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Summary of pages

This document comprises a front cover, an inside front cover, pages i and ii, pages 1 to 20, an inside back cover and a back cover.

Foreword

Publishing information

This Published Document is published by BSI and came into effect on 30 May 2008. It was prepared by Subcommittee B/525/10, *Bridges*, in consultation with B/525/31, *Structural use of steel*, under the authority of Technical Committee B/525, *Building and civil engineering structures*. A list of organizations represented on these committees can be obtained on request to their secretary.

Relationship with other publications

This Published Document is a background paper that gives non-contradictory complementary information for use in the UK with part 1-9 of the Eurocode for the design of steel structures, BS EN 1993, and its National Annex.

Presentational conventions

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

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

The word "should" is used to express recommendations of this Published Document. The word "may" is used in the text to express permissibility, e.g. as an alternative to the primary recommendation of the clause. The word "can" is used to express possibility, e.g. a consequence of an action or an event.

Contractual and legal considerations

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

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

1 Scope

This Published Document gives non-contradictory complementary information for use in the UK with BS EN 1993-1-9 and its UK National Annex.

2 Material and execution tolerances and inspection [BS EN 1993-1-9:2005, 1.1(2)]

2.1 General

The safety of structures subjected to fatigue loading is generally more dependent on deviations in materials and workmanship than structures subject only to static loading. This is because fatigue life is very sensitive to local stress raisers such as joint misalignment or out-of-flatness, which cannot be discounted on the grounds of plastic redistribution (as is the case with ULS failure modes such as buckling and rupture). Fatigue life is also particularly sensitive to pre-existing crack-like imperfections close to sites of potential fatigue initiation, as they in effect eliminate much of the early propagation life. For this reason workmanship and inspection requirements for execution are generally made more sensitive as the cyclic stress levels and loading frequency increase.

2.2 Implementation with materials and specification to BS 5400-6

In BS 5400-6, four levels of quality for welds have been specified depending on the magnitude and frequency of the cyclic stresses. For low levels of cyclic stressing which would be acceptable for a curve conforming to BS 5400-10:1980 Class F2 *S–N* ($\Delta\sigma_c$ = (60) curve (see Table 1), the lowest level is acceptable. This is termed "unspecified" because the areas of the structure which would tolerate a fatigue Class F2 *S–N* curve or lower (G or W) do not have to be identified. Only if the degree of stressing is such that a higher fatigue *S–N* curve than F2 is required does the minimum class requirement have to be identified on the drawings at that location in the structure. The method of doing this is by, using a "Fat" reference and an arrow on the drawings to denote the extent affected. The three minimum class requirements higher than "unspecified" are Fat F, Fat E and Fat D.

In order to derive the minimum required Fat class from the relevant *S–N* curve in BS EN 1993-1-9, which is denoted by the reference fatigue strength $\Delta\sigma_c$, an approximate correlation has been used in the National Annex. This is shown in Table 1.

Table 1 **Fatigue class requirement in BS 5400-6 corresponding to minimum required detail category in BS EN 1993-1-9**

Minimum class requirement (BS 5400-6:1999)	**σ_r – N curve (BS 5400-10:1980)**	**σ_r at $N = 2 \times 10^6$ (BS 5400-10:1980)** N/mm²	**$\Delta\sigma_c$ (BS EN 1993-1-9:2005)** N/mm²
Unspecified	F2	60	56
Fat F	F	68	63
Fat E	E	80	80
Fat D	D	91	90

NOTE This correlation is nothing to do with the detail category at that point in the structure. A particular detail may be classified in BS EN 1993-1-9:2005, Table 8 as having a detail category of (say) 80. However, if the fatigue stressing at that point is so moderate that detail category of (say) 36, i.e. $\Delta\sigma_c$ = 36 N/mm², would still give an acceptable life, then the minimum class requirements would be "unspecified".

It is important not to over-specify or under-specify the minimum class requirement. The latter might lead to unsafe structures in later life.

The above principle may be applied to structures other than bridges, where fatigue needs to be considered. Alternatively, ISO 10721-2 may be applied until such time as EN 1090-2 is published as BS EN 1090-2.[1)]

2.3 Implementation with materials and workmanship specification to BS EN 1090-2[1)]

The same principles as described in **2.2** should be applied except that the Fat quality designation system is numerical instead of alphabetical and the term "minimum class requirement" is replaced by "quality requirement". The levels, which are numerically different from some of those in Table 1, are as shown in Table 2.

Table 2 **Fatigue class requirement corresponding to minimum required detail category in BS EN 1993-1-9**

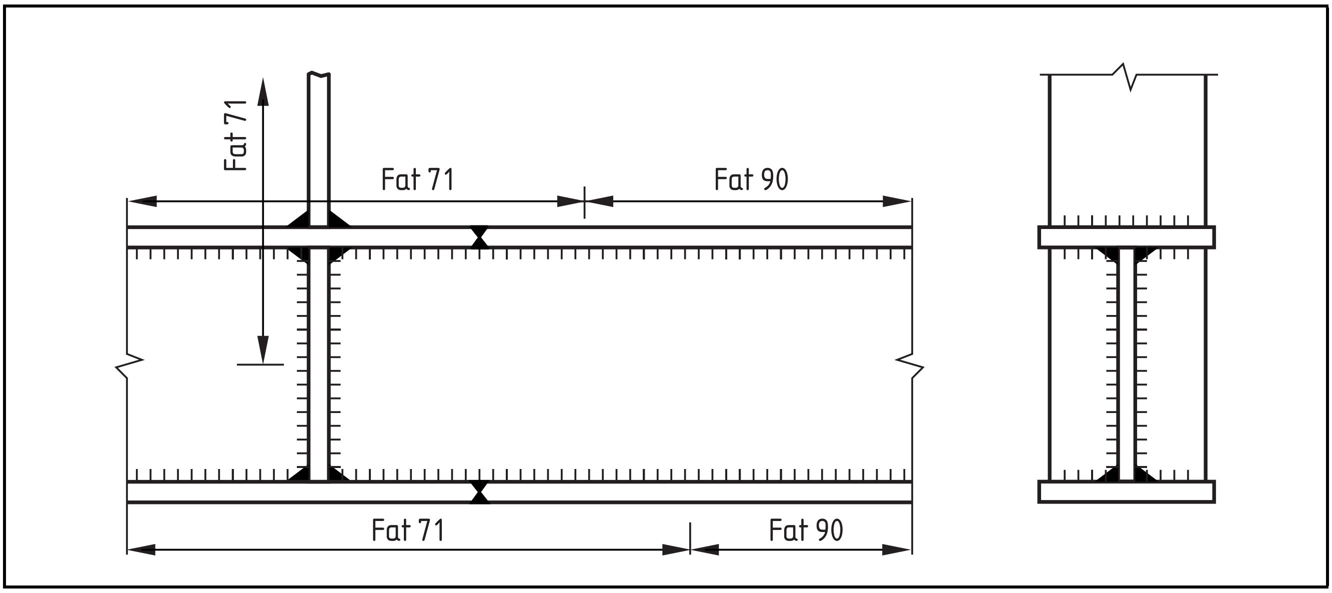
Quality requirement	**Required value of reference fatigue strength $\Delta\sigma_c$**	**Indicate on drawings (see Figure 1)**
Fat 56	$\Delta\sigma_c \leqslant 56$ N/mm²	No
Fat 71	$56 < \Delta\sigma_c \leqslant 71$ N/mm²	Yes
Fat 90	$71 < \Delta\sigma_c \leqslant 90$ N/mm²	Yes
Fat 112	$90 < \Delta\sigma_c \leqslant 112$ N/mm²	Yes
Fat 140	$112 < \Delta\sigma_c \leqslant 140$ N/mm²	Yes

The above quality designations are in alignment with those in ISO 10721-2 and assume that full static stressing will be applied as permitted by BS EN 1993-1-9.

1) At the time of publication of this part of PD 6695, EN 1090-2 is still in preparation. The equivalent British Standards should be used until BS EN 1090-2 is published.

Fat 56 is the new "unspecified" level. All zones of the structure requiring quality levels above Fat 56 should be indicated on the relevant drawings according to the method shown in Figure 1. The directions of the arrows are parallel to the direction of the relevant stress fluctuation.

Figure 1 **Method of indicating quality requirements higher than Fat 56 on drawings when using BS EN 1090-2 for execution**



2.4 Assurance of quality

Fracture mechanics calculations confirm that when the cyclic stressing is sufficiently high that the minimum class requirement exceeds 80 N/mm^2 or thereabouts, the acceptable sizes of planar fabrication flaws such as cracks of lack of fusion, when orientated normal to stress direction, are generally no more than about 1 mm to 2 mm in height. For higher stress levels the acceptable sizes rapidly reduce to fractions of a millimetre. Such sizes are not detectable by eye, even if surface breaking, and are close to the threshold of reliable detection and evaluation by normal commercial non-destructive testing techniques. They are also of a size which many welding processes operated under normal commercial shop (or site) conditions cannot be relied upon not to leave in the weld. In joints with difficult access (both for welding and NDT) the sizes of flaws which are likely to occur and which might not be detected might be two or three times the above size. This leaves a problem of how the quality required to sustain these high cyclic stress levels in a safe life design can be assured.

The above problem can be overcome by restricting the detail category for certain details to a level where there is an improved probability of attainment of the required quality and a high probability of detection and correct evaluation. This applies not only to certain high category transverse and longitudinal welds, but also to flame cut edges and plain surfaces. The latter can be susceptible to corrosion pitting and very minor accidental damage.

Where safe life design applies and fatigue stressing is very high, and where higher categories have to be used, it is recommended that the special acceptance criteria and methods of fabrication control and inspection are agreed with the relevant experts at the design stage. Alternatively the damage tolerant method might have to be applied.

3 Derivation of specific fatigue loading models [BS EN 1993-1-9:2005, 2(2)]

Loading for fatigue should normally be described in terms of a design load spectrum, which defines a range of intensities of a specific live load event, the method of application, and the number of times that each intensity level is applied during the structure's design life. If two or more independent live load events are likely to occur, the sequence and phasing between them should be specified.

Where no published data for live loading exist, load history data should be obtained from existing structures subjected to similar effects. Alternatively, loading data can be inferred by analysis of the response of continuous strain or deflection measurements over a suitable sampling period. Dynamic magnification effects where loading frequencies are close to one of the natural frequencies of the structure should be taken into account.

In this situation the partial safety factors for fatigue load intensity for safe life design should take into account the degree of confidence in the prediction of the design load spectrum from the available data. Recommended values of γ_{Ff} are given in the National Annex to BS EN 1993-1-9.

4 Determining fatigue strengths from tests [BS EN 1993-1-9:2005, 2(4)]

4.1 General

The guidance given in **4.2** to **4.7** is based on BS EN 1999-1-3:2006, Annex C.

4.2 Test specimens

Test specimens should represent the intended application detail as closely as practicable, with regard to material, dimensions, manufacturing procedures and workmanship quality limits allowed by BS EN 1090-2 and BS EN 1993-1-9. These features should be measured using the methods specified in BS EN 1090-2.[2)]

4.3 Testing conditions

The loading mode should represent the most likely loading mode expected to be applied to the detail in the structure.

Any environmental conditions outside the scope of BS EN 1993-1-9 should be simulated.

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2) At the time of publication of this part of PD 6695, EN 1090-2 is still in preparation. The equivalent British Standards should be used until BS EN 1090-2 is published, and any other agreed alternative methods should be specified for the individual projects.

4.4 Instrumentation

The test specimen should be strain gauged in the region(s) of expected fatigue initiation in such a way that the nominal, modified nominal or hot spot stress at the initiation site can be determined.

Load intensity should be measured continuously and turning points counted.

Crack growth length (and in some cases depth) should be monitored using appropriate NDT methods when damage tolerant design data are sought.

4.5 Loading history

Variable amplitude loading histories should be representative of the design load spectrum.

Constant amplitude testing for the purposes of deriving an $\Delta\sigma - N$ design curve should employ a selection of load intensities to provide endurance data in the range of 10^5 to (5×10^6) cycles. A minimum of ten finite endurance data points should be obtained (i.e. non-run-outs).

The mean load level should be selected to ensure that tensile mean stress conditions at the initiation site are representative of the upper bound likely to be experienced in the structure, taking into account lack of fit forces and residual stress effects not incorporated in the test specimen.

4.6 Monitoring of test

The test specimen and loading conditions should be monitored at regular intervals to verify that the data specified in the National Annex to BS EN 1993-1-9 are being correctly recorded.

4.7 Analysis of results

The fatigue fracture face should be examined for evidence of material or manufacturing discontinuities particularly close to the initiation site.

In the derivation of design data for general use, allowance should be made for the following effects, where they are not adequately represented in the test specimens:

a) lack fit and residual stresses;

b) dimensional tolerances and scale effects;

c) manufacturing procedures;

d) material and workmanship imperfections, taking into account the acceptance criteria and methods of inspection in the execution standard;

e) environment.

5 Assessment methods for fatigue design [BS EN 1993-1-9:2005, 3(1)]

5.1 General

BS EN 1993-1-9 offers two main methods for fatigue assessment. These are "safe life"' and "damage tolerant" methods. The essential difference between the two is that a prescribed inspection and maintenance regime for detecting and correcting fatigue damage is implemented through the design life of the structure when the damage tolerant method is used. BS EN 1993-1-9 also permits provisions for inspection programmes, which are discussed in **5.2** to **5.5**.

5.2 Safe life method

The safe life method should provide an acceptable level of reliability that a structure will perform satisfactorily for its design life without the need for regular in-service inspection for fatigue damage.

5.3 Damage tolerant method

The damage tolerant method is based on the use of higher stresses than would be allowed for in safe life design. This leads to a safe life which is less than the design life and a greater probability of failure for that part of the life between the safe life and the design life. The probability of failure can be brought down to an acceptable level by means of a mitigation regime involving ready access, regular inspection for signs of early fatigue cracking, and the use of crack arresting details.

In practice this method might be used where there is an overriding design requirement to achieve minimum weight and where there is a well established maintenance regime which lends itself to easy inspection and (preferably) easy replacement of damaged parts (e.g. military bridges, aircraft).

The assessment procedure for the methods is the same except that a lower partial factor γ_{Mf} may be used for the damage tolerant method in BS EN 1993-1-9. With BS EN 1993-1-9, the designer may use design fatigue strengths 15% to 17% higher for the damage tolerant method than for the safe life method. For low and medium cycle endurance application (where the main damage is coming from the part of the *S–N* curve up to 5 million cycles) the safe life for a design life of (say) 100 years based on the damage tolerant method would be about 60 years (based on an effective m value of 3). For high cycle applications where the effective m value could be from 5 upwards the safe life would be 45 years or less. For very high cycle applications (over 100 million cycles), the safe life could be as low as 10 years, on account of the horizontal cut off in the curves at that endurance. For higher stress increases than 17% the safe lives would be lower still. In practice therefore it is likely that a mitigation regime would have to be put in place for the major part of the service life if resort is made to the damage tolerant methods.

It should be noted that an increase in stress level of approximately 12% is equivalent to an increase of one detail category, so that in high fatigue loading situations an improvement in fatigue strength by one or two detail categories might be all that is required to avoid resorting to the damage tolerant method. If stresses cannot be lowered by increase of section, this may be achieved by modification of the detail design, relocation of joints or attachments to areas of lower stress, etc. In extreme cases weld improvement techniques may be specified.

For the reasons explained above, the National Annex recommends that the fatigue design for new building or civil engineering structures should usually be based on safe life principles. If there are special conditions where a damage tolerant method might be considered to be a viable option, the decision should be agreed with the Maintaining Authority taking into account the inspection requirements and their frequency.

5.4 Consequence class

BS EN 1990 defines the consequences of failure or malfunction in terms of:

- loss of human life;
- economic consequences;
- social consequences;
- environmental consequences.

Three consequence classes are defined, namely "very great" (= "high"), "considerable" (= "medium") and "small or negligible" (= "low").

BS EN 1990:2002, Annex B suggests that three different target levels of reliability class can be justified according to the consequence class. Three possible methods of differentiating between reliability classes are:

a) by applying different multiplication factors on actions (1,1, 1,0 and 0,9 for "high", "medium" and "low" respectively; see BS EN 1990:2002, Table B.3);

b) by applying different levels of checking of designs (third party, independent in-house and self checking for "high", "medium" and "low" respectively; see BS EN 1990:2002, Table B.4);

c) by applying different levels of inspection during execution (third party, in-house procedures, and self inspection for "high", "medium" and "low" respectively; see BS EN 1990:2002, Table B.5).

BS EN 1990 indicates that reliability differentiation through partial resistance factors is "not normally used" (with the exception of fatigue verification in BS EN 1993-1-9 only). It also says that a partial resistance factor may be reduced if a higher inspection level is used to compensate. However partial resistance factors should be used for "differentiation of reliability".

For the purposes of fatigue assessment of new building and civil engineering structures, it is assumed that the consequences of fatigue failure or malfunction will normally be in the “medium” to “high” class. The potential economic or social consequences of fatigue failures in industrial or public sector structures (e.g. machinery supporting structures, masts, chimneys, bridges) can be very considerable in terms of loss of production or loss of service. This has been the assumption in UK codes of practice for fatigue.

5.5 Partial factor γ_{Mf}

In previous UK structural fatigue codes it has been normal practice to use partial load and resistance factors of unity when applied to upper and lower bound data respectively. A similar notional level of reliability is adopted when using the fatigue data in BS EN 1993-1-9 and BS EN 1991.

The main difference on the resistance side lies in the *S–N* curves. In BS 5400-10, the design curves for variable amplitude loading have a bend at 10^7 cycles, whereas in BS EN 1993-1-9 the bend is at 5×10^6 cycles. At endurances of 10^8 cycles and above there is a complete cut-off in BS EN 1993-1-9, whereas in the UK standard the lower stress levels are still damaging. At the low endurance, high stress end of the *S–N* curve the true slopes of the data for detail categories above about $\Delta\sigma_c = 100$ N/mm^2 are flatter than given by $m = 3$. The whole *S–N* curve data base is notionally based on a 5% probability of failure rather than 2,3% as in BS 5400-10.

The above difference gives a fatigue strength between 10^7 cycles and 10^8 cycles, i.e. 10% higher in BS EN 1993-1-9 compared to BS 5400-10 for fatigue design for bridges. Provided that the limitations on higher categories recommended for quality assurance are met and based on the reasons given above, a lower γ_{Mf} value of 1.1 has been recommended in the National Annex for all safe life fatigue assessments made in accordance with BS EN 1993-1-9.

6 Use of nominal, modified nominal and geometric stress ranges [BS EN 1993-1-9:2005, Clause 5 and Clause 6]

6.1 General

The guidance given in this clause is applicable to both the equivalent stress and the damage summation methods of fatigue assessment.

6.2 Guidance on global analysis

The method of analysis should be selected so as to provide an accurate prediction of the elastic stress response of the structure to the specified fatigue loading. Note that an elastic model used for static assessment (ultimate or serviceability limit state) might not necessarily be adequate for fatigue assessment.

Dynamic effects should be included in the calculation of the stress history, except where an equivalent loading is being applied which already allows for such effects. Where the elastic response is significantly affected by degree of damping, the damping coefficient should be determined by test evidence from similar structures which have been subjected to the similar types of loadings. No plastic redistribution of forces between members should be assumed in statically indeterminate structures.

The stiffening effect of any other materials which are fixed to the structural steelwork should be taken into account in the elastic analysis.

Elastic finite element analysis models should be used for the global analysis of statically indeterminate structures and latticed frames with rigid or semi rigid joints, except where strain data have been obtained from prototype structures or accurately scaled physical models. The use of semi rigid joints in fatigue sensitive structures should be avoided.

NOTE The term "elastic finite element analysis" is used to denote all analytical techniques where structural members and joints are represented by arrangements of bar, beam, membrane, shell, solid or other element forms. The purpose of the analysis is to find the state of stress where displacement compatibility and static (or dynamic) equilibrium are maintained Further guidance on stress analysis is given in BS EN 1999-1-3:2006, Annex D.

6.3 Nominal stresses

6.3.1 General

Nominal stresses (see Figure 2) should be used directly for the assessment of initiation sites in simple members and joints where the following conditions apply.

a) The details associated with the site are in reasonable agreement with the appropriate detail category requirements in BS EN 1993-1-9.

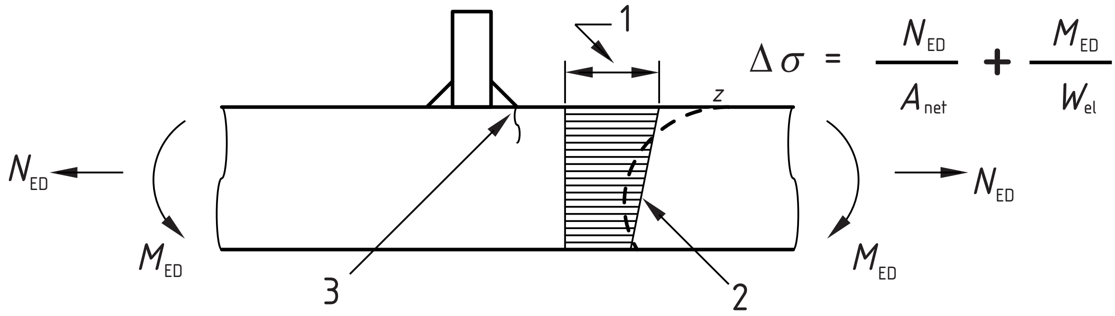
b) In the event that a) does not apply, the detail category has been established by test in accordance with National Annex recommendations and the results have been expressed in terms of the nominal stresses.

c) Gross geometrical effects such as those detailed in the National Annex are not present in the vicinity of the initiation site.

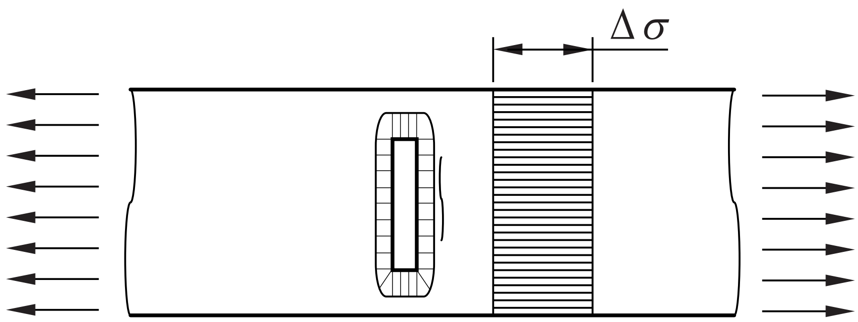
d) The crack initiation site is located at the root of a fillet weld or a partial penetration butt weld.

e) The crack location is in the thread or under the head of a bolt in axial tension and/or bending.

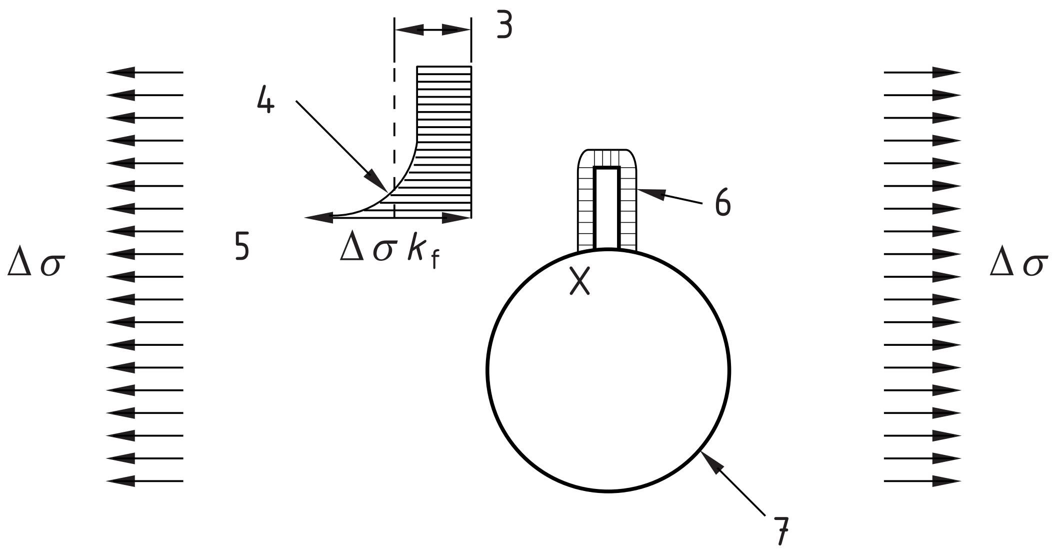
Figure 2 **Effect of stress concentrations on nominal and modified nominal stresses**



a) i) Local stress concentration (weld toe) – elevation view

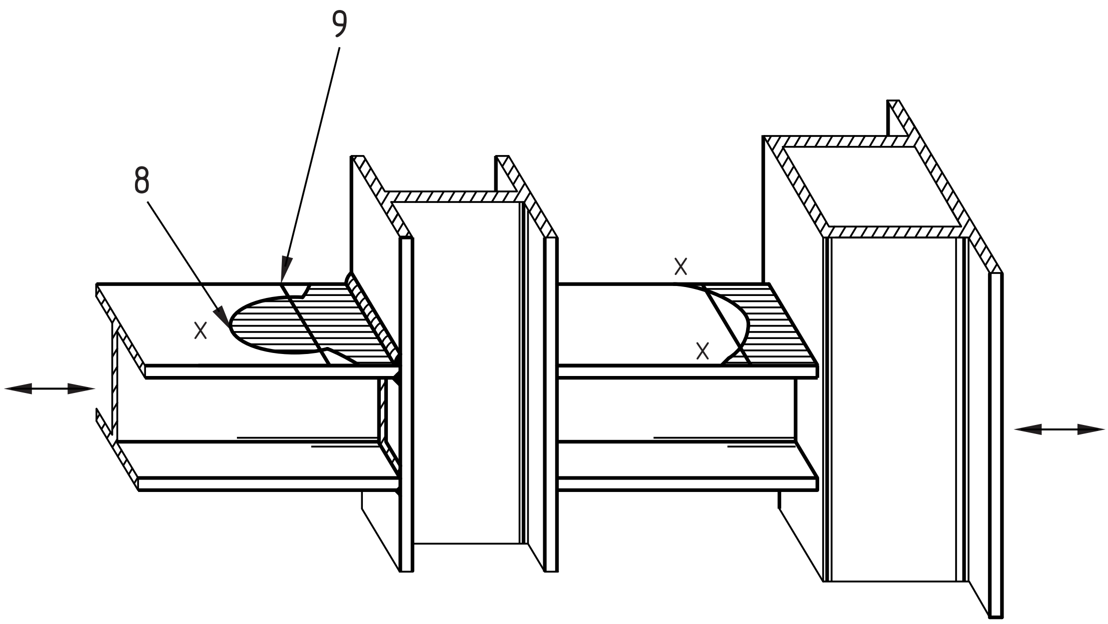


a) ii) Local stress concentration (weld toe) – plan view



b) Gross stress concentration (large opening)

Figure 2 **Effect of stress concentrations on nominal and modified nominal stresses** (*continued*)



c) Hard points in a connection

Key

1 Nominal stress range
2 Linear stress distribution assumed; weld toe stress concentration factor at z not calculated
3 Crack initiation site
4 Non-linear stress distribution
5 Modified nominal stress range at initiation site X
6 Welded attachment
7 Opening
8 Modified nominal $\Delta\sigma k_f$
9 Nominal $\Delta\sigma$

6.3.2 Derivation of nominal stresses

6.3.2.1 Structural models using beam elements

The axial and shear stresses at the initiation site should be calculated from the axial, bending, shear and torsional forces at the section concerned using linear elastic section properties.

The cross-sectional areas and section moduli should take account of any specific requirements of BS EN 1993-1-9.

6.3.2.2 Structural models using membrane, shell or solid elements

Where the axial stress distribution is linear across the member section about both axes, the stresses at the initiation point may be used directly.

Where the axial stress distribution is non-linear across the member section about either axis, the stresses across the section should be integrated to obtain the axial force and bending moments. The latter should be used in conjunction with the appropriate cross-sectional area and section moduli in accordance with BS EN 1993-1-9 to obtain the nominal stresses.

In the case of bolts in axial tension, the effect of joint fit-up and preload in the bolts should be taken into account. The geometry of the surrounding material might need to be modelled with solid elements, and variable contact between joint faces might be necessary.

6.3.3 Modified nominal stresses

6.3.3.1 Range of use of modified nominal stress

Modified nominal stresses should be used in place of nominal stresses where the initiation site is in the vicinity of one or more of the following gross geometrical stress concentrating effects (see Figure 2):

a) gross changes in cross-section shape, e.g. at cut-outs or re-entrant corners;

b) gross changes in stiffness around the member cross-section at unstiffened angled junctions between open or hollow sections;

c) changes in direction or alignment from those given in detail category tables (Tables 8.1 to 8.10) in BS EN 1993-1-9:2005;

d) shear lag and distortion in wide plated or hollow members;

e) non-linear out-of-plane bending effects in slender components such as flat plates where the static stress is close to the elastic critical stress, e.g. tension field in webs.

6.3.3.2 Derivation of modified nominal stresses – Structural models using beam elements

The nominal stresses should be multiplied by the appropriate elastic stress concentration factors k_f according to the location of the initiation site and the type of stress field.

Factor k_f should take into account all geometrical discontinuities except for those already incorporated within the detail category and should be determined by one of the following methods:

a) standard solutions for stress concentration factors;

b) substructuring of the surrounding geometry using shell elements taking into account geometrical discontinuities that need to be modelled, and applying the nominal stresses to the boundaries;

c) measurement of elastic strains on a physical model which incorporates the gross geometrical discontinuities, but excludes those features already incorporated within the detail category [see item b)].

6.3.3.3 Derivation of modified nominal stresses – Structural models using membrane, shell or solid elements

Where the modified nominal stress is to be obtained from the global analysis in the region of the initiation site it should be selected on the following basis.

a) Local stress concentrations such as the classified detail and the weld profile already included in the detail category should be omitted.

b) The mesh in the region of the initiation site should be fine enough to predict the general stress field around the site accurately but without incorporating the effects in a).

6.3.4 Geometrical (hot spot) stresses

6.3.4.1 Range of use of geometrical (hot spot) stresses

Geometrical stresses should be used where the following conditions apply:

a) the initiation site is a weld toe in a joint with complex geometry where the nominal stress is not clearly defined; or

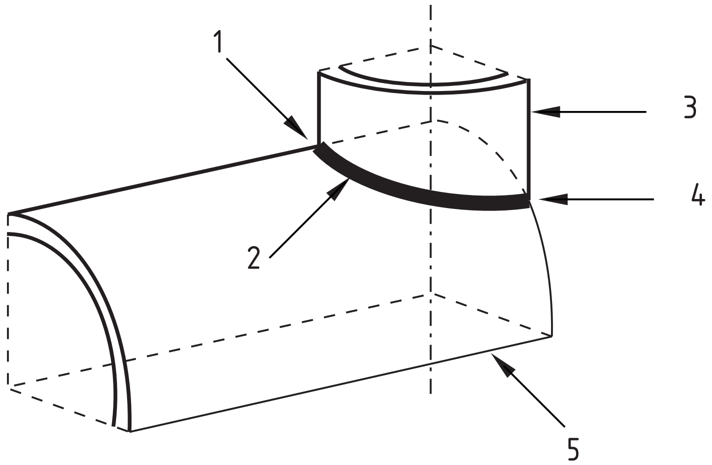
b) a hot spot detail category has been established by test where the results have been expressed in terms of the hot spot stress, for the appropriate loading mode.

6.3.4.2 Derivation of geometrical (hot spot) stresses

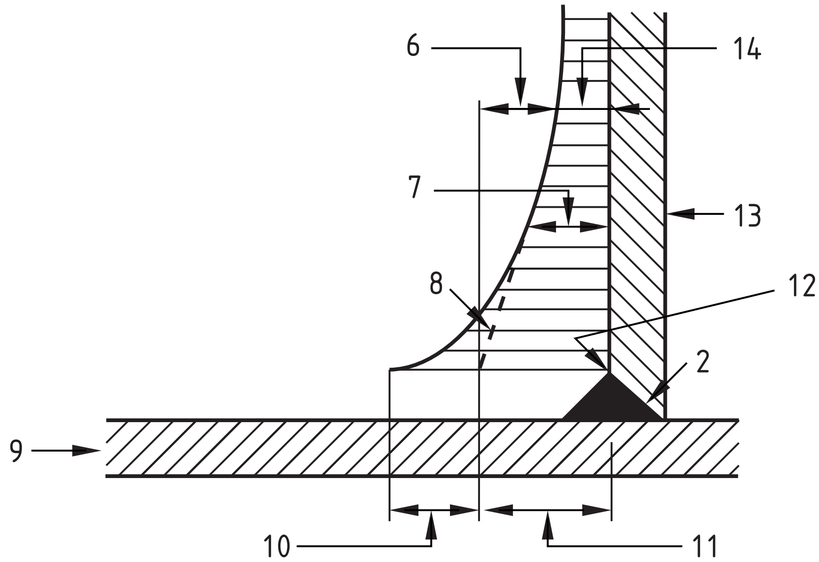
The hot spot stress is the principal stress predominantly transverse to the weld toe line and should be evaluated in general by finite element or experimental methods, except in cases where standard solutions are available. For simple cases, as in Figure 3c), hot spot stress should be evaluated by multiplying the nominal stress by the geometrical stress concentration factor k_f, which is defined as the theoretical stress concentration evaluated for linear elastic material omitting all the influences (local or geometric) already taken into account in the design $\Delta\sigma - N$ curve of the classified detail.

For structural configurations for which standard stress concentration factors are not applicable and which therefore require special analysis, the hot spot stress at the weld toe should omit the stress concentration effects due to the local notch effect i.e. the weld toe geometry. The stresses should be extrapolated linearly to the weld toe position as shown in Figure 3.

Figure 3 **Example of hot spot stresses in a tubular lattice joint – load applied in the brace**

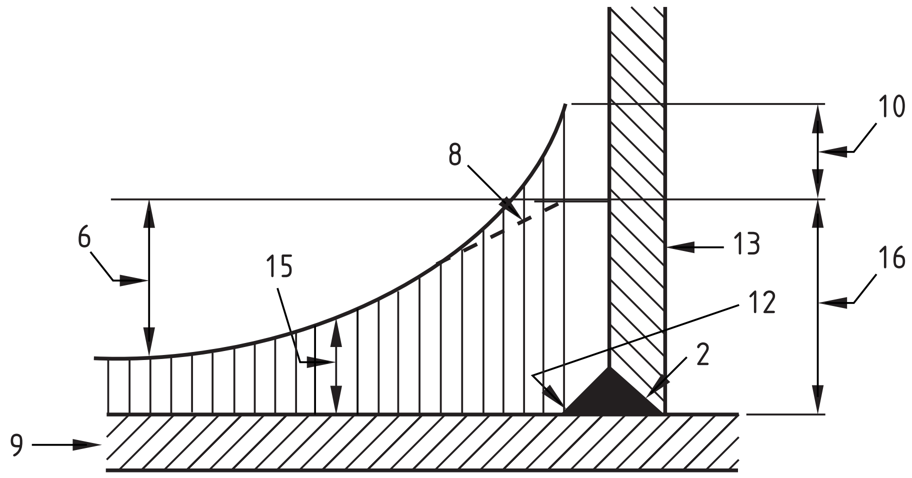


a) Nodal joint nomenclature – load applied in the brace



b) Stress distribution in brace

Figure 3 **Example of hot spot stresses in a tubular lattice joint – load applied in the brace** (*continued*)



c) Stress distribution in chord

Key

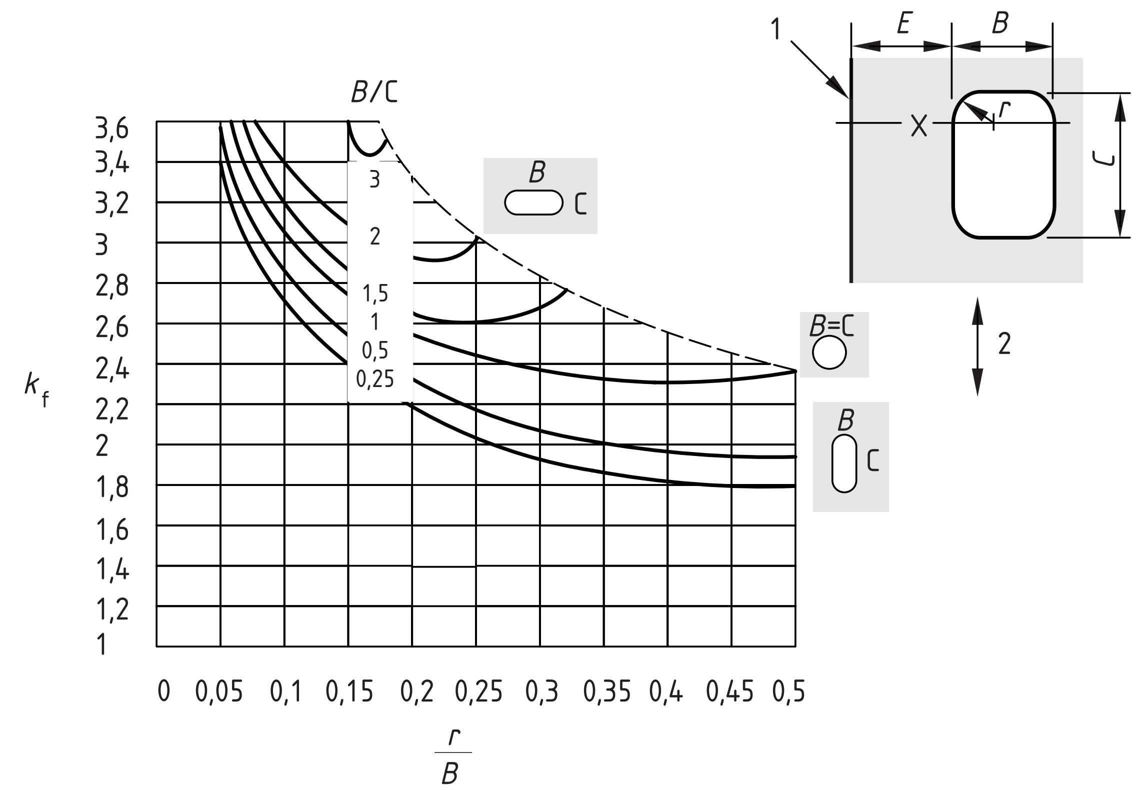
1 Crown point
2 Weld
3 Brace
4 Saddle point
5 Chord
6 Increase in stress due to overall joint geometry
7 Stress in brace
8 Extrapolation of geometric stress distribution to weld toe
9 Chord wall
10 Stress increase due to weld geometry (taken into account by detail category)
11 Brace hot spot stress = nominal stress × k_f
12 Weld toe
13 Brace wall
14 Nominal stress
15 Stress in chord
16 Chord hot spot stress = nominal stress × k_f

7 Stress concentration factors (BS EN 1993-1-9:2005, Clause 6)

Values of stress concentration factors for commonly occurring geometries can be obtained from published data.

Typical values of k_f for radiused corners in flat plate are given in Figure 4.

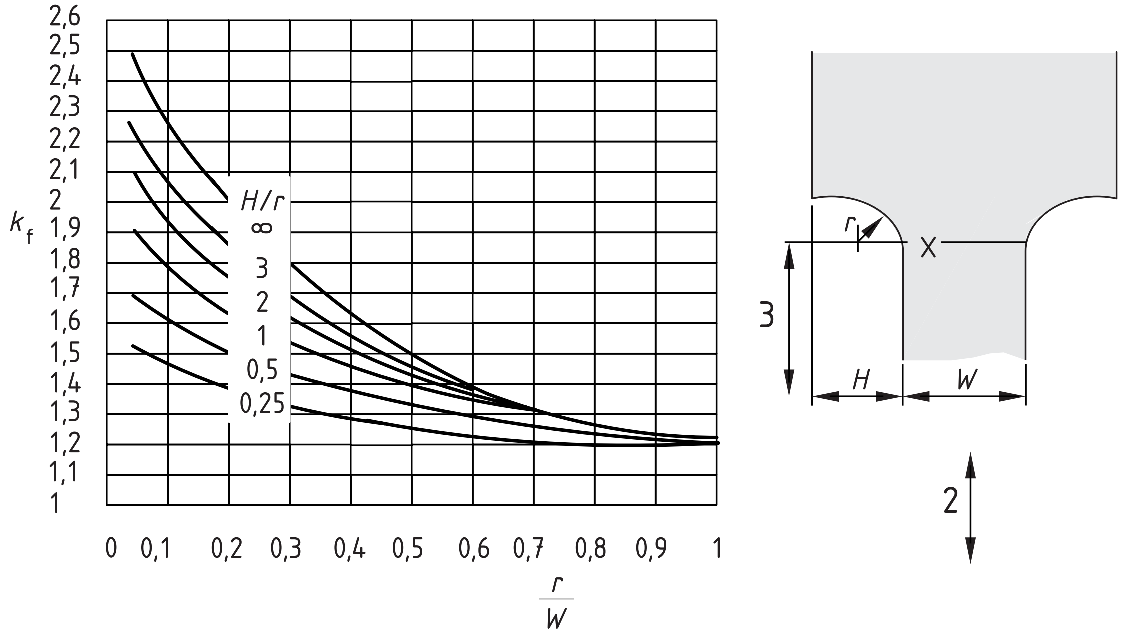
Figure 4 **Typical stress concentration factors from radiused corners in flat plate (from BS 5400-10:1980)**



NOTE Not applicable if E < B.

a) Fatigue stress concentration factor for Unreinforced apertures based on net stress at X

Figure 4 **Typical stress concentration factors from radiused corners in flat plate (from BS 5400-10:1980)** (*continued*)



b) Fatigue stress concentration factor k_f for re-entrant corners based on net stress at X

Key

1 Free edge
2 Stress fluctuation
3 Length of straight > $2r$

8 Determination of fatigue load parameters and verification formats [BS EN 1993-1-9:2005, Annex A]

8.1 General

BS EN 1993-1-9:2005 provides a simple method for checking the adequacy of a steel structure by comparison between a factored value of a stress range under a particular fatigue load model (referred to as the equivalent constant amplitude stress range) and a factored value of the reference fatigue strength (for 2 million cycles). The calculation of the factored stress range includes application of the partial factor γ_{Ff} and several λ factors. The values of the latter are provided in some of the specific application parts of BS EN 1993, and relate to certain structural conditions.

NOTE This method is analogous to the simplified procedures for checking highway and railway bridges in BS 5400-10. Such procedures tend to be conservative due to the need to ensure that the simplifying assumptions do not give rise to unsafe designs under any condition.

Where no appropriate data are available or a more realistic fatigue load model is required, BS EN 1993-1-9:2005 provides Annex A, which gives an alternative verification format. The objective of this subclause is to give further guidance on the use of Annex A for carrying out fatigue assessment where verification by the equivalent constant amplitude stress method is not applicable.

8.2 Application of the cumulative damage method in BS EN 1993-1-9:2005, Annex A

8.2.1 Fatigue loading

Where there is no appropriate fatigue loading in BS EN 1991, a suitable fatigue load model should be derived using the guidance in the National Annex to BS EN 1993-1-9:2005. See **NA.2.2**.

8.2.2 λ factor

Where an application part of BS EN 1993 does not provide an appropriate λ factor for use with a simplified load model, it is preferable to use a load model which is more representative of the range of loadings expected. The more representative model can be applied directly to the structure in question without the need for using any λ factors. The check can then be carried out in the damage domain, rather than the stress domain, using BS EN 1993-1-9:2005, Annex A.

The relevant part of BS EN 1991 might have a choice of fatigue load models, in which case the most detailed model should be used. Use of the simplified model which is dependent on the λ factor method in BS EN 1993-1-9:2005, Section **6** should be avoided. This is especially important in high cycle situations where the stress range under the simplified model might be close to the cut-off level.

8.2.3 Particular points when applying BS EN 1993-1-9:2005, Annex A

8.2.3.1 BS EN 1993-1-9:2005, A.1

When independent fatigue loads are applied to a structure, it is important to consider that sequence (and phasing if their actions overlap in time) as this can effect the stress range spectrum.

8.2.3.2 BS EN 1993-1-9:2005, A.2

Minimum stress troughs are as important as minimum stress peaks when determining stress ranges of individual cycles.

Where the rate of loading of any of the fatigue loads is within ±40% of the natural frequency of a model excited by that loading, the stress response should be magnified from the static response.

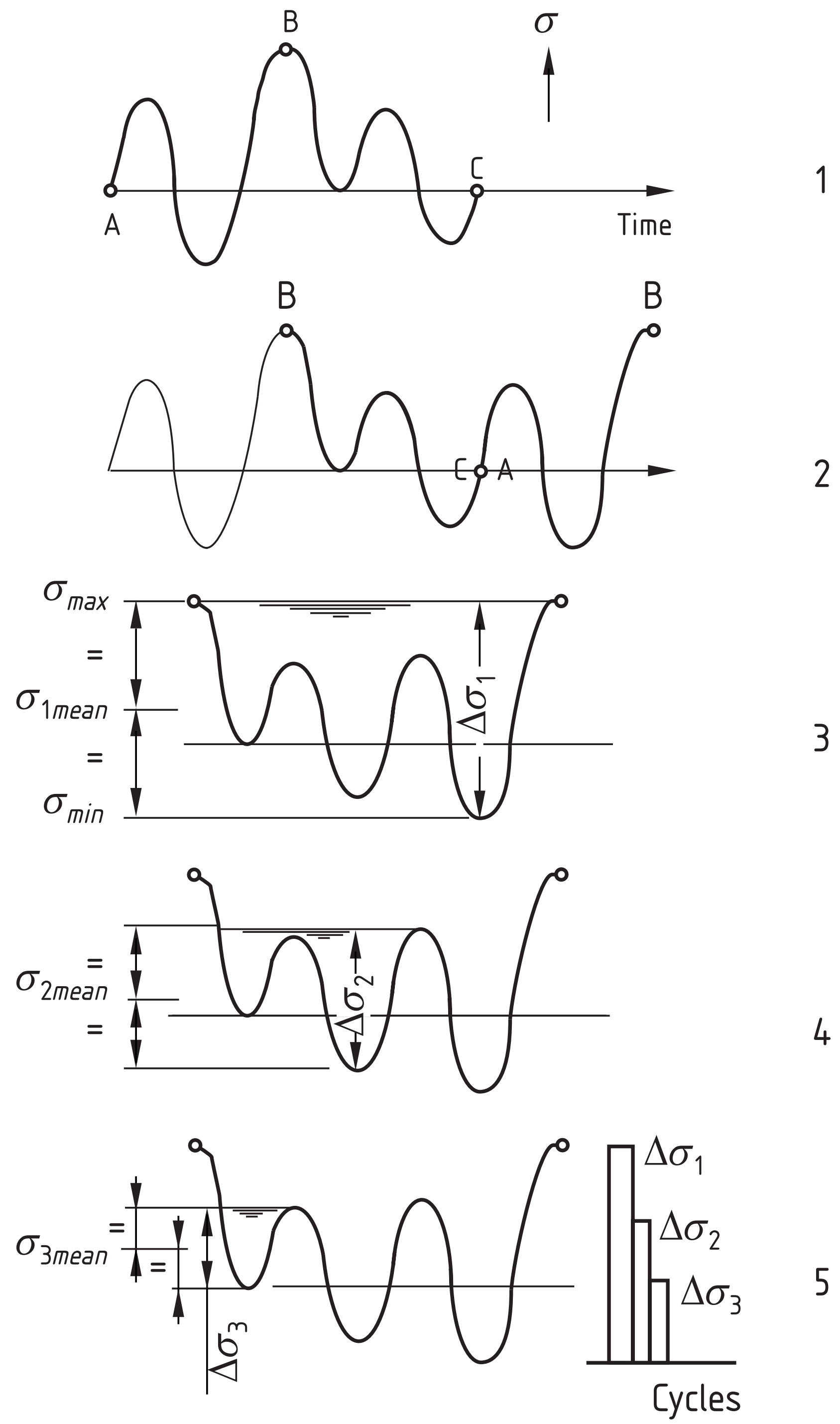
8.2.3.3 BS EN 1993-1-9:2005, A.3

The method of cycle counting by the reservoir method is given in Figure 5.

8.2.3.4 BS EN 1993-1-9:2005, A.4

It is preferable not to simplify the number of bands in the design spectrum by an averaging process. If this is done it should be on the basis of a weighted mean $\Sigma n_{ih}\Delta\sigma_{I})^{m}$ and not a linear average. More conservatively the range of the highest stress band in the group of bands to be averaged may be used.

Figure 5 **Procedure on cycle counting using the reservoir method**



Key

1 Step 1. Determine stress history for loading event. Identify peak B.
2 Step 2. Move stress history on left of peak B to right.
3 Step 3. Fill "reservoir" with "water". Greatest depth is major cycle.
4 Step 4. Drain at greatest depth. Find new maximum depth. This is second largest cycle.
5 Step 5 onwards. Repeat until all "water" drained. Sum of all cycles is stress spectrum for above history.

Bibliography

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

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BS 5400-10:1980 (incorporating Amendment No.1:1999), *Steel, concrete and composite bridges – Part 10: Code of practice for fatigue*

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

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BS EN 1993-1-1, *Eurocode 3 – Design of steel structures – Part 1-1: General rules and rules for buildings*

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BS EN 1993-1-9:2005, *Eurocode 3 – Design of steel structures – Part 1-9: Fatigue*

BS EN 1090-2, *Execution of steel structures and aluminium structures – Part 2: Technical requirements for the execution of steel structures – Stage 34* [3)]

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

3) At the time of publication of this part of PD 6695, EN 1090-2 is still in preparation. The equivalent British Standards should be used until BS EN 1090-2 is published.

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