 3.2 and 3.3 respectively); whereas if stressed transversely through the base of the Tee it would be restricted typically to nominal stress class E or F (detail type 4.2 or 4.3 respectively, within certain dimensional limits). If stressed transversely through the stalk of the Tee it would be restricted to W1 with respect to weld throat stresses.

The control of welding in production is generally achieved by use of the following measures:

- a) relevant documented weld procedures qualified by test;
- b) welders appropriately qualified by test for the range of procedures used on the product;
- c) appropriate welding quality management system;
- d) appropriate inspection and testing procedures and acceptance criteria for the production welds; and
- e) good practice for storage and handling of welding consumables to prevent dampness and contamination.

Where fatigue performance is an important requirement for the product (i.e. the requirement is class W1 or higher) all these control measures should be adopted in accordance with BS EN 1011-1, BS EN 1011-2 (for ferritic steels) and BS EN 1011-3 (for stainless steels).

For small mass-produced initial products it might be practicable to inspect the quality on a random sampling basis by destructive tests (e.g. sectioning of welds). Routine performance testing (by loading) is usually impracticable for verifying fatigue life because of the time it takes. In the majority of cases verification that the required quality has been achieved in production is by NDT. If high fatigue classes are required the limitations of the various testing techniques in detection, characterization and sizing of the various welding imperfections should be taken into account.

In some instances it might be current practice to use the same acceptance criteria in production as used for procedure or weld qualification (see BS EN ISO 15609-1 and BS EN 287-1) or those in BS EN ISO 5817. Such specifications are based on arbitrary quality criteria and might have aspects that are not adequate for higher fatigue class requirements. They are also likely to contain requirements that incur additional cost for lower fatigue class requirements. For these reasons it is preferable to specify quality requirements that are based more on fitness-for-purpose principles. Guidance is given  in Table 11  on appropriate limits of those imperfection types which need to be controlled for fatigue purposes in addition to those specified in Table 3 to Table 10. This guidance is expressed in terms of the "required class", described in 14.3.1, so that an economic level of quality can be specified for any given product.

Where an existing production weld quality specification exists for the product, it should be checked to ensure that it covers the types and limiting sizes of imperfection recommended below for controlling fatigue performance. Where it does not fully cover the fatigue quality requirements the specification should be amended accordingly and it should be made clear that if any fatigue imperfection limit is exceeded in production it is cause for rejection. The scope of inspection might need to be enhanced in accordance with the recommendations that follow.

If no production weld quality specification already exists for the product the specification should be based on the recommendations in this clause, provided that any other relevant performance requirements (see **14.1**) do not require enhancement above those required for fatigue.

Where the fatigue stressing requirements in a product are moderate, e.g. a maximum class requirement no higher than F2 anywhere, a general fitness-for-purpose requirement for the product quality should be based on the maximum class required, subject to any enhancement for other performance requirements (see **14.1**). If only a small minority of specific welds in the product experience high fatigue loading and have a higher class requirement than F2, it might be more economical to identify these by their class requirement so that extra inspection and higher quality requirements can be targeted to those welds that are more critical. The welds in question should be indicated on the drawings with their class requirement as defined in **14.3.1** (not their detail class as given in Table 3 to Table 10).

Table 12 gives guidance on the fatigue acceptance of volumetric embedded imperfections to meet Class C or lower (Class B is excluded because no embedded imperfections are permitted).

Table 13 gives acceptance levels for undercut at transverse weld toes. These limits might not be small enough for other performance requirements (see **14.1**) and might be larger than in some general quality control specifications.

The welds should not be smaller than the specified size. This applies particularly to transversely loaded partial penetration butt welds and both the leg length and throat dimension of transversely loaded fillet welds, where the fatigue life is significantly reduced by small shortfalls in these dimensions.

With regard to deviations from the nominal geometry, particular attention is drawn to joint misalignment, as the acceptance levels in many quality control-based specifications are too large for fatigue-loaded joints. It is usually necessary to allow for the effect of even nominally acceptable misalignment as a source of additional stress. This effect can be expressed in terms of the stress magnification factor, k_m , which is used either to increase the estimated applied stress range or to reduce the fatigue strength obtained from the relevant $S-N$ curve (see **B.5.2.1**). Assessment of any misalignment is required for transverse butt welds as Class D refers to perfectly aligned joints. This is also true for any assessment of potential weld toe failure using the hot-spot stress, although that effect could be included in the calculation of the hot-spot stress if the relevant type and extent of misalignment was included in the finite element model or the hot-spot stress was obtained by surface stress extrapolation from strains measured on the actual welded detail concerned. However, linear misalignment e/t up to 0.05, corresponding to $k_m = 1.15$, is included in the data behind Classes F and F2 for cruciform joints. Therefore, on a fitness-for-purpose basis, only misalignment above this level needs to be considered when assessing cruciform joints. Table 14 to Table 16 illustrate the effect of misalignment on fatigue strength for these three situations.