



BSI Standards Publication

Eurocode 9 — Design of aluminium structures

Part 1-3: Structures susceptible to fatigue

National foreword

This British Standard is the UK implementation of EN 1999-1-3:2023. It supersedes BS EN 1999-1-3:2007+A1:2011, which will be withdrawn on 30 March 2028.

The UK participation in its preparation was entrusted to Technical Committee B/525/9, Structural use of aluminium.

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

National choice is allowed in this standard where explicitly stated within notes. The National Annex to this standard contains the national choices to be used for buildings and civil engineering works constructed in the UK.

The first generation of EN Eurocodes was published between 2002 and 2007, with conflicting British Standards withdrawn in 2010. This document forms part of the second generation of EN Eurocodes.

The second generation of EN Eurocodes is expected to be published between 2023 and 2026. These documents are being published as soon as they are available. This is being done to enable users to prepare for the transition from the first generation to second generation of EN Eurocodes.

UK adoptions of the first generation of EN Eurocodes will be withdrawn by BSI on 30 March 2028. Until that date, the first generation documents should be considered as the applicable standards for buildings and civil engineering works constructed in the UK unless otherwise specified by the relevant authority or in the specification for a particular project.

This standard is intended to be used with its National Annex and other referenced documents, including other second generation Eurocodes, as an interdependent suite of documents.

While the use of provisions in this standard in conjunction with first generation Eurocodes is not precluded, it should be undertaken with care and should only be done when users are satisfied that it will not result in a lower level of reliability than the minimum level set in the first generation Eurocodes and associated UK National Annexes.

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Amendments/corrigenda issued since publication

Date	Text affected
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English Version

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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 European Standard was approved by CEN on 2 January 2023.

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European foreword

This document (EN 1999-1-3:2023) has been prepared by Technical Committee CEN/TC250 “Structural Eurocodes”, the secretariat of which is held by BSI. CEN/TC 250 is responsible for all Structural Eurocodes and has been assigned responsibility for structural and geotechnical design matters by CEN.

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 September 2027, and conflicting national standards shall be withdrawn at the latest by March 2028.

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

This document supersedes EN 1999-1-3:2007.

The first generation of EN Eurocodes was published between 2002 and 2007. This document forms part of the second generation of the Eurocodes, which have been prepared under Mandate M/515 issued to CEN by the European Commission and the European Free Trade Association.

The Eurocodes have been drafted to be used in conjunction with relevant execution, material, product and test standards, and to identify requirements for execution, materials, products and testing that are relied upon by the Eurocodes.

The Eurocodes recognize the responsibility of each Member State and have safeguarded their right to determine values related to regulatory safety matters at national level through the use of National Annexes.

The main changes compared to the previous edition are listed below:

- Some reorganization of the text and its coherence with EN 1999-1-1 and the other Eurocodes;
- Improvement of figures;
- Improvement of detail categories for fillet-welded joints between members (Table J.9);
- Improvement of detail categories for bolted joints (Table J.15);
- Inclusion of Friction Stir Welding (FSW) in the scope;
- Inclusion of detail categories for members with Friction Stir Welding (New Table J.17)

Any feedback and questions on this document should be directed to the users’ national standards body. A complete listing of these bodies can be found on the CEN website.

According to the CEN-CENELEC Internal Regulations, the national standards organisations 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, Republic of North Macedonia, Romania, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Türkiye and the United Kingdom.

Introduction

0.1 Introduction to the Eurocodes

The Structural Eurocodes comprise the following standards generally consisting of a number of Parts:

- EN 1990 Eurocode: Basis of structural and geotechnical design
- EN 1991 Eurocode 1: Actions on structures
- EN 1992 Eurocode 2: Design of concrete structures
- EN 1993 Eurocode 3: Design of steel structures
- 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
- New parts are under development, e.g. Eurocode for design of structural glass

The Eurocodes are intended for use by designers, clients, manufacturers, constructors, relevant authorities (in exercising their duties in accordance with national or international regulations), educators, software developers, and committees drafting standards for related product, testing and execution standards.

NOTE Some aspects of design are most appropriately specified by relevant authorities or, where not specified, can be agreed on a project-specific basis between relevant parties such as designers and clients. The Eurocodes identify such aspects making explicit reference to relevant authorities and relevant parties.

0.2 Introduction to EN 1999 (all parts)

EN 1999 (all parts) applies to the design of buildings and civil engineering and structural works made of 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.

EN 1999 (all parts) 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.

EN 1999 (all parts) does not cover the special requirements of seismic design. Provisions related to such requirements are given in EN 1998, which complements, and is consistent with EN 1999.

Eurocode 9 is subdivided in various parts:

- EN 1999-1-1 Design of Aluminium Structures — Part 1-1: General rules.
- EN 1999-1-2 Design of Aluminium Structures — Part 1-2: Structural fire design.
- EN 1999-1-3 Design of Aluminium Structures — Part 1-3: Structures susceptible to fatigue.

- EN 1999-1-4 Design of Aluminium Structures — Part 1-4: Cold-formed structural sheeting.
- EN 1999-1-5 Design of Aluminium Structures — Part 1-5: Shell structures.

0.3 Introduction to EN 1999-1-3

This document gives the basis for the design of aluminium alloy structures subject to fatigue in the ultimate limit state.

0.4 Verbal forms used in the Eurocodes

The verb “shall” expresses a requirement strictly to be followed and from which no deviation is permitted in order to comply with the Eurocodes.

The verb “should” expresses a highly recommended choice or course of action. Subject to national regulation and/or any relevant contractual provisions, alternative approaches could be used/adopted where technically justified.

The verb “may” expresses a course of action permissible within the limits of the Eurocodes.

The verb “can” expresses possibility and capability; it is used for statements of fact and clarification of concepts.

0.5 National annex for EN 1999-1-3

National choice is allowed in this document where explicitly stated within notes. National choice includes the selection of values for Nationally Determined Parameters (NDPs).

The national standard implementing EN 1999-1-3 can have a National Annex containing all national choices to be used for the design of buildings and civil engineering works to be constructed in the relevant country.

When no national choice is given, the default choice given in this document is to be used.

When no national choice is made and no default is given in this document, the choice can be specified by a relevant authority or, where not specified, agreed for a specific project by appropriate parties.

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

4.1(2)	4.3.1(2)	4.3.2(5)	4.4(1) – 2 choices
5(1)	6(2)	7.8.1(1)	7.8.2(1)
8.1.3(1) – 2 choices	8.2.1(2)	8.2.1(7)	8.2.1(10)
A.4.1(4)	A.4.1(5)	E.2(6)	E.2(8)
I.3.2(1)	I.3.3.2(1)	I.3.4(1)	L.4.2(5)
L.5(2)	L.6(3) – 2 choices	L.6(4)	L.6(5)
L.7.1(1)			

National choice is allowed in EN 1999-1-3 on the application of the following informative annexes:

Annex B	Annex C	Annex D	Annex E
Annex F	Annex G	Annex H	Annex I
Annex J	Annex K	Annex L	

The National Annex can contain, directly or by reference, non-contradictory complementary information for ease of implementation, provided it does not alter any provisions of the Eurocodes.

1 Scope

1.1 Scope of EN 1999-1-3

(1) EN 1999-1-1 gives the basis for the design of aluminium alloy structures subject to fatigue in the ultimate limit state.

(2) This document gives rules for:

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

(3) This document does not cover pressurized containment vessels or pipework.

1.2 Assumptions

(1) The general assumptions of EN 1990 apply.

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

(3) This document is intended to be used in conjunction with EN 1990, EN 1991 (all parts), relevant parts in EN 1992 to EN 1999, EN 1090-1 and EN 1090-3 for requirements for execution, and ENs, EADs and ETAs for construction products relevant to aluminium structures.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

NOTE See the Bibliography for a list of other documents cited that are not normative references, including those referenced as recommendations (i.e. through 'should' clauses) and permissions (i.e. through 'may' clauses).

EN 1090-3:2019, *Execution of steel structures and aluminium structures - Part 3: Technical requirements for aluminium structures*

EN 1990, *Eurocode - Basis of structural design*

EN 1999-1-1:2023, *Eurocode 9 — Design of aluminium structures — Part 1-1: General rules*

3 Terms, definitions and symbols

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in EN 1990, EN 1999-1-1:2023 and the following apply.

3.1.1

fatigue

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

3.1.2

fatigue loading

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

3.1.3

loading event

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

3.1.4

nominal stress

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

3.1.5

modified nominal stress

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

3.1.6

geometric stress

structural stress

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., and is in principle the same stress parameter as the modified nominal stress, but generally evaluated by a different method

3.1.7

geometric stress concentration factor

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

3.1.8

hot spot stress

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

3.1.9**stress history**

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

3.1.10**stress turning point**

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

3.1.11**stress peak**

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

3.1.12**stress valley**

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

3.1.13**constant amplitude**

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

3.1.14**variable amplitude**

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

3.1.15**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) and a specific part of a variable amplitude stress history as determined by a cycle counting method

3.1.16**cycle counting**

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

3.1.17**rainflow method**

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

3.1.18**reservoir method**

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

3.1.19**stress amplitude**

half the value of the stress range

3.1.20**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

3.1.21

stress intensity ratio

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

3.1.22

mean stress

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

3.1.23

stress range

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

3.1.24

stress intensity range

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

3.1.25

stress-range spectrum

stress spectrum

histogram of the frequency of occurrence for all stress ranges of different magnitudes recorded or calculated for a particular load event

3.1.26

design spectrum

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

3.1.27

detail category

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

3.1.28

endurance

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

3.1.29

fatigue strength curve

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

Note 1 to entry: The fatigue resistance curves are also known as $\log\Delta\sigma$ - $\log N$ curves, S-N curves, or Wöhler curves.

3.1.30

reference fatigue strength

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

3.1.31

constant amplitude fatigue limit

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

3.1.32**cut-off limit**

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

3.1.33**design service life**

assumed period for which a structure or part of it is to be used for its intended purpose with anticipated maintenance but without major repair being necessary

3.1.34**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 approach

3.1.35**damage tolerance**

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

3.1.36**fatigue damage**

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

3.1.37**Miner's summation**

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

3.1.38**equivalent fatigue loading**

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

3.1.39**equivalent stress range**

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

3.1.40**equivalent constant amplitude loading**

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

3.2 Symbols

Latin upper-case letters

A	constant in the crack growth relationship
D	fatigue damage value calculated for a given period of service
D_L	fatigue damage value calculated for the full design service life
$D_{L,d}$	design fatigue damage value calculated for the full design service life
D_{lim}	prescribed limit of the fatigue damage value
K	stress intensity factor
K_{gt}	geometric stress concentration factor
L_{adh}	effective length of adhesively bonded lap joints
N	number (or total number) of stress range cycles
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_i	predicted number of cycles to failure of a stress range $\Delta\sigma_i$
N_L	number of cycles (10^8) at which the cut-off limit is defined
P	probability
R	stress ratio
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_f	time for a crack to grow from a detectable size to a fracture critical size
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.
T_i	inspection interval
T_L	design service life
T_S	safe life

Latin lower-case letters

a	fillet weld throat
a_c	crack width on surface
da/dN	crack growth rate (m/cycle)
$f_{v,adh}$	characteristic shear strength of adhesive
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_d	minimum detectable length of crack

l_f	fracture critical length of crack
$\log$	logarithm to base 10
m	inverse slope constant of $\log\Delta\sigma$ - $\log N$ fatigue strength curve, or respectively crack growth rate exponent
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_i	number of cycles of stress range $\Delta\sigma_i$
t	thickness
y	crack geometry factor in crack growth relationship

Greek upper-case letters

ΔK	stress intensity range
$\Delta\tau$	effective shear stress range
$\Delta\sigma$	nominal stress range (normal stress), refers either to action effects or to fatigue strength depending on context
ΔT_G	recommended maximum time interval for general inspection
ΔT_F	recommended maximum time interval for fatigue inspection
$\Delta\sigma_C$	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
$\Delta\sigma_{E,2e}$	equivalent constant amplitude stress range related to 2×10^6 cycles
$\Delta\sigma_{E,Ne}$	equivalent constant amplitude stress range related to N_{max}
$\Delta\sigma_i$	constant stress range for the principal stresses in the construction detail for n_i cycles
$\Delta\sigma_L$	cut-off limit
$\Delta\sigma_R$	fatigue strength (normal stress)

Greek lower-case letters

γ_{FF}	partial factor for fatigue load intensity
λ_i	damage equivalent factor depending on the load situation and the structural characteristics, see 7.8.2
γ_{Mf}	partial factor for fatigue strength
σ_m	mean stress
$\sigma_{max},$ σ_{min}	maximum and minimum values of the fluctuating stresses in a stress cycle

4 Basis of design

4.1 Basic rules

(1) When designing a structure in the fatigue design situation, it shall be ensured, with an acceptable level of probability, that its performance is satisfactory during its entire design service life, i.e. the structure does not fail by fatigue nor is likely to require undue repair of damage caused by fatigue during the design service life.

(2) The design of aluminium structures in the fatigue design situation may be based on one of following methods:

- a) safe life design (SLD) (see 4.2.1);
- b) damage tolerant design (DTD) (see 4.2.2).

Either of methods a) and b) may be supplemented or replaced by design assisted by testing (see 4.3.3).

NOTE Conditions for the application of the above methods of design can be given by the National Annex.

(3) The method for design against fatigue should be selected taking the use of the structure into account, considering the consequence class of 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.

(4) Fatigue assessment of components and structures should be considered in cases where the loads are frequently changing, particularly if reversing.

NOTE 1 Common situations where this can occur are e.g.:

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

NOTE 2 The provisions for fatigue resistance given in this document apply generally to high cycle fatigue. For low cycle fatigue, guidelines are given in Annex F.

(5) The basis for calculation of fatigue resistance given in Annex A should be observed.

4.2 Methods of fatigue design

4.2.1 Safe life design (SLD)

(1) The safe life design approach should be used when no in-service inspection for fatigue damage is foreseen.

(2) When using the safe life design approach, the basis for calculation of fatigue resistance given in A.4 should be followed.

4.2.2 Damage tolerant design (DTD)

(1) The damage tolerant design approach should be used when a prescribed inspection and maintenance programme for detecting and correcting any fatigue damage is prepared and followed throughout the design service life of the structure. It should provide an acceptable reliability that a structure will perform satisfactorily for its design service life.

NOTE 1 Damage tolerant design can be suitable for applications 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 service life can 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 can be applied in two different types of approach, DTD-I and DTD-II, see Annex L.

(2) When using the damage tolerant design approach, the prerequisites for its use and the rules for the inspection strategy given in A.5 should be followed.

4.2.3 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 optimization of construction details. Test data should only be used in lieu of standard data if they are obtained and applied under controlled conditions.

NOTE Guidance for the verification of design by testing is given in Annex C.

4.3 Fatigue loading

4.3.1 Sources of fatigue loading

(1) All sources of fluctuating stress in the structure should be identified.

NOTE 1 Common fatigue loading situations are given in 4.1(4).

NOTE 2 For limitation of fatigue induced by repeated local buckling, see D.5.

(2) The fatigue loading should be obtained from EN 1991 (all parts) or other relevant European Standards. In addition to that, 4.3.2 should be considered.

NOTE Determination of the fatigue loads for cases not covered by a European Standard can be given by the National Annex.

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

4.3.2 Derivation of fatigue loading

(1) Loading for fatigue should 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 service life. If two or more independent live load events are likely to occur, the phasing between them should be specified.

(2) 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 subject to similar load effects should be used.

(3) 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.

(4) The design load spectrum should be selected as an upper bound estimate of the accumulated service conditions over the full design service 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.

(5) 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 The value of k_F is 2,0 and the value of k_N is 2,0 unless the National Annex gives different values. See also NOTE 2 under 4.4(1).

4.3.3 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 8.1, 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 can 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 Miner's 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.

4.4 Partial factors for fatigue loads

(1) Where the fatigue loads F_{Ek} have been derived in accordance with the requirements of 4.3.1(2) and 4.3.2 a partial factor for fatigue loads γ_{Ff} should be applied to the loads to obtain the design load F_{Ed} as given by Formula (4.1):

$$F_{Ed} = \gamma_{Ff} F_{Ek} \quad (4.1)$$

NOTE 1 The value of γ_{Ff} is 1,0 unless the National Annex gives a different value.

NOTE 2 Where fatigue loads have been based on confidence limits other than those in 4.3.2(6), the values for partial factors on loads are given in Table 4.1 (NDP) unless the National Annex gives different values.

Table 4.1 (NDP) — 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

4.5 Execution requirements

4.5.1 General

- (1) An execution specification shall be prepared (see 4.5.3).
- (2) An Operation manual should be prepared (see 4.5.4).
- (3) An Inspection and Maintenance manual should be prepared (see 4.5.5).

4.5.2 Execution classes

- (1) The relevant execution class should be selected in accordance with EN 1999-1-1:2023.

NOTE 1 EN 1090-3 requires execution classes to be selected. These can be related to service category.

NOTE 2 Guidance on utilization grade is given in L.7 for use when Annex J resistance data are adopted. Definition of Utilization grade is given in EN 1999-1-1:2023, Annex A.

4.5.3 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.
- (2) The execution specification shall specify that execution is to be carried out in accordance with EN 1090-3.

4.5.4 Operation manual

(1) The operation manual should include:

- details of the fatigue loading and the design service 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).

4.5.5 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.

5 Materials, constituent products and connecting devices

(1) The design rules of this document shall apply to constituent products in components and structures as listed in EN 1999-1-1:2023, 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. Fatigue data for such alloys and tempers, respectively, can be given by the National Annex.

NOTE 2 Guidance on how to obtain data from testing is given in Annex C.

NOTE 3 Guidance on castings is given in Annex I.

(2) This document covers components with open and hollow sections, including members built up from combinations of these products.

(3) This document covers components and structures with the following connecting devices:

- arc welding (metal inert gas and tungsten inert gas);
- Friction Stir Welding;
- steel bolts listed in EN 1999-1-1:2023, Table 5.9.

NOTE 1 Guidance on adhesive bonding is given in Annex E.

NOTE 2 For the fatigue design and verification of steel bolts in tension and shear, see EN 1993-1-9.

6 Durability

(1) Fatigue resistance data given in this document 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 this document do not apply, unless an efficient corrosion preventing coating is provided.

(2) Fatigue resistance data are not applicable under all conditions of aggressive exposure. The provisions in 8.2 and 8.4 on materials and exposure conditions should be followed.

NOTE Further information on durability, based on local exposure conditions, can be given by the National Annex.

(3) For adhesively bonded joints, special environmental conditions and effects should be considered.

NOTE For guidance, see Annex E.

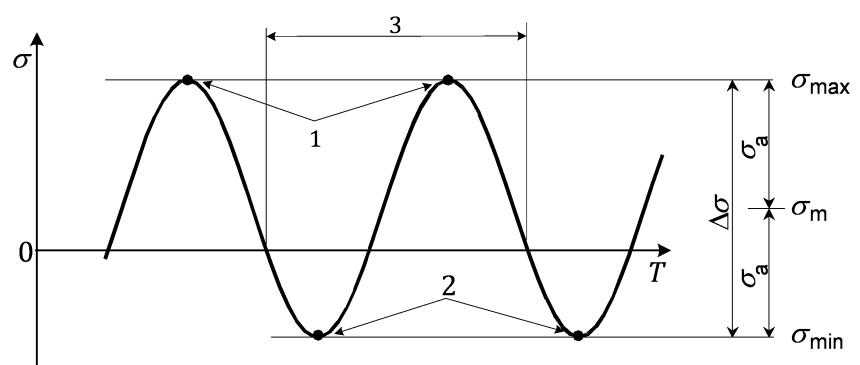
7 Structural analysis

7.1 Global analysis

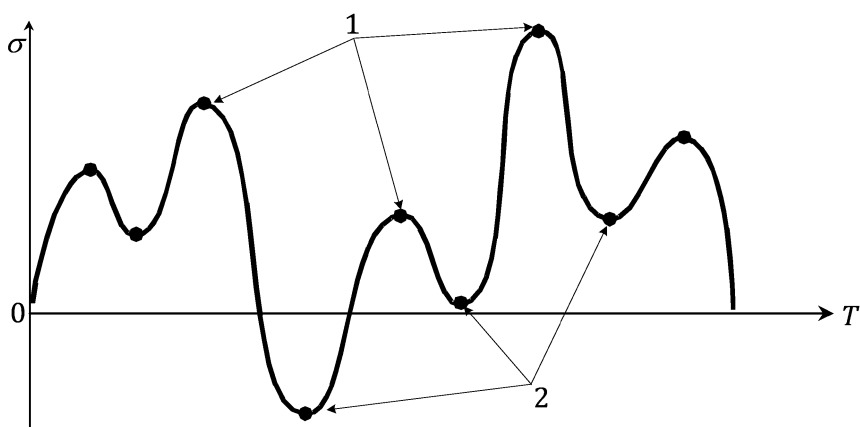
7.1.1 General

(1) The method of analysis should be selected 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 7.1.

NOTE An elastic model used for static assessment (for the ultimate or serviceability limit state) in accordance with EN 1999-1-1 is not necessarily adequate for fatigue assessment.



a) Constant amplitude



b) Variable amplitude

Key

1	stress peak
2	stress valley
3	stress cycle
0	stress turning point
$\sigma_{\max}$	maximum stress
$\sigma_{\min}$	minimum stress
σ_m	mean stress
$\Delta\sigma$	stress range
σ_a	stress amplitude

Figure 7.1 — 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, its value should be determined by test.

NOTE Guidance on testing is given in Annex C.

(4) Plastic redistribution of forces between members should not 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.

7.1.2 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).

(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 subject 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 static equilibrium. Similar springs as in (6) should be used if necessary.

7.1.3 Use of membrane, shell and solid elements

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

(2) Shell elements may be used for 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 7.2.3, the mesh size should be small enough in the part of the member containing the initiation site to assess the effect fully.

NOTE Guidance on stress analysis is given in Annex D.

7.2 Types of stresses

7.2.1 General

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

- a) nominal stresses, see 7.2.2 and 7.3.1;
- b) modified nominal stresses, see 7.2.3 and 7.3.2;
- c) hot spot stresses, see 7.2.4 and 7.3.3.

7.2.2 Nominal stresses

(1) Nominal stresses, see Figure 7.2, 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; and

NOTE For detail categories, see 8.1.

- b) the detail category has been established by tests where the results have been expressed in terms of the nominal stresses; and

NOTE Guidance on testing is given in Annex C.

- c) gross geometrical effects, such as those listed in 7.2.3, are not present in the vicinity of the initiation site.

7.2.3 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 7.2), provided that conditions 7.2.2(a) or (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 plates;

NOTE See EN 1999-1-1:2023, Annex J.

- e) distortion of hollow members;
- f) nonlinear out-of-plane bending 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 Guidance on stress analysis is given in Annex D.

(2) The above geometrical stress concentrating effects should be taken into account through the factor, K_{gt} , see Figure 7.2, 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.

7.2.4 Hot spot stresses

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

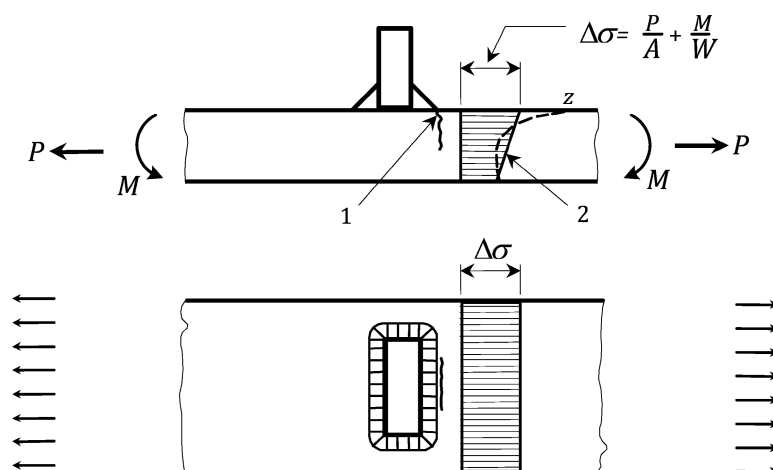
- a) the initiation site is a weld toe in a joint with complex geometry where the nominal stresses are not clearly defined;

NOTE 1 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 to aluminium.

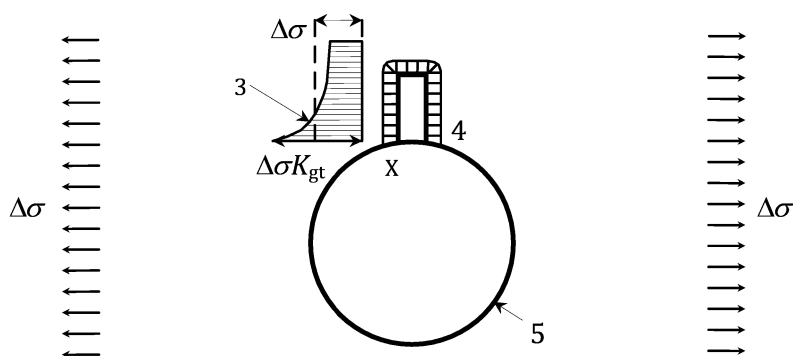
- b) a hot spot detail category has been established by tests and the results have been expressed in terms of the hot spot stress, for the appropriate action mode;
- c) shell bending stresses are generated in flexible joints and taken into account according to 7.1.2(6);

NOTE 2 For guidance, see Annexes C, D and K.

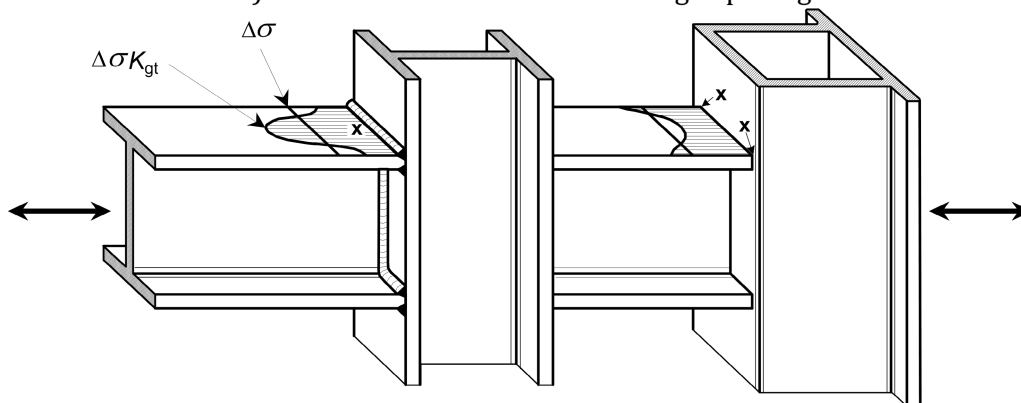
NOTE 3 For derivation of hot spot stresses, see 7.3.3 and 8.2.4.



a) Local stress concentration at weld toe



b) Gross stress concentration at large opening



c) Hard point in connection

Key

- 1 crack initiation site
- 2 linear stress distribution, weld toe stress factor at z not calculated
- 3 non-linear stress distribution
- 4 weld
- 5 large opening
- $\Delta\sigma$ nominal stress range
- $\Delta\sigma K_{gt}$ modified nominal stress range at initiation site x due to the opening
modified nominal stress range at initiation site x due to the geometrical stress concentration effects

Figure 7.2 — Examples of nominal and modified nominal stresses

7.3 Derivation of stresses

7.3.1 Derivation of nominal stresses

7.3.1.1 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.

7.3.1.2 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 nonlinear 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, along with the appropriate cross-sectional area and section moduli, to obtain the nominal stresses.

7.3.2 Derivation of modified nominal stresses

7.3.2.1 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) Elastic stress concentration factors K_{gt} should take into account all geometrical discontinuities, except for those already incorporated within the detail category.
- (3) Elastic stress concentration factors K_{gt} should be determined by one of the following approaches:
 - a) standard solutions for stress concentration factors;

NOTE Guidance on stress concentration factors is given in D.4.

- b) sub structuring 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)).

7.3.2.2 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 Guidance on the use of finite elements for fatigue analysis is given in D.3.

7.3.3 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 For guidance, see D.3.

(2) For simple cases, as the one shown in Figure 7.2 (c), the hot spot stress may be taken as the modified nominal stress and calculated according to 7.2.3.

(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.

7.3.4 Stress orientation

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

(2) If the direction of the principal tensile stress is less than 45° to the weld axis, a constructional detail should be assumed to be parallel to that axis.

7.4 Stress ranges for specific initiation sites

7.4.1 Parent material, welds, and mechanically fastened joints

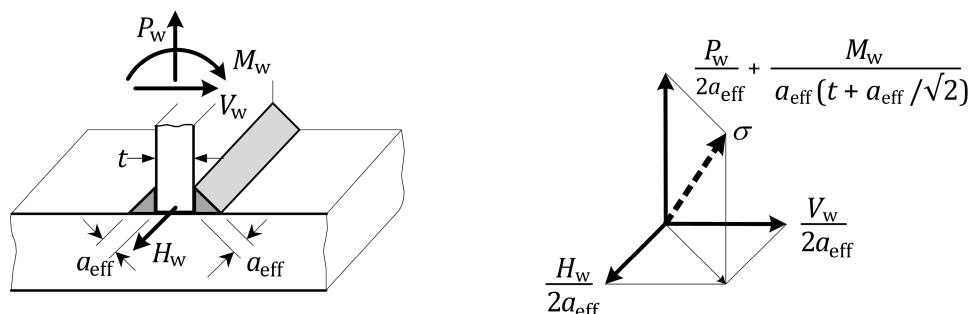
(1) Cracks initiating from weld toes, weld caps, fastener holes, fraying surfaces, etc. and propagating through parent material or weld metal, should be assessed using the nominal principal stress range in the member at that point.

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

7.4.2 Fillet and partial penetration butt welds

(1) Cracks initiating from weld roots and propagating through the weld throat should be assessed using stress range $\Delta\sigma$ where σ is the vector sum of the stresses in the weld metal based on the effective throat thickness, see Figure 7.3.

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



Key

P_w , H_w and M_w are forces (moment) per unit length

Figure 7.3 — Stresses in weld throats

(2) In lapped joints in a single plane, the stress per unit length of weld may be calculated on the basis of the average area for axial forces and of an elastic polar modulus of the weld group for in-plane moments (see Figure 7.4).

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

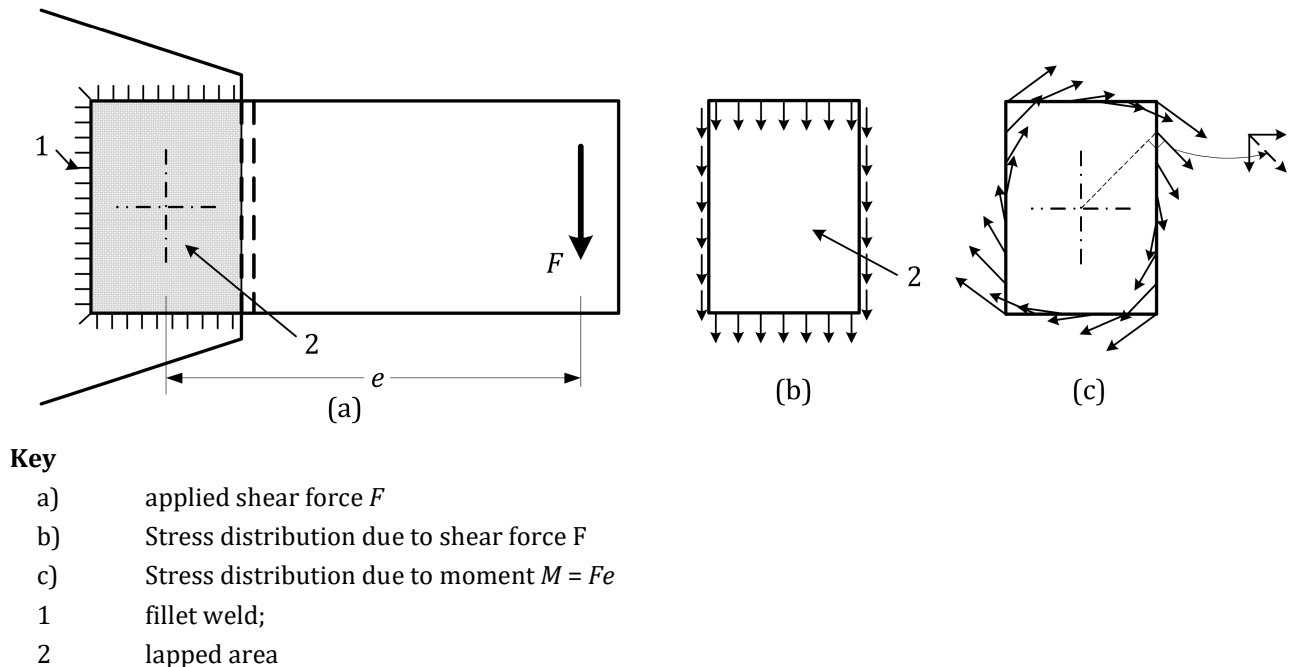


Figure 7.4 — Stresses in lapped joints

7.5 Adhesive bonds

(1) Fatigue assessment should be based on a failure surface through the bond plane.

NOTE Guidance is given in Annex E.

7.6 Castings

(1) The principal geometric stress should be used.

(2) Finite Element stress analysis or strain gauging in the case of complex shapes may be required, if standard calculations are not available.

7.7 Stress spectra

(1) The methods in Annex A for cycle counting of stress ranges should be used to derive stress spectra.

7.8 Calculation of equivalent stress range for standardized fatigue load models

7.8.1 General

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

- a) nominal stress ranges for constructional details shown in the detail category information;
- b) modified nominal stress ranges, where abrupt changes of section occur close to the initiation site which are not included in the constructional detail information;

c) geometric stress ranges where high stress gradients occur close to a weld toe.

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

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

7.8.2 Design value of stress range

(1) The design value of nominal stress ranges, $\gamma_{\text{Ff}}\Delta\sigma_{\text{E},2\text{e}}$, should be determined according to Formulae (7.1) and (7.2):

$$\gamma_{\text{Ff}}\Delta\sigma_{\text{E},2\text{e}} = \lambda_1 \times \lambda_2 \times \dots \lambda_i \times \dots \lambda_n \times \Delta\sigma(\gamma_{\text{Ff}}Q_k) \text{ for nominal stress} \quad (7.1)$$

$$\gamma_{\text{Ff}}\Delta\sigma_{\text{E},2\text{e}}^* = K_{\text{gt}} \gamma_{\text{Ff}}\Delta\sigma_{\text{E},2\text{e}} \text{ for modified nominal stress} \quad (7.2)$$

where

$\Delta\sigma(\gamma_{\text{Ff}}Q_k)$ is the stress range caused by the fatigue loads specified in EN 1991 (all parts);

λ_i are damage equivalent factors depending on the load situation, the structural characteristics and other relevant factors;

K_{gt} is the stress concentration factor to take account of the local stress magnification in relation to detail geometry not included in the reference fatigue strength curve, see 7.3.2.1.

NOTE 1 The values of λ_i can be given in the National Annex.

NOTE 2 λ_i -values for steel components might not be applicable to aluminium components.

8 Fatigue resistance and detail categories

8.1 Detail categories

8.1.1 General

(1) The verification of fatigue resistance should be based on the resistance values of a number of standardized detail categories.

(2) A detail category may comprise one or more frequently used and classified constructional details. The detail categories should be defined by their reference fatigue strength and the corresponding value for the inverse slope of the main part of the linearized $\Delta\sigma$ - N relationship, and should comply with the provisions in 8.2.

8.1.2 Factors affecting detail category

(1) The fatigue strength of a constructional detail should take into account the following factors:

- a) the direction of the fluctuating stress relative to the constructional detail;
- b) the location of the initiating crack in the constructional detail;
- c) the geometrical arrangement and relative proportion of the constructional detail.

NOTE The fatigue strength depends on the following:

- a) the product form;
- b) the material (unless welded);
- c) the method of execution;
- d) the quality level (in the case of welds and castings);
- e) the type of connection.

8.1.3 Constructional details

(1) Constructional details may be divided into the following three main groups:

- a) plain-members, welded members and bolted joints;
- b) adhesively bonded joints;
- c) castings.

NOTE 1 Guidelines for the detail categories and constructional details with $\Delta\sigma$ - N relationships for fatigue strength of group a) members subject to ambient temperatures and which do not require surface protection (see Table 8.2) are given in Annex J.

NOTE 2 The National Annex can specify a set of detail categories and constructional details together with a set of consistence criteria for such members, taking the provisions in 8.1.2 and 8.3 into account.

NOTE 3 In addition to the constructional details given in Annex J, other constructional details can be provided by the National Annex.

NOTE 4 For guidance on castings, see Annex I.

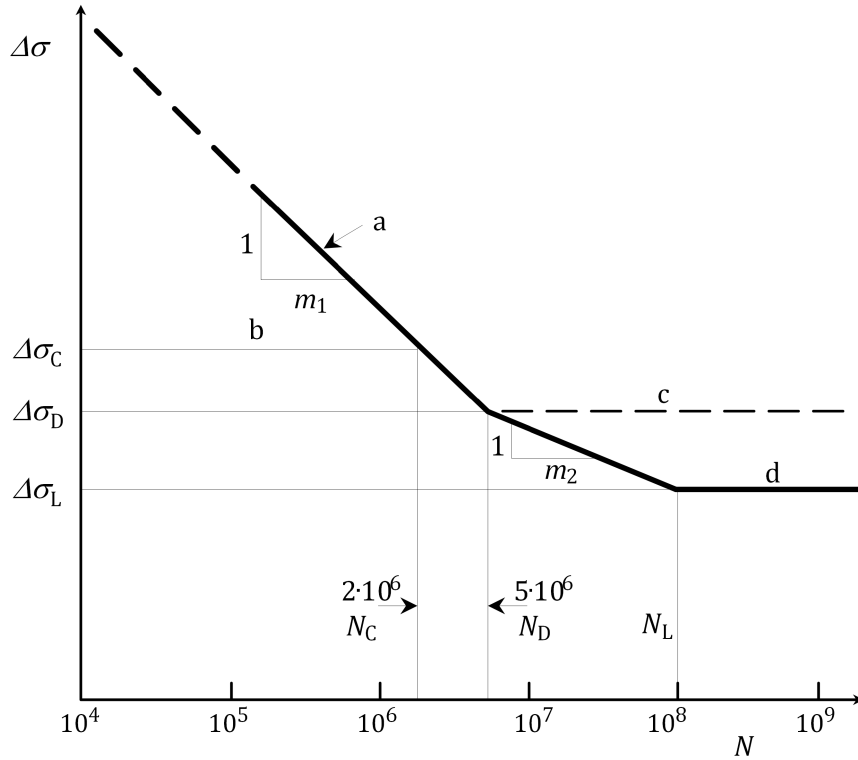
NOTE 5 For guidance on adhesively bonded joints, see Annex E.

8.2 Fatigue strength data

8.2.1 Classified constructional details

(1) The generalized form of the $\Delta\sigma$ - N relationship should be as defined in Figure 8.1.

NOTE Figure 8.1 is plotted on logarithmic scales with the fatigue strength curve as the mean line minus 2 standard deviations from the experimental data.



Key

- a fatigue strength curve
- b reference fatigue strength
- c constant amplitude fatigue limit
- d cut-off limit

Figure 8.1 — Fatigue strength curve $\log\Delta\sigma$ - $\log N$

(2) The fatigue design relationship for endurance in the range between 10^5 to 5×10^6 cycles should be defined by the Formula (8.1):

$$N_i = 2 \times 10^6 \left(\frac{\Delta\sigma_c}{\Delta\sigma_i} \frac{1}{\gamma_{Ff} \gamma_{Mf}} \right)^{m_1} \quad (8.1)$$

where

- N_i is the predicted number of cycles to failure of a stress range $\Delta\sigma_i$;
- $\Delta\sigma_c$ is the reference value of fatigue strength at 2×10^6 cycles, depending on the detail category, with standardized values given for information in Table 8.1;
- $\Delta\sigma_i$ is the constant stress range for the principal stresses in the construction detail for n_i cycles;
- m_1 is the inverse slope of the fatigue strength curve and depends on the construction detail category;
- γ_{Ff} is the partial factor for uncertainties in the loading spectrum and analysis of the response;
- γ_{Mf} is the partial factor for materials and execution.

NOTE 1 For values of γ_{Ff} , see 4.4.

NOTE 2 The values given in L.6 for specific structural details and in Annex E for adhesively bonded joints are appropriate to be taken as partial factors γ_{Mf} for the design, unless the National Annex gives different values.

Table 8.1 — Standardized $\Delta\sigma_c$ values (N/mm²)

140, 125, 112, 100, 90, 80, 71, 63, 56, 50, 45, 40, 36, 32, 28, 25, 23, 20, 18, 16, 14, 12
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(3) For N_D under certain exposure conditions, 8.4 should be followed.

(4) The fatigue design relationship for endurances in the range between 5×10^6 to 10^8 cycles should be defined by the Formula (8.2):

$$N_i = 5 \times 10^6 \left(\frac{\Delta\sigma_c}{\Delta\sigma_i} \frac{1}{\gamma_{Ff}\gamma_{Mf}} \right)^{m_2} \left(\frac{2}{5} \right)^{\frac{m_2}{m_1}} \quad (8.2)$$

(5) Constant amplitude stress cycles below the constant amplitude fatigue limit, $\Delta\sigma_D$, at 5×10^6 cycles (for parent material at 2×10^6 cycles), may be assumed to be non-damaging.

(6) In case of variable amplitude stress cycles, as occasional cycles above the constant amplitude fatigue limit can cause crack propagation resulting in lower amplitude cycles to become damaging, the inverse logarithmic slope of the basic fatigue strength curves between 5×10^6 and 10^8 cycles should be changed to m_2 for general spectrum action conditions, where $m_2 = m_1 + 2$.

NOTE The use of the inverse slope constant $m_2 = m_1 + 2$ can be conservative for some spectra.

(7) Any stress cycles below the cut-off limit $\Delta\sigma_L$, assumed at 10^8 cycles, may be assumed to be non-damaging.

NOTE For stress ranges applied less than 10^5 times the resistance values according to Figure 8.1 can be too conservative for certain constructional details. Fatigue design provisions for endurances below 10^5 cycles can be given by the National Annex. Guidance is given in Annex F.

(8) In the range between 10^3 and 10^5 stress cycles a check should be made that the design stress range does not result in a maximum tensile stress that exceeds other ultimate limit state design resistance values for the constructional detail, see EN 1999-1-1:2023.

(9) The detail categories apply to all values of mean stress, unless otherwise stated.

NOTE For guidance on enhanced fatigue strength values for compressive or low tensile stress values see Annex G.

(10) For flat members under bending stresses where $\Delta\sigma_1$ and $\Delta\sigma_2$ (see Figure 8.2) are of opposite sign, the respective fatigue stress value for certain detail types may be increased by one or two detail categories according to Table 8.1 for $t \leq 15\text{mm}$.

NOTE The detail type and the thickness range for which an increase in fatigue stress values can be permitted, as well as the number of categories, can be given in the National Annex.

(11) For the purpose of defining a finite range of detail categories and to enable a detail category to be increased or decreased by a constant geometric interval, a standard range of $\Delta\sigma_c$ values should be used as given in Table 8.1.

NOTE An increase (or decrease) of 1 detail category means selecting the next larger (or smaller) $\Delta\sigma_c$ value whilst leaving m_1 and m_2 unchanged. This does not apply to adhesively bonded joints.