

Eurocode 9: Design of aluminium structures —

Part 1-3: Structures susceptible to fatigue

ICS 77.150.10; 91.010.30; 91.080.10

National foreword

This British Standard is the UK implementation of EN 1999-1-3:2007+A1:2011. It supersedes BS EN 1999-1-3:2007 which is withdrawn. Details of superseded British Standards are given in the table below.

Please note that the UK National Annex to BS EN 1999-1-3:2007 should only be used with BS EN 1999-1-3:2007 and not with BS EN 1999-1-3:2007+A1:2011. The UK National Annex is currently being amended so that it is aligned with the text of BS EN 1999-1-3:2007+A1:2011.

The start and finish of text introduced or altered by amendment is indicated in the text by tags. Tags indicating changes to CEN text carry the number of the CEN amendment. For example, text altered by CEN amendment A1 is indicated by **A1** **A1**.

The structural Eurocodes are divided into packages by grouping Eurocodes for each of the main materials: concrete, steel, composite concrete and steel, timber, masonry and aluminium.

In the UK, the following national standards are superseded by the Eurocode 9 series and are withdrawn.

Eurocode	Superseded British Standards
EN 1999-1-1	BS 8118-2:1991 DD ENV 1999-1-1:2000 BS 8118-1:1991 (partial)
EN 1999-1-2	DD ENV 1999-1-2:2000
EN 1999-1-3	DD ENV 1999-2:2000 BS 8118-1:1991 (partial)
EN 1999-1-4	BS 8118-1:1991 (partial)
EN 1999-1-5	None

The UK participation in its preparation was entrusted by Technical Committee B/525, Building and civil engineering structures, to Subcommittee B/525/9, Structural use of aluminium.

A list of organizations represented on this committee can be obtained on request to its secretary.

Where a normative part of this EN allows for a choice to be made at the national level, the range and possible choice will be given in the normative text, and a note will qualify it as a Nationally Determined Parameter (NDP). NDPs can be a specific value for a factor, a specific level or class, a particular method or a particular application rule if several are proposed in the EN.

To enable EN 1999-1-3 to be used in the UK, the NDPs have been published in a National Annex, which is available from BSI.

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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.

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English Version

Eurocode 9: Design of aluminium structures - Part 1-3: Structures susceptible to fatigue

Eurocode 9: Calcul des structures en aluminium - Partie 1-3: Structures sensibles à la fatigue

Eurocode 9: Bemessung und Konstruktion von Aluminiumtragwerken - Teil 1-3: Ermüdungsbeanspruchte Tragwerke

This amendment A1 modifies the European Standard EN 1999-1-3:2007; it was approved by CEN on 26 May 2011.

CEN members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for inclusion of this amendment into the relevant national standard without any alteration. Up-to-date lists and bibliographical references concerning such national standards may be obtained on application to the CEN-CENELEC Management Centre or to any CEN member.

This amendment exists in three official versions (English, French, German). A version in any other language made by translation under the responsibility of a CEN member into its own language and notified to the CEN-CENELEC Management Centre has the same status as the official versions.

CEN members are the national standards bodies of Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland and United Kingdom.



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Foreword

This document (EN 1999-1-3:2007) has been prepared by Technical Committee CEN/TC 250 “Structural Eurocodes”, the secretariat of which is held by BSI.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by November 2007, and conflicting national standards shall be withdrawn at the latest by March 2010.

This European Standard supersedes ENV 1999-2: 1998.

According to the CEN/CENELEC Internal Regulations, the national standards organizations of the following countries are bound to implement this European Standard:

Austria, Belgium, Bulgaria, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland and the United Kingdom.

Background to the Eurocode programme

In 1975, the Commission of the European Community decided on an action programme in the field of construction, based on article 95 of the Treaty. The objective of the programme was the elimination of technical obstacles to trade and the harmonisation of technical specifications.

Within this action programme, the Commission took the initiative to establish a set of harmonised technical rules for the design of construction works, which in a first stage would serve as an alternative to the national rules in force in the Member States and, ultimately, would replace them.

For fifteen years, the Commission, with the help of a Steering Committee with Representatives of Member States, conducted the development of the Eurocodes programme, which led to the first generation of European codes in the 1980s.

In 1989, the Commission and the Member States of the EU and EFTA decided, on the basis of an agreement¹⁾ between the Commission and CEN, to transfer the preparation and the publication of the Eurocodes to the CEN through a series of Mandates, in order to provide them with a future status of European Standard (EN). This links de facto the Eurocodes with the provisions of all the Council's Directives and/or Commission's Decisions dealing with European standards (e.g. the Council Directive 89/106/EEC on construction products – CPD – and Council Directives 93/37/EEC, 92/50/EEC and 89/440/EEC on public works and services and equivalent EFTA Directives initiated in pursuit of setting up the internal market).

The Structural Eurocode programme comprises the following standards generally consisting of a number of Parts:

EN 1990 Eurocode 0: Basis of structural design

EN 1991 Eurocode 1: Actions on structures

EN 1992 Eurocode 2: Design of concrete structures

EN 1993 Eurocode 3: Design of steel structures

1) Agreement between the Commission of the European Communities and the European Committee for Standardisation (CEN) concerning the work on EUROCODES for the design of building and civil engineering works (BC/CEN/03/89).

EN 1994 Eurocode 4: Design of composite steel and concrete structures

EN 1995 Eurocode 5: Design of timber structures

EN 1996 Eurocode 6: Design of masonry structures

EN 1997 Eurocode 7: Geotechnical design

EN 1998 Eurocode 8: Design of structures for earthquake resistance

EN 1999 Eurocode 9: Design of aluminium structures

Eurocode standards recognise the responsibility of regulatory authorities in each Member State and have safeguarded their right to determine values related to regulatory safety matters at national level where these continue to vary from State to State.

Status and field of application of Eurocodes

The Member States of the EU and EFTA recognise that Eurocodes serve as reference documents for the following purposes:

- As a means to prove compliance of building and civil engineering works with the essential requirements of Council Directive 89/106/EEC, particularly Essential Requirement N°1 - Mechanical resistance and stability - and Essential Requirement N°2 - Safety in case of fire;
- as a basis for specifying contracts for construction works and related engineering services;
- as a framework for drawing up harmonised technical specifications for construction products (ENs and ETAs).

The Eurocodes, as far as they concern the construction works themselves, have a direct relationship with the Interpretative Documents²⁾ referred to in Article 12 of the CPD, although they are of a different nature from harmonised product standard³⁾. Therefore, technical aspects arising from the Eurocodes work need to be adequately considered by CEN Technical Committees and/or EOTA Working Groups working on product standards with a view to achieving a full compatibility of these technical specifications with the Eurocodes.

The Eurocode standards provide common structural design rules for everyday use for the design of whole structures and component products of both a traditional and an innovative nature. Unusual forms of construction or design conditions are not specifically covered and additional expert consideration will be required by the designer in such cases.

2) According to Art. 3.3 of the CPD, the essential requirements (ERs) shall be given concrete form in interpretative documents for the creation of the necessary links between the essential requirements and the mandates for hENs and ETAGs/ETAs.

3) According to Art. 12 of the CPD the interpretative documents shall:

- a) give concrete form to the essential requirements by harmonising the terminology and the technical bases and indicating classes or levels for each requirement where necessary;
- b) indicate methods of correlating these classes or levels of requirement with the technical specifications, e.g. methods of calculation and of proof, technical rules for project design, etc.;
- c) serve as a reference for the establishment of harmonised standards and guidelines for European technical approvals. The Eurocodes, de facto, play a similar role in the field of the ER 1 and a part of ER 2.

National Standards implementing Eurocodes

The National Standards implementing Eurocodes will comprise the full text of the Eurocode (including any annexes), as published by CEN, which may be preceded by a National title page and National foreword, and may be followed by a National Annex (informative).

The National Annex (informative) may only contain information on those parameters which are left open in the Eurocode for national choice, known as Nationally Determined Parameters, to be used for the design of buildings and civil engineering works to be constructed in the country concerned, i.e.:

- Values for partial factors and/or classes where alternatives are given in the Eurocode;
- values to be used where a symbol only is given in the Eurocode;
- geographical and climatic data specific to the Member State, e.g. snow map;
- the procedure to be used where alternative procedures are given in the Eurocode;
- references to non-contradictory complementary information to assist the user to apply the Eurocode.

Links between Eurocodes and product harmonised technical specifications (ENs and ETAs)

There is a need for consistency between the harmonised technical specifications for construction products and the technical rules for works⁴⁾. Furthermore, all the information accompanying the CE Marking of the construction products which refer to Eurocodes should clearly mention which Nationally Determined Parameters have been taken into account.

Additional information specific to EN 1999-1-3

EN 1999 is intended to be used with Eurocodes EN 1990 – Basis of Structural Design, EN 1991 – Actions on structures and EN 1992 to EN 1999, where aluminium structures or aluminium components are referred to.

EN 1999-1-3 is one of five parts EN 1999-1-1 to EN 1999-1-5 each addressing specific aluminium components, limit states or type of structure. EN 1999-1-3 describes the principles, requirements and rules for the structural design of aluminium components and structures subjected to fatigue actions.

Numerical values for partial factors and other reliability parameters are recommended as basic values that provide an acceptable level of reliability. They have been selected assuming that an appropriate level of workmanship and quality management applies.

Foreword to amendment A1

This document (EN 1999-1-3:2007/A1:2011) has been prepared by Technical Committee CEN/TC 250 “Structural Eurocodes”, the secretariat of which is held by BSI.

This Amendment to the European Standard EN 1999-1-3:2007 shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by August 2012, and conflicting national standards shall be withdrawn at the latest by August 2012.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CEN [and/or CENELEC] shall not be held responsible for identifying any or all such patent rights.

According to the CEN/CENELEC Internal Regulations, the national standards organizations of the following countries are bound to implement this European Standard: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland and the United Kingdom.

National Annex for EN 1999-1-3

This standard gives alternative procedures, values and recommendations for classes with NOTES indicating where national choices may have to be made. Therefore the National Standard implementing EN 1999-1-1 should have a National Annex containing all Nationally Determined Parameters to be used for the design of aluminium structures to be constructed in the relevant country.

4) See Art.3.3 and Art.12 of the CPD, as well as clauses 4.2, 4.3.1, 4.3.2 and 5.2 of ID 1. Construction products which refer to Eurocodes should clearly mention which Nationally Determined Parameters have been taken into account.

National choice is allowed in EN 1999-1-3 through clauses:

A1 — 2.1.1 (1)

— 2.2.1 (4)

— 2.3.1 (2) **A1**

— 2.3.2 (6)

— 2.4 (1)

— 3 (1)

— 4 (2)

— 5.8.1 (1)

— 5.8.2 (1)

— 6.1.3 (1)

— 6.2.1(2)

— 6.2.1 (7)

— 6.2.1 (11)

A1 *Text deleted* **A1**

— E (5)

— E (7)

— 1.2.2 (1)

— 1.2.3.2 (1)

— 1.2.4 (1).

1 General

1.1 Scope

1.1.1 Scope of EN 1999

(1) P EN 1999 applies to the design of buildings and civil engineering and structural works in aluminium. It complies with the principles and requirements for the safety and serviceability of structures, the basis of their design and verification that are given in EN 1990 – Basis of structural design.

(2) EN 1999 is only concerned with requirements for resistance, serviceability, durability and fire resistance of aluminium structures. Other requirements, e.g. concerning thermal or sound insulation, are not considered.

(3) EN 1999 is intended to be used in conjunction with:

- EN 1990 Basis of structural design
- EN 1991 Actions on structures
- European Standards for construction products relevant for aluminium structures
- EN 1090-1: Execution of steel structures and aluminium structures – Part 1: Conformity assessment of structural components⁵⁾
- EN 1090-3: Execution of steel structures and aluminium structures – Part 3: Technical requirements for aluminium structures⁶⁾

(4) EN 1999 is subdivided in five parts:

EN 1999-1-1 Design of Aluminium Structures: General structural rules

EN 1999-1-2 Design of Aluminium Structures: Structural fire design

EN 1999-1-3 Design of Aluminium Structures: Structures susceptible to fatigue

EN 1999-1-4 Design of Aluminium Structures: Cold-formed structural sheeting

EN 1999-1-5 Design of Aluminium Structures: Shell structures

1.1.2 Scope of EN 1999-1-3

(1) EN 1999-1-3 gives the basis for the design of aluminium alloy structures with respect to the limit state of fracture induced by fatigue.

(2) EN 1999-1-3 gives rules for:

- Safe life design;
- damage tolerant design;
- design assisted by testing.

5) To be published

6) To be published

(3) EN 1999-1-3 is intended to be used in conjunction with EN 1090-3 “Technical requirements for the execution of aluminium structures” which contains the requirements necessary for the design assumptions to be met during execution of components and structures.

(4) EN 1999-1-3 does not cover pressurised containment vessels or pipe-work.

(5) The following subjects are dealt with in EN 1999-1-3:

Section 1: General

Section 2: Basis of design

Section 3: Materials, constituent products and connecting devices

Section 4: Durability

Section 5: Structural analysis

Section 6: Ultimate limit state of fatigue

Annex A: Basis for calculation of fatigue resistance [normative]

Annex B: Guidance on assessment by fracture mechanics [informative]

Annex C: Testing for fatigue design [informative]

Annex D: Stress analysis [informative]

Annex E: Adhesively bonded joints [informative]

Annex F: Low cycle fatigue range [informative]

Annex G: Influence of R-ratio [informative]

Annex H: Fatigue strength improvement of welds [informative]

Annex I: Castings [informative]

Annex J: Detail category tables [informative]

Annex K: Hot spot reference detail method [informative]

Bibliography

1.2 Normative references

(1) The normative references of EN 1999-1-1 apply.

1.3 Assumptions

(1) P The general assumptions of EN 1990, 1.3 apply.

(2) P The provisions of EN 1999-1-1, 1.8 apply.

(3) P The design procedures are valid only when the requirements for execution in EN 1090-3 or other equivalent requirements are complied with.

1.4 Distinction between principles and application rules

(1) P The rules in EN 1990, 1.4 apply.

1.5 Terms and definitions

1.5.1 General

(1) The rules in EN 1990, 1.5 apply.

1.5.2 Additional terms used in EN 1999-1-3

(1) For the purpose of this European Standard the following terms and definitions in addition to those defined in EN 1990 and EN 1999-1-1 apply.

1.5.2.1

fatigue

weakening of a structural part, through crack initiation and propagation caused by repeated stress fluctuations

1.5.2.2

fatigue loading

a set of typical load events described by the positions or movements of actions, their variation in intensity and their frequency and sequence of occurrence

1.5.2.3

loading event

a defined load sequence applied to the structure, which, for design purposes, is assumed to repeat at a given frequency

1.5.2.4

nominal stress

a stress in the parent material adjacent to a potential crack location, calculated in accordance with simple elastic strength of materials theory, i.e. assuming that plane sections remain plane and that all stress concentration effects are ignored

1.5.2.5

modified nominal stress

A nominal stress increased by an appropriate geometrical stress concentration factor K_{gt} , to allow only for geometric changes of cross section which have not been taken into account in the classification of a particular constructional detail

1.5.2.6

geometric stress

also known as structural stress, is the elastic stress at a point, taking into account all geometrical discontinuities, but ignoring any local singularities where the transition radius tends to zero, such as notches due to small discontinuities, e.g. weld toes, cracks, crack like features, normal machining marks etc. It is in principle the same stress parameter as the modified nominal stress, but generally evaluated by a different method

1.5.2.7

geometric stress concentration factor

the ratio between the geometric stress evaluated with the assumption of linear elastic behaviour of the material and the nominal stress

1.5.2.8

hot spot stress

the geometric stress at a specified initiation site in a particular type of geometry, such as a weld toe in an angle hollow section joint, for which the fatigue strength, expressed in terms of the hot spot stress range, is usually known

1.5.2.9

stress history

a continuous chronological record, either measured or calculated, of the stress variation at a particular point in a structure for a given period of time

1.5.2.10

stress turning point

the value of stress in a stress history where the rate of change of stress changes sign

1.5.2.12

stress peak

a turning point where the rate of change of stress changes from positive to negative

1.5.2.12

stress valley

a turning point where the rate of change of stress changes from negative to positive

1.5.2.13

constant amplitude

relating to a stress history where the stress alternates between stress peaks and stress valleys of constant values

1.5.2.14

variable amplitude

relating to any stress history containing more than one value of peak or valley stress

1.5.2.15

stress cycle

part of a constant amplitude stress history where the stress starts and finishes at the same value but, in doing so passes through one stress peak and one stress valley (in any sequence). Also, a specific part of a variable amplitude stress history as determined by a cycle counting method

1.5.2.16

cycle counting

the process of transforming a variable amplitude stress history into a spectrum of stress cycles, each with a particular stress range, e.g. the 'Reservoir' method and the 'Rain flow' method

1.5.2.17

rainflow method

particular cycle counting method of producing a stress-range spectrum from a given stress history

1.5.2.18

reservoir method

particular cycle counting method of producing a stress-range spectrum from a given stress history

1.5.2.19

stress amplitude

half the value of the stress range

1.5.2.20

stress ratio

minimum stress divided by the maximum stress in a constant amplitude stress history or a cycle derived from a variable amplitude stress history

1.5.2.21

stress intensity ratio

minimum stress intensity divided by the maximum stress intensity derived from a constant amplitude stress history or a cycle from a variable amplitude stress history

1.5.2.22

mean stress

the mean value of the algebraic sum of maximum and minimum stress values

1.5.2.23

stress range

the algebraic difference between the stress peak and the stress valley in a stress cycle

1.5.2.24

stress intensity range

the algebraic difference between the maximum stress intensity and the minimum stress intensity derived from the stress peak and the stress valley in a stress cycle

1.5.2.25

stress-range spectrum

histogram of the frequency of occurrence for all stress ranges of different magnitudes recorded or calculated for a particular load event (also known as 'stress spectrum')

1.5.2.26

design spectrum

the total of all stress-range spectra relevant to the fatigue assessment

1.5.2.27

detail category

the designation given to a particular fatigue initiation site for a given direction of stress fluctuation in order to indicate which fatigue strength curve is applicable for the fatigue assessment

1.5.2.28

endurance

the life to failure expressed in cycles, under the action of a constant amplitude stress history

1.5.2.29

fatigue strength curve

the quantitative relationship relating stress range and endurance, used for the fatigue assessment of a category of constructional detail, plotted with logarithmic axes in this standard

1.5.2.30

reference fatigue strength

the constant amplitude stress range $\Delta\sigma_c$ for a particular detail category for an endurance $N_c = 2 \times 10^6$ cycles

1.5.2.31

constant amplitude fatigue limit

the stress range below which value all stress ranges in the design spectrum should lie for fatigue damage to be ignored

1.5.2.32

cut-off limit

limit below which stress ranges of the design spectrum may be omitted from the cumulative damage calculation

1.5.2.33

design life

the reference period of time for which a structure is required to perform safely with an acceptable probability that structural failure by fatigue cracking will not occur

A1 1.5.2.34

safe life

period of time for which a structure is estimated to perform safely with an acceptable probability that failure by fatigue cracking will not occur, when using the safe life design method **A1**

1.5.2.35

damage tolerance

ability of the structure to accommodate fatigue cracking without structural failure or unserviceability

1.5.2.36

fatigue damage

the ratio of the number of cycles of a given stress range which is required to be sustained during a specified period of service to the endurance of the constructional detail under the same stress range

1.5.2.37

miner's summation

the summation of the damage due to all cycles in a stress-range spectrum (or a design spectrum), based on the Palmgren-Miner rule

1.5.2.38

equivalent fatigue loading

a simplified loading, usually a single load applied a prescribed number of times in such a way that it may be used in place of a more realistic set of loads, within a given range of conditions, to give an equivalent amount of fatigue damage, to an acceptable level of approximation

1.5.2.39

equivalent stress range

the stress range at a constructional detail caused by the application of an equivalent fatigue load

1.5.2.40

equivalent constant amplitude loading

simplified constant amplitude loading causing the same fatigue damage effects as a series of actual variable amplitude load events

1.6 Symbols

A	constant in the crack growth relationship
a	fillet weld throat
a	crack length
a_c	crack width on surface
da/dN	crack growth rate (m/cycle)
D	fatigue damage value calculated for a given period of service
D_L	fatigue damage value calculated for the full design life
D_{lim}	prescribed limit of the fatigue damage value
$f_{v,adh}$	characteristic shear strength of adhesive
K_{gt}	geometric stress concentration factor
K	stress intensity factor
ΔK	stress intensity range
k_{adh}	fatigue strength factor for adhesive joints

k_F	number of standard deviations above mean predicted intensity of loading
k_N	number of standard deviations above mean predicted number of cycles of loading
L_{adh}	effective length of adhesively bonded lap joints
l_d	minimum detectable length of crack
l_f	fracture critical length of crack
$\log$	logarithm to base 10
$\boxed{A1} m$	inverse slope of $\log \Delta \sigma$ - $\log N$ fatigue strength curve, or respectively crack growth rate exponent $\boxed{A1}$
m_1	value of m for $N \leq 5 \times 10^6$ cycles
m_2	value of m for $5 \times 10^6 < N \leq 10^8$ cycles
N	number (or total number) of stress range cycles
$\boxed{A1} N_i$	predicted number of cycles to failure of a stress range $\Delta \sigma_i$ $\boxed{A1}$
N_C	number of cycles (2×10^6) at which the reference fatigue strength is defined
N_D	number of cycles (5×10^6) at which the constant amplitude fatigue limit is defined
N_L	number of cycles (10^8) at which the cut-off limit is defined
n_i	number of cycles of stress range $\Delta \sigma_i$
P	probability
R	stress ratio
t	thickness
$\boxed{A1} T_i$	inspection interval
T_F	recommended time after completed erection for the start of fatigue inspection, where the fatigue inspection comprises the inspection of areas with high probability for cracks
T_G	recommended time after completed erection for start of general inspection, where the general inspection comprises checking that the structure is as it was when it was completed and approved, i.e. that no deterioration has taken place, such as deterioration caused by adding detrimental holes or welds for additional elements, damage due to vandalism or accidents, unexpected corrosion etc $\boxed{A1}$
T_f	time for a crack to grow from a detectable size to a fracture critical size
T_L	design life
T_S	safe life
y	crack geometry factor in crack growth relationship
$\boxed{A1} \lambda_i$	damage equivalent factor depending on the load situation and the structural characteristics as well as other factors
γ_{Ff}	partial factor for fatigue load intensity
γ_{Mf}	partial factor for fatigue strength $\boxed{A1}$

$\Delta\sigma$ nominal stress range (normal stress)

NOTE $\Delta\sigma$ refers either to action effects or to fatigue strength depending on context.

$\Delta\tau$ effective shear stress range

$\Delta\sigma_i$ constant stress range for the principal stresses in the construction detail for n_i cycles

$\Delta\sigma_C$ reference fatigue strength at 2×10^6 cycles (normal stress)

$\Delta\sigma_D$ constant amplitude fatigue limit

$\Delta\sigma_E$ nominal stress range from fatigue actions

$\Delta\sigma_{E,Ne}$ equivalent constant amplitude stress range related to N_{max}

$\Delta\sigma_{E,2e}$ equivalent constant amplitude stress range related to 2×10^6 cycles

$\Delta\sigma_L$ cut-off limit

$\Delta\sigma_R$ fatigue strength (normal stress)

ΔT_F recommended maximum time interval for general inspection

ΔT_G recommended maximum time interval for fatigue inspection

$\sigma_{max}, \sigma_{min}$ maximum and minimum values of the fluctuating stresses in a stress cycle

σ_m mean stress

$D_{L,d}$ design fatigue damage value calculated for the full design life $\langle A_1 \rangle$

1.7 Specification for execution

1.7.1 Execution specification

(1) The execution specification should include all requirements for material preparation, assembly, joining, post treatment and inspection in order that the required fatigue strengths are achieved.

1.7.2 Operation manual

(1) The operation manual should include:

- Details of the fatigue loading and the design life assumed in the design;
- any necessary requirements to monitor loading intensity and frequency during service;
- an instruction forbidding any modification of the structure, e.g. making of holes or welding, without qualified analysis of any structural consequences;
- instructions for dismantling and reassembly of parts, e.g. tightening of fasteners;
- acceptable repair methods in the event of accidental damage in-service (e.g. dents, penetrations, tears, etc).

1.7.3 Inspection and maintenance manual

(1) The maintenance manual should include a schedule of any necessary in-service inspection of fatigue critical parts. In particular, where damage tolerant design has been used, this should include:

- The methods of inspection;
- the locations for inspection;
- the frequency of inspections;
- the maximum permissible crack size before correction is necessary;
- details of methods of repair or replacement of fatigue cracked parts.

A1 2 Basis of design

2.1 General

2.1.1 Basic requirements

(1) P The aim of designing a structure against the limit state of fatigue is to ensure, with an acceptable level of probability, that its performance is satisfactory during its entire design life, such that the structure shall not fail by fatigue nor shall it be likely to require undue repair of damage caused by fatigue during the design life. The design of aluminium structures against the limit state of fatigue may be based on one of following methods:

- a) safe life design (SLD) (see 2.2.1);
- b) damage tolerant design (DTD) (see 2.2.2).

Either of methods a) and b) may be supplemented or replaced by design assisted by testing (see 2.2.3).

NOTE The national annex may specify conditions for the application for the above methods of design.

(2) The method for design against fatigue should be selected taking the use of the structure into account, considering the consequence class fixed for the components of the structure. In particular the accessibility for inspection of components and details where fatigue cracks are likely to occur should be considered.

(3) Fatigue assessment of components and structures should be considered in cases where the loads are frequently changing, particularly if reversing. Common situations where this may occur are e.g.:

- members supporting lifting appliances or rolling loads;
- members subjected to repeated stress cycles from vibrating machinery;
- members subjected to wind-induced oscillations;
- members subject to crowd-induced oscillations;
- moving structures (structures subject to inertia forces);
- members subjected to fluid flow induced oscillations or wave action.

NOTE The rules for fatigue resistance given in this standard apply generally to high cycle fatigue. For low cycle fatigue, guidelines are given in Annex F.

(4) The design rules in the other parts of EN 1999 apply.

2.2 Procedures for fatigue design

2.2.1 Safe life design (SLD)

(1) The safe life design method is based on the calculation of damage accumulation during the structure's design life or comparing the maximum stress range with the constant amplitude limit, using standard lower bound endurance data and an upper bound estimate of the fatigue loading, all based on design values. The approach provides a conservative estimate of the fatigue strength and does not normally depend on in-service inspection for fatigue damage.

NOTE Options considering in-service inspection are given in L1 for use when Annex J resistance data is adopted.

(2) The fatigue design involves prediction of the stress histories at potential crack initiation sites, followed by counting of load cycles with the associated stress ranges and compilation of stress spectra. From this information an estimate of the design life is made using the appropriate stress range endurance data for the construction detail concerned. This method is given in A.2. **A1**

A1 (3) The safe life design method may be based on one of two procedures to ensure sufficient resistance of the component or structure. The procedures are respectively based on that

- a) the linear damage accumulation calculation is used, see (4);
- b) the equivalent stress range approach is used, see (5)

NOTE A third procedure, for the case where all design stress ranges are less than the design constant amplitude fatigue limit, is given in L.1(4).

(4) For safe life design based on the assumption of linear damage accumulation (Palmgren-Miner's summation) the damage value D_L for all cycles should fulfill the condition:

$$D_{L,d} \leq 1 \quad (2.1 \text{ a})$$

where

$D_{L,d} = \sum n_i / N_i$ is calculated in accordance with the procedure given in A.2.

or

$$D_L \leq D_{lim} \quad (2.1 \text{ b})$$

where:

$D_L = \sum n_i / N_i$ is calculated in accordance with the procedure given in A.2 with $\gamma_{Mf} = \gamma_{Ff} = 1,0$.

NOTE The national annex may specify values for D_{lim} , see L.4. Recommended values of D_{lim} are given in L.4 for use when resistance data in Annex J is adopted.

(5) In case the design is based on the equivalent stress range approach ($\Delta\sigma_{E,2e}$) the following condition should be fulfilled:

$$\frac{\gamma_{Ff} \Delta\sigma_{E,2e}}{\Delta\sigma_C / \gamma_{Mf}} \leq 1 \quad (2.2)$$

NOTE Recommended values for γ_{Mf} are given in L.4. For γ_{Ff} , see 2.4.

2.2.2 Damage tolerant design (DTD)

(1) P A damage tolerant design requires that a prescribed inspection and maintenance programme for detecting and correcting any fatigue damage is prepared and followed throughout the design life of the structure. It should provide an acceptable reliability that a structure will perform satisfactorily for its design life. Prerequisites for use of this method and determination of an inspection strategy are given in A.3.

NOTE 1 Damage tolerant design may be suitable for application where a safe life assessment shows that fatigue has a significant effect on design economy and where a higher risk of fatigue cracking during the design life may be justified than is permitted using safe life design principles. The approach is intended to result in the same reliability level as obtained by using the approach of safe life design.

NOTE 2 Damage tolerant design may be applied in two different types of approach, DTD-I and DTD-II, see Annex L.

(2) The following guidelines should be considered for the structural layout and detailing: **A1**

- A1** — select details, material and stress levels so that in the event of the formation of cracks a low rate of crack propagation and a long critical crack length would result;
- choose wherever possible a structural concept where in the event of fatigue damage a redistribution of load effects within the structure or within the cross section of a member can occur (principle of redundancy);
 - provide crack-arresting details;
 - assure that critical components and details are readily inspectable during regular inspection;
 - ensure that cracks can be kept under control by monitoring or, if needed, that components are readily repairable or replaceable.

2.2.3 Design assisted by testing

(1) This approach should be used where the necessary loading data, response data, fatigue strength data or crack growth data are not available from standards or other sources for a particular application, and for optimisation of construction details. Test data should only be used in lieu of standard data on condition that they are obtained and applied under controlled conditions.

NOTE Verification of design by testing should be carried out in accordance with Annex C.

2.3 Fatigue loading

2.3.1 Sources of fatigue loading

(1) P All sources of fluctuating stress in the structure should be identified. Common fatigue loading situations are given in 2.1.1.

NOTE For limitation of fatigue induced by repeated local buckling, see D.3.

(2) The fatigue loading should be obtained from EN 1991 or other relevant European Standard.

NOTE The national annex may give rules for the determination of the fatigue loads for cases not covered by a European Standard.

(3) Dynamic effects should be taken into account unless already allowed for in the fatigue load effects.

2.3.2 Derivation of fatigue loading

(1) In addition to the fatigue loading standards the following clauses should be considered:

(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 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 then it will be necessary to specify the phasing between them.

(3) Realistic assessment of the fatigue loading is crucial to the calculation of the life of the structure. Where no published data for live load exists, fatigue loading data from existing structures subjected to similar load effects should be used.

(4) By recording continuous strain or deflection measurements over a suitable sampling period, fatigue loading data should be inferred from subsequent analysis of the structural responses. Particular care should be taken to assess dynamic magnification effects where load frequencies are close to one of the natural frequencies of the structure.

NOTE Further guidance is given in Annex C. **A1**

A1 (5) The design load spectrum should be selected on the basis that it is an upper bound estimate of the accumulated service conditions over the full design life of the structure. Account should be taken of all likely operational and exposure condition effects arising from the foreseeable usage of the structure during that period.

(6) The confidence limit to be used for the intensity of the design load spectrum should be based on the mean predicted value plus k_F standard deviations. The confidence limit to be used for the number of cycles in the design load spectrum should be based on the mean predicted value plus k_N standard deviations.

NOTE Values of k_F and k_N may be defined in the national annex. The numerical values $k_F = 2$, and $k_N = 2$ are recommended. See also NOTE 2 under 2.4 (1).

2.3.3 Equivalent fatigue loading

(1) A simplified equivalent fatigue loading may be used if the following conditions are satisfied:

- a) the structure falls within the range of basic structural forms and size for which the equivalent fatigue loading was originally derived;
- b) the real fatigue loading is of similar intensity and frequency and is applied in a similar way to that assumed in the derivation of the equivalent fatigue loading;
- c) the values of m_1 , m_2 , N_D and N_L , see Figure 6.1, assumed in the derivation of equivalent fatigue loading are the same as those appropriate to the construction detail being assessed;

NOTE Some equivalent fatigue loads may have been derived assuming a simple continuous slope where $m_2 = m_1$ and $\Delta\sigma_L = 0$. For many applications involving numerous low amplitude cycles this will result in a very conservative estimate of life.

- d) the dynamic response of the structure is sufficiently low that the resonant effects, which will be affected by differences in mass, stiffness and damping coefficient, will have little effect on the overall Palmgren-Miner summation.

(2) In the event that an equivalent fatigue loading is derived specifically for an aluminium alloy structural application, all the matters addressed in (1) above should be taken into account.

2.4 Partial factors for fatigue loads

(1) Where the fatigue loads F_{Ek} have been derived in accordance with the requirements of 2.3.1 (2) and 2.3.2 a partial factor should be applied to the loads to obtain the design load F_{Ed} .

$$F_{Ed} = \gamma_{ff} F_{Ek} \quad (2.4)$$

where

γ_{ff} is the partial factor for fatigue loads.

NOTE 1 The partial factors may be defined in the national annex. A value of $\gamma_{ff} = 1,0$ is recommended.

NOTE 2 Where fatigue loads have been based on confidence limits other than those in 2.3.2 (6), recommended values for partial factors on loads are given in Table 2.1. Alternative values may be specified in the national annex. **A1**

Table 2.1 — Recommended partial factors γ_{ff} for intensity and number of cycles in the fatigue load spectrum

k_F	γ_{ff}	
	$k_N = 0$	$k_N = 2$
0	1,5	1,4
1	1,3	1,2
2	1,1	1,0

2.5 Execution requirements

(1) EN 1090-3 requires execution classes to be selected. These may be related to service category.

NOTE Guidance on selection of execution class and service category is given in EN 1999-1-1. Guidance on utilization grade is given in L.5 for use when Annex J resistance data is adopted. **A1**

3 Materials, constituent products and connecting devices

(1) The design rules of EN 1999-1-3 apply to constituent products in components and structures as listed in 1999-1-1:05-2005 with the exception of the low strength alloys EN AW-3005, EN AW-3103, EN AW-5005, EN AW-8011A in all tempers, and EN AW-6060 in temper T5.

NOTE 1 For the above mentioned low strength alloys and tempers no reliable fatigue data exist. The National Annex may give fatigue data for such alloys and tempers, respectively. Tests to obtain the data should be carried out in accordance with Annex C.

NOTE 2 For castings see Annex I.

(2) EN 1999-1-3 covers components with open and hollow sections, including members built up from combinations of these products.

(3) EN 1999-1-3 covers components and structures with the following connecting devices:

- Arc welding (metal inert gas and tungsten inert gas);
- steel bolts listed in EN 1999-1-1, Table 3.4.

NOTE For adhesive bonding see Annex E.

(4) For the fatigue design and verification of steel bolts in tension and shear see EN 1993-1-9, Table 8.1.

4 Durability

(1) Fatigue strength data given in EN 1999-1-3 are applicable under normal atmospheric conditions up to temperatures of 100 °C. However in the case of alloy EN AW-5083, at temperatures of more than 65 °C fatigue strength data in EN 1999-1-3 do not apply unless an efficient corrosion preventing coating is provided.

(2) Fatigue strength data may not be applicable under all conditions of aggressive exposure. Guidance on materials and exposure conditions is given in 6.2 and 6.4.

NOTE The National Annex may give further information on durability, based on local exposure conditions.

(3) For adhesively bonded joints special environmental conditions and effects may have to be considered.

NOTE See Annex E.

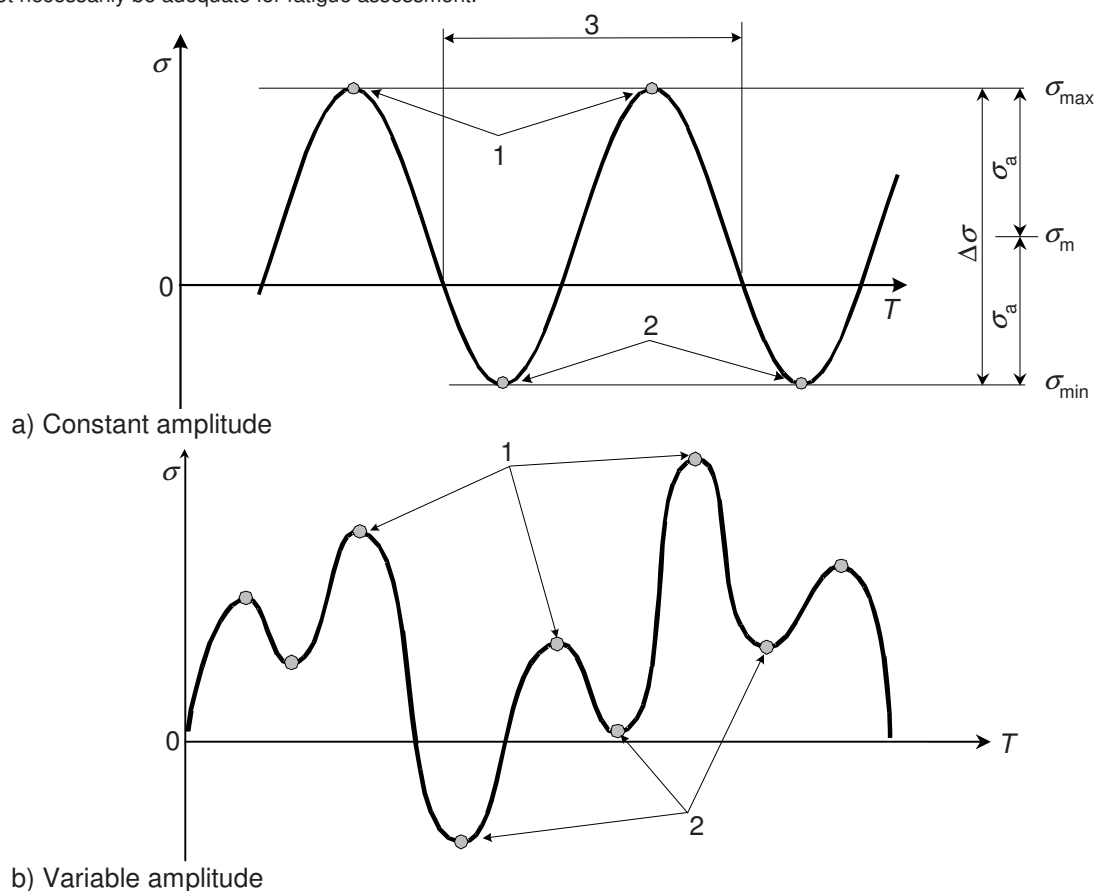
5 Structural analysis

5.1 Global analysis

5.1.1 General

(1) 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 action, so that the maximum and minimum stress peaks in the stress history are determined, see Figure 5.1.

NOTE An elastic model used for static assessment (for the ultimate or serviceability limit state) in accordance with EN 1990-1-1 may not necessarily be adequate for fatigue assessment.



1 – stress peak; 2 – stress valley; 3 – stress cycle; o – stress turning point

$\sigma_{\max}$: maximum stress; $\sigma_{\min}$: minimum stress; σ_m : mean stress; $\Delta\sigma$: stress range; σ_a : stress amplitude

Figure 5.1 —Terminology relating to stress histories and cycles

(2) Dynamic effects should be included in the calculation of the stress history, except where an equivalent action is being applied which already allows for such effects.

(3) Where the elastic response is affected by the degree of damping this should be determined by test.

NOTE See Annex C.

(4) No plastic redistribution of forces between members should be assumed in statically indeterminate structures.

(5) The stiffening effect of any other materials which are permanently fixed to the aluminium structure should be taken into account in the elastic analysis.

(6) Models for global analysis of statically indeterminate structures and latticed frames with rigid or semi rigid joints (e.g. finite element models) should be based on elastic material behaviour, except where strain data have been obtained from prototype structures or accurately scaled physical models.

NOTE The term finite element is used to express 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.

5.1.2 Use of beam elements

(1) Beam elements should be applicable to the global analysis of beam, framed or latticed structures subject to the limitations in (2) to (7) below.

(2) Beam elements should not be used for the fatigue analysis of stiffened plate structures of flat or shell type members or for cast or forged members unless of simple prismatic form.

(3) The axial, bending, shear and torsional section stiffness properties of the beam elements should be calculated in accordance with linear elastic theory assuming plane sections remain plane. However warping of the cross-section due to torsion should be considered.

(4) Where beam elements are used in structures with open section members or hollow section members prone to warping, which are subjected to torsional forces, the elements should have a minimum of 7 degrees of freedom including warping. Alternatively, shell elements should be used to model the cross-section.

(5) The section properties for the beam elements adjacent to member intersections should take into account the increased stiffness due to the size of the joint region and the presence of additional components (e.g. gussets, splice plates, etc.).

(6) The stiffness properties of beam elements used to model joint regions at angled intersections between open or hollow members where their cross-sections are not carried fully through the joint (e.g. unstiffened tubular nodes), or where the constructional detail is semi-rigid (e.g. bolted end plate or angle cleat connections), should be assessed either using shell elements or by connecting the elements via springs. The springs should possess sufficient stiffness for each degree of freedom and their stiffness should be determined either by tests or by shell element models of the joint.

(7) Where beam elements are used to model a structure with eccentricities between member axes at joints or where actions and restraints are applied to members other than at their axes, rigid link elements should be used at these positions to maintain the correct static equilibrium. Similar springs as in (6) should be used if necessary.

5.1.3 Use of membrane, shell and solid elements

(1) Membrane elements should only be applicable to those parts of a structure where out-of-plane bending stresses are known to be negligible.

(2) Shell elements should be applicable to all structural types except where cast, forged or machined members of complex shape involving 3-dimensional stress fields are used, in which case solid elements should be used.

(3) Where membrane or shell elements are used within the global analysis to take account of gross stress concentrating effects such as those listed in 5.2.2, the mesh size should be small enough in the part of the member containing the initiation site to assess the effect fully.

NOTE See Annex D.

5.2 Types of stresses

5.2.1 General

(1) Three different types of stresses may be used, namely:

- a) Nominal stresses, see 5.2.2. For derivation of nominal stress see 5.3.1;
- b) modified nominal stresses, see 5.2.3. For derivation of modified nominal stresses see 5.3.2;
- c) hot spot stresses, see 5.2.4 and 5.3.3.

5.2.2 Nominal stresses

(1) Nominal stresses, see Figure 5.2 should be used directly for the assessment of initiation sites in simple members and joints where the following conditions apply:

- a) the constructional details associated with the initiation site are represented by detail categories, or
- b) the detail category has been established by tests where the results have been expressed in terms of the nominal stresses;

NOTE Tests should be in accordance with Annex C.

- c) gross geometrical effects such as those listed in 5.2.3 are not present in the vicinity of the initiation site.

5.2.3 Modified nominal stresses

(1) 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 5.2) provided that conditions 5.2.1(a) and (b) still apply:

- 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 beyond those permitted in detail category tables;
 - d) shear lag in wide plate;
- NOTE See EN 1999-1-1, K.1.
- e) distortion of hollow members;
 - f) non-linear out-of-plane bending effects in slender flat plates, e.g. class 4 sections, where the static stress is close to the elastic critical stress, e.g. tension-field in webs.

NOTE See Annex D.

(2) The above geometrical stress concentrating effects should be taken into account through the factor K_{gt} , see Figure 5.2, defined as the theoretical stress concentration evaluated for linear elastic material omitting all the influences (local or geometric) already included in the $\Delta\sigma$ - N fatigue strength curve of the classified constructional detail considered as a reference.

5.2.4 Hot spot stresses

(1) Hot spot stresses may be used only where the following conditions apply:

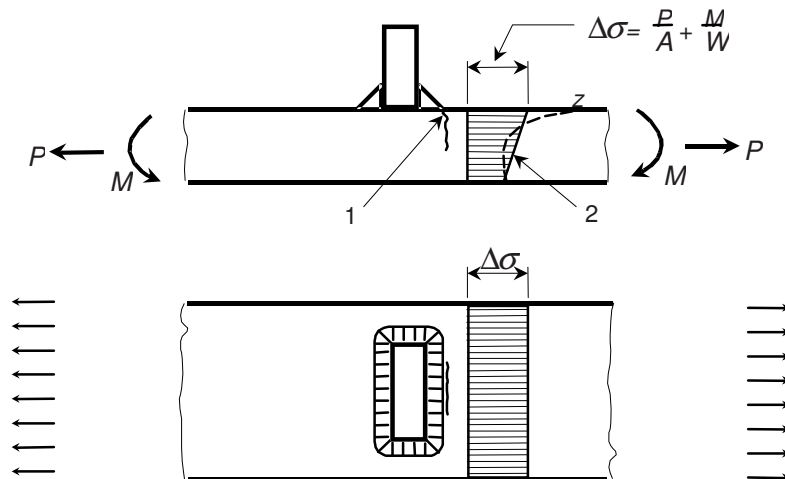
- a) The initiation site is a weld toe in a joint with complex geometry where the nominal stresses are not clearly defined;

NOTE Due to the large influence of the heat affected zone in the strength of welded aluminium components, the experience from structural steel details is not generally applicable for aluminium.

- b) a hot spot detail category has been established by tests and the results have been expressed in terms of the hot spot stress, for the appropriate action mode;
- c) shell bending stresses are generated in flexible joints and taken into account according to 5.1.2 (6);

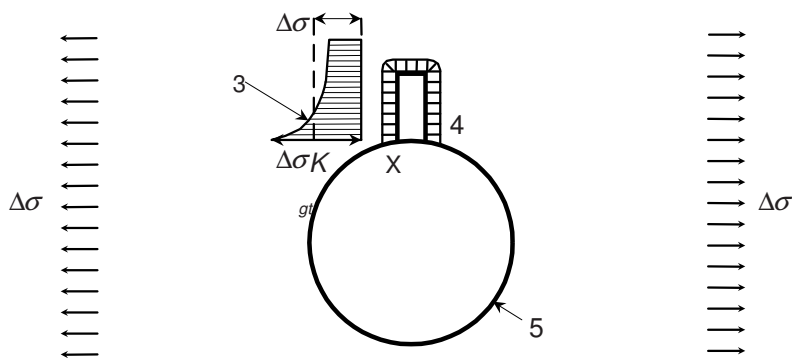
NOTE See Annexes C, D and K.

- d) for derivation of hot spot stresses see 5.3.3 and 6.2.4.



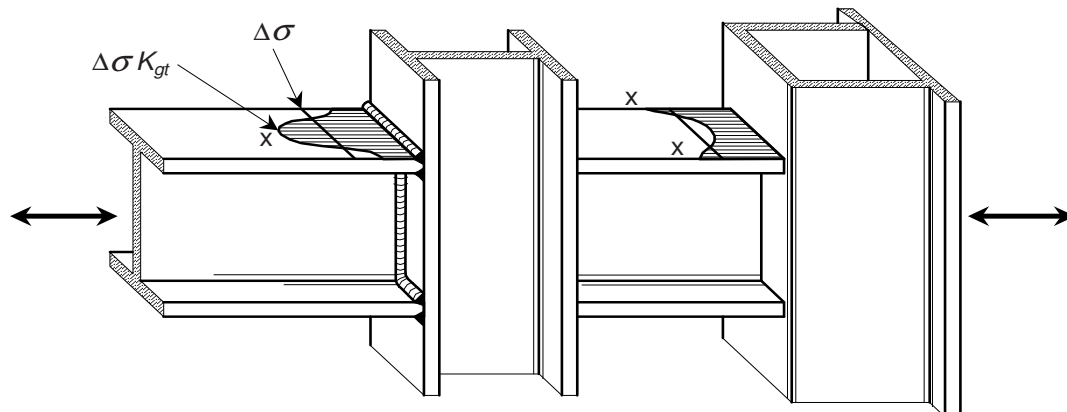
a) Local stress concentration at weld toe;

1 – crack initiation site; 2 – linear stress distribution, weld toe stress factor at z not calculated



b) Gross stress concentration at large opening

$\Delta\sigma$ = nominal stress range; $\Delta\sigma K_{gt}$ = modified nominal stress range at initiation site X due to the opening; 3 – non-linear stress distribution; 4 – weld; 5 – large opening



c) Hard point in connection;

$\Delta\sigma$ = nominal stress range; $\Delta\sigma K_{gt}$ = modified nominal stress range at initiation site X due to the geometrical stress concentration effects

Figure 5.2 – Examples of nominal and modified nominal stresses

5.3 Derivation of stresses

5.3.1 Derivation of nominal stresses

5.3.1.1 Structural models using beam elements

(1) The axial and shear stresses at the initiation site should be calculated from the axial, bending, shear and torsional action effects at the section concerned using linear elastic section properties.

(2) The cross-sectional areas and section moduli should take account of any specific requirements of a constructional detail.

5.3.1.2 Structural models using membrane, shell or solid elements

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

(2) Where the axial 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.

NOTE The latter should be used in conjunction with the appropriate cross-sectional area and section moduli to obtain the nominal stresses.

5.3.2 Derivation of modified nominal stresses

5.3.2.1 Structural models using beam elements

(1) The nominal stresses should be multiplied by the appropriate elastic stress concentration factors K_{gt} according to the location of the initiation site and the type of stress field.

(2) K_{gt} should take into account all geometrical discontinuities except for those already incorporated within the detail category.

(3) K_{gt} should be determined by one of the following approaches:

a) Standard solutions for stress concentration factors;

NOTE See D.2

b) substructuring of the surrounding geometry using shell elements taking into account (2), 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 (2)).

5.3.2.2 Structural models using membrane, shell or solid elements

(1) 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 constructional 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)

NOTE See D.1.

5.3.3 Derivation of hot spot stresses

(1) The hot spot stress is the principal stress predominantly transverse to the weld toe line and should be evaluated in general by numerical or experimental methods, except where standard solutions are available.

NOTE See D.1.

(2) For simple cases, as the one shown in Figure 5.2 (c), the hot spot stress may be taken as the modified nominal stress and calculated according to 5.2.3.

(3) In general, for structural configurations for which standard stress concentration factors are not applicable and which therefore require special analysis, the fatigue stress at the weld toe should omit the stress concentration effects due to the classified constructional detail considered as a reference, i.e. the weld toe geometry.

5.3.4 Stress orientation

(1) The principal stress range is the greatest algebraic difference between the principal stresses acting in principal planes no more than 45° apart.

(2) For the purposes of assessing whether a constructional detail is normal or parallel to the axis of a weld if the direction of the principal tensile stress is less than 45° to the weld axis it should be assumed to be parallel to it.

5.4 Stress ranges for specific initiation sites

5.4.1 Parent material, welds, and mechanically fastened joints

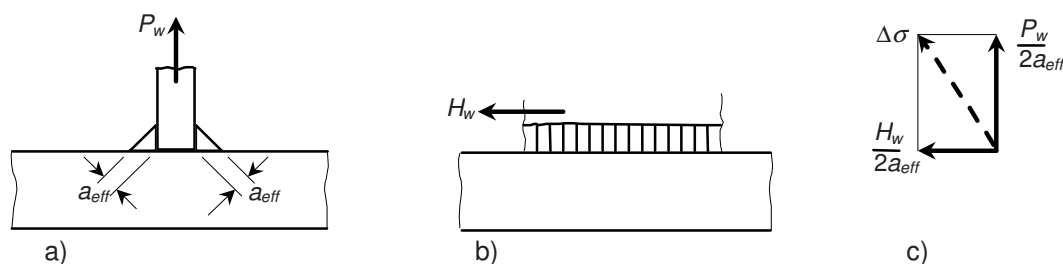
(1) Cracks initiating from weld toes, weld caps, fastener holes, fraying surfaces, etc. and propagating through parent material or weld metal should be assessed using the nominal principal stress range in the member at that point (see Figure 5.3).

(2) The local stress concentration effects of weld profile, bolt and rivet holes are taken into account in the $\Delta\sigma$ - N strength data for the appropriate constructional detail category.

5.4.2 Fillet and partial penetration butt welds

(1) Cracks initiating from weld roots and propagating through the weld throat should be assessed using the vector sum $\Delta\sigma$ of the stresses in the weld metal based on the effective throat thickness, see Figure 5.3.

NOTE The reference strength value may be taken as in constructional detail 9.2, Table J.9.



P_w and H_w are forces per unit length

Figure 5.3 —Stresses in weld throats

(2) In lapped joints in one plane the stress per unit length of weld may be calculated on the basis of the average area for axial forces and an elastic polar modulus of the weld group for in-plane moments (see Figure 5.4).

NOTE The reference strength value may be taken as in constructional detail 9.4, Table J.9.

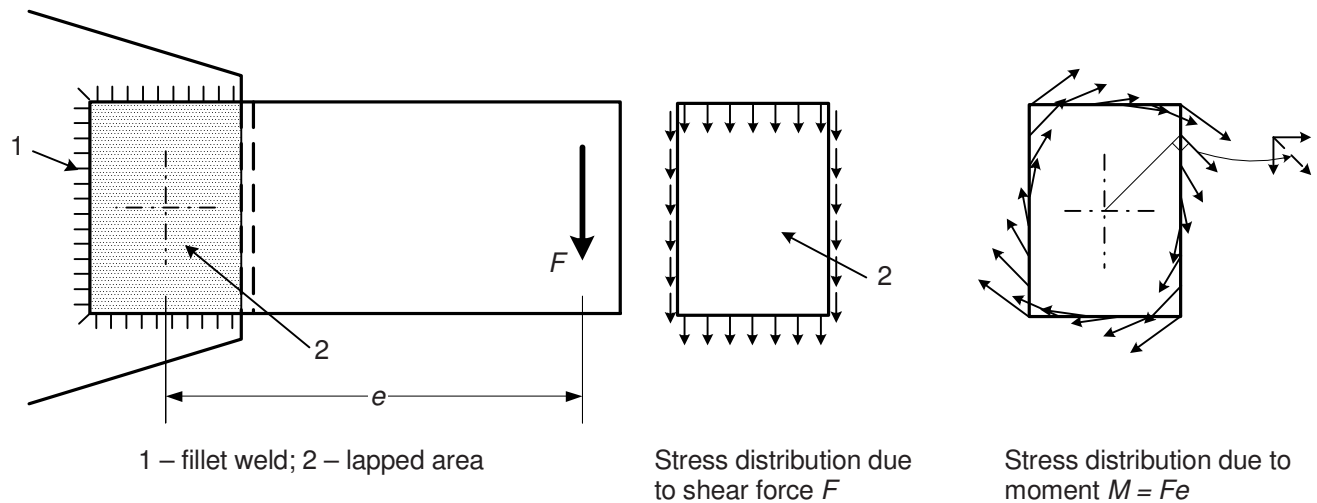


Figure 5.4 —Stresses in lapped joints

5.5 Adhesive bonds

(1) Fatigue assessment should include failure surface through the bond plane.

NOTE See Annex E.

5.6 Castings

(1) The principal geometric stress should be used. Finite stress analysis or strain gauging in the case of complex shapes may be required, if standard solutions are not available.

5.7 Stress spectra

(1) The methods for cycle counting of stress ranges for the purpose of deriving stress spectra are given in Annex A.

5.8 Calculation of equivalent stress range for standardised fatigue load models

5.8.1 General

(1) The fatigue assessment for standardized fatigue loads as specified in EN 1991 should be carried out according to one of the following approaches:

- Nominal stress ranges for constructional details shown in the detail category information;
- modified nominal stress ranges where abrupt changes of section occur close to the initiation site which are not included in the constructional detail information;
- geometric stress ranges where high stress gradients occur close to a weld toe.

NOTE The National Annex may give information on the use of the nominal stress ranges or modified nominal stress ranges.

A1 (2) The design value of stress range to be used for the fatigue assessment should be the stress ranges $\gamma_{Ff} \Delta\sigma_{E,2e}$ corresponding to $N_C = 2 \times 10^6$ cycles. **A1**