The European Union

☞ EDICT OF GOVERNMENT ☜

In order to promote public education and public safety, equal justice for all, a better informed citizenry, the rule of law, world trade and world peace, this legal document is hereby made available on a noncommercial basis, as it is the right of all humans to know and speak the laws that govern them.

EN 1993-1-9 (2005) (English): Eurocode 3: Design of steel structures - Part 1-9: Fatigue [Authority: The European Union Per Regulation 305/2011, Directive 98/34/EC, Directive 2004/18/EC]

BLANK PAGE

EUROPEAN STANDARD

NORME EUROPÉENNE

EUROPÄISCHE NORM

EN 1993-1-9

May 2005

ICS 91.010.30

Supersedes ENV 1993-1-1:1992

Incorporating corrigenda December 2005 and April 2009

English version

Eurocode 3: Design of steel structures - Part 1-9: Fatigue

Eurocode 3: Calcul des structures en acier - Partie 1-9: Fatigue

Eurocode 3: Bemessung und Konstruktion von Stahlbauten - Teil 1-9: Ermüdung

This European Standard was approved by CEN on 23 April 2004.

CEN members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this European Standard the status of a national standard without any alteration. Up-to-date lists and bibliographical references concerning such national standards may be obtained on application to the Central Secretariat or to any CEN member.

This European Standard 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 Central Secretariat has the same status as the official versions.

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

EUROPEAN COMMITTEE FOR STANDARDIZATION
COMITÉ EUROPÉEN DE NORMALISATION
EUROPÄISCHES KOMITEE FÜR NORMUNG

Management Centre: rue de Stassart, 36 B-1050 Brussels

Contents

Foreword

This European Standard EN 1993, Eurocode 3: Design of steel structures, has been prepared by Technical Committee CEN/TC250 « Structural Eurocodes », the Secretariat of which is held by BSI. CEN/TC250 is responsible for all Structural Eurocodes.

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 2005, and conflicting National Standards shall be withdrawn at latest by March 2010.

This Eurocode supersedes ENV 1993-1-1.

According to the CEN-CENELEC Internal Regulations, the National Standard Organizations of the following countries are bound to implement these European Standard: Austria, Belgium, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Slovakia, Slovenia, Spain, Sweden, Switzerland and 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 harmonization of technical specifications.

Within this action programme, the Commission took the initiative to establish a set of harmonized 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 agreement[1] between the Commission and CEN, to transfer the preparation and the publication of the Eurocodes to 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
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

[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).

Eurocode standards recognize 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 recognize 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 harmonized 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 Documents[2] referred to in Article 12 of the CPD, although they are of a different nature from harmonized product standards[3]. 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 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.

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.

The National annex 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 and/or classes where alternatives are given in the Eurocode,
- values to be used where a symbol only is given in the Eurocode,
- country specific data (geographical, climatic, etc.), *e.g.* snow map,
- the procedure to be used where alternative procedures are given in the Eurocode.

It may contain
- decisions on the application of informative annexes,
- references to non-contradictory complementary information to assist the user to apply the Eurocode.

---

[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 harmonized ENs and ETAGs/ETAs.

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

a) give concrete form to the essential requirements by harmonizing 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 harmonized 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.

Links between Eurocodes and harmonized technical specifications (ENs and ETAs) for products

There is a need for consistency between the harmonized technical specifications for construction products and the technical rules for works[4]. 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.

National annex for EN 1993-1-9

This standard gives alternative procedures, values and recommendations with notes indicating where national choices may have to be made. The National Standard implementing EN 1993-1-9 should have a National Annex containing all Nationally Determined Parameters for the design of steel structures to be constructed in the relevant country.

National choice is allowed in EN 1993-1-9 through:

- 1.1(2)
- 2(2)
- 2(4)
- 3(2)
- 3(7)
- 5(2)
- 6.1(1)
- 6.2(2)
- 7.1(3)
- 7.1(5)
- 8(4)

[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.

1 General

1.1 Scope

(1) EN 1993-1-9 gives methods for the assessment of fatigue resistance of members, connections and joints subjected to fatigue loading.

(2) These methods are derived from fatigue tests with large scale specimens, that include effects of geometrical and structural imperfections from material production and execution (e.g. the effects of tolerances and residual stresses from welding).

NOTE 1 For tolerances see EN 1090. The choice of the execution standard may be given in the National Annex, until such time as EN 1090 is published.

NOTE 2 The National Annex may give supplementary information on inspection requirements during fabrication.

(3) The rules are applicable to structures where execution conforms with EN 1090.

NOTE Where appropriate, supplementary requirements are indicated in the detail category tables.

(4) The assessment methods given in this part are applicable to all grades of structural steels, stainless steels and unprotected weathering steels except where noted otherwise in the detail category tables. This part only applies to materials which conform to the toughness requirements of EN 1993-1-10.

(5) Fatigue assessment methods other than the $\Delta\sigma_R$-N methods as the notch strain method or fracture mechanics methods are not covered by this part.

(6) Post fabrication treatments to improve the fatigue strength other than stress relief are not covered in this part.

(7) The fatigue strengths given in this part apply to structures operating under normal atmospheric conditions and with sufficient corrosion protection and regular maintenance. The effect of seawater corrosion is not covered. Microstructural damage from high temperature (> 150 °C) is not covered.

1.2 Normative references

This European Standard incorporates by dated or undated reference, provisions from other publications. These normative references are cited at the appropriate places in the text and the publications are listed hereafter. For dated references, subsequent amendments to or revisions of any of these publications apply to this European Standard only when incorporated in it by amendment or revision. For undated references the latest edition of the publication referred to applies (including amendments).

The following general standards are referred to in this standard.

EN 1090 Execution of steel structures – Technical requirements

EN 1990 Basis of structural design

EN 1991 Actions on structures

EN 1993 Design of Steel Structures

EN 1994-2 Design of Composite Steel and Concrete Structures: Part 2: Bridges

1.3 Terms and definitions

(1) For the purpose of this European Standard the following terms and definitions apply.

1.3.1 General

1.3.1.1
fatigue
The process of initiation and propagation of cracks through a structural part due to action of fluctuating stress.

1.3.1.2
nominal stress
A stress in the parent material or in a weld adjacent to a potential crack location calculated in accordance with elastic theory excluding all stress concentration effects.

> **NOTE** The nominal stress as specified in this part can be a direct stress, a shear stress, a principal stress or an equivalent stress.

1.3.1.3
modified nominal stress
A nominal stress multiplied by an appropriate stress concentration factor k_f, to allow for a geometric discontinuity that has not been taken into account in the classification of a particular constructional detail.

1.3.1.4
geometric stress
hot spot stress
The maximum principal stress in the parent material adjacent to the weld toe, taking into account stress concentration effects due to the overall geometry of a particular constructional detail.

> **NOTE** Local stress concentration effects e.g. from the weld profile shape (which is already included in the detail categories in Annex B) need not be considered.

1.3.1.5
residual stress
Residual stress is a permanent state of stress in a structure that is in static equilibrium and is independent of any applied action. Residual stresses can arise from rolling stresses, cutting processes, welding shrinkage or lack of fit between members or from any loading event that causes yielding of part of the structure.

1.3.2 Fatigue loading parameters

1.3.2.1
loading event
A defined loading sequence applied to the structure and giving rise to a stress history, which is normally repeated a defined number of times in the life of the structure.

1.3.2.2
stress history
A record or a calculation of the stress variation at a particular point in a structure during a loading event.

1.3.2.3
rainflow method
Particular cycle counting method of producing a stress-range spectrum from a given stress history.

1.3.2.4
reservoir method
Particular cycle counting method of producing a stress-range spectrum from a given stress history.

> **NOTE** For the mathematical determination see annex A.

1.3.2.5
stress range
The algebraic difference between the two extremes of a particular stress cycle derived from a stress history.

1.3.2.6
stress-range spectrum
Histogram of the number of occurrences for all stress ranges of different magnitudes recorded or calculated for a particular loading event.

1.3.2.7
design spectrum
The total of all stress-range spectra in the design life of a structure relevant to the fatigue assessment.

1.3.2.8
design life
The reference period of time for which a structure is required to perform safely with an acceptable probability that failure by fatigue cracking will not occur.

1.3.2.9
fatigue life
The predicted period of time to cause fatigue failure under the application of the design spectrum.

1.3.2.10
Miner's summation
A linear cumulative damage calculation based on the Palmgren-Miner rule.

1.3.2.11
equivalent constant amplitude stress range
The constant-amplitude stress range that would result in the same fatigue life as for the design spectrum, when the comparison is based on a Miner's summation.

> **NOTE** For the mathematical determination see Annex A.

1.3.2.12
fatigue loading
A set of action parameters based on typical loading events described by the positions of loads, their magnitudes, frequencies of occurrence, sequence and relative phasing.

> **NOTE 1** The fatigue actions in EN 1991 are upper bound values based on evaluations of measurements of loading effects according to Annex A.
>
> **NOTE 2** The action parameters as given in EN 1991 are either
>
> - Q_{max}, n_{max}, standardized spectrum or
> - $Q_{E,n_{max}}$ related to n_{max} or
> - $Q_{E,2}$ corresponding to $n = 2\times10^6$ cycles.
>
> Dynamic effects are included in these parameters unless otherwise stated.

1.3.2.13
equivalent constant amplitude fatigue loading
Simplified constant amplitude loading causing the same fatigue damage effects as a series of actual variable amplitude loading events

1.3.3 Fatigue strength

1.3.3.1
fatigue strength curve
The quantitative relationship between the stress range and number of stress cycles to fatigue failure, used for the fatigue assessment of a particular category of structural detail.

> **NOTE** The fatigue strengths given in this part are lower bound values based on the evaluation of fatigue tests with large scale test specimens in accordance with EN 1990 – Annex D.

1.3.3.2
detail category
The numerical designation given to a particular detail for a given direction of stress fluctuation, in order to indicate which fatigue strength curve is applicable for the fatigue assessment (The detail category number indicates the reference fatigue strength $\Delta\sigma_C$ in N/mm²).

1.3.3.3
constant amplitude fatigue limit
The limiting direct or shear stress range value below which no fatigue damage will occur in tests under constant amplitude stress conditions. Under variable amplitude conditions all stress ranges have to be below this limit for no fatigue damage to occur.

1.3.3.4
cut-off limit
Limit below which stress ranges of the design spectrum do not contribute to the calculated cumulative damage.

1.3.3.5
endurance
The life to failure expressed in cycles, under the action of a constant amplitude stress history.

1.3.3.6
reference fatigue strength
The constant amplitude stress range $\Delta\sigma_C$, for a particular detail category for an endurance $N = 2\times10^6$ cycles

1.4 Symbols

$\Delta\sigma$	stress range (direct stress)
$\Delta\tau$	stress range (shear stress)
$\Delta\sigma_E$, $\Delta\tau_E$	equivalent constant amplitude stress range related to n_{max}
$\Delta\sigma_{E,2}$, $\Delta\tau_{E,2}$	equivalent constant amplitude stress range related to 2 million cycles
$\Delta\sigma_C$, $\Delta\tau_C$	reference value of the fatigue strength at N_C = 2 million cycles
$\Delta\sigma_D$, $\Delta\tau_D$	fatigue limit for constant amplitude stress ranges at the number of cycles N_D
$\Delta\sigma_L$, $\Delta\tau_L$	cut-off limit for stress ranges at the number of cycle N_L
$\Delta\sigma_{eq}$	equivalent stress range for connections in webs of orthotropic decks
$\Delta\sigma_{C,red}$	reduced reference value of the fatigue strength
γ_{Ff}	partial factor for equivalent constant amplitude stress ranges $\Delta\sigma_E$, $\Delta\tau_E$
γ_{Mf}	partial factor for fatigue strength $\Delta\sigma_C$, $\Delta\tau_C$
m	slope of fatigue strength curve
λ_i	damage equivalent factors
ψ_1	factor for frequent value of a variable action
Q_k	characteristic value of a single variable action
k_s	reduction factor for fatigue stress to account for size effects
k_1	magnification factor for nominal stress ranges to account for secondary bending moments in trusses
k_f	stress concentration factor
N_R	design life time expressed as number of cycles related to a constant stress range

2 Basic requirements and methods

AC1 (1)P Structural members shall be designed for fatigue such that there is an acceptable level of probability that their performance will be satisfactory throughout their design life. AC1

NOTE Structures designed using fatigue actions from EN 1991 and fatigue resistance according to this part are deemed to satisfy this requirement.

(2) Annex A may be used to determine a specific loading model, if

- no fatigue load model is available in EN 1991,
- a more realistic fatigue load model is required.

NOTE Requirements for determining specific fatigue loading models may be specified in the National Annex.

(3) Fatigue tests may be carried out

- to determine the fatigue strength for details not included in this part,
- to determine the fatigue life of prototypes, for actual or for damage equivalent fatigue loads.

(4) In performing and evaluating fatigue tests EN 1990 should be taken into account (see also 7.1).

NOTE Requirements for determining fatigue strength from tests may be specified in the National Annex.

(5) The methods for the fatigue assessment given in this part follows the principle of design verification by comparing action effects and fatigue strengths; such a comparison is only possible when fatigue actions are determined with parameters of fatigue strengths contained in this standard.

(6) Fatigue actions are determined according to the requirements of the fatigue assessment. They are different from actions for ultimate limit state and serviceability limit state verifications.

NOTE Any fatigue cracks that develop during service life do not necessarily mean the end of the service life. Cracks should be repaired with particular care for execution to avoid introducing more severe notch conditions.

3 Assessment methods

(1) Fatigue assessment should be undertaken using either:

- damage tolerant method or
- safe life method.

(2) The damage tolerant method should provide an acceptable reliability that a structure will perform satisfactorily for its design life, provided that a prescribed inspection and maintenance regime for detecting and correcting fatigue damage is implemented throughout the design life of the structure.

NOTE 1 The damage tolerant method may be applied when in the event of fatigue damage occurring a load redistribution between components of structural elements can occur.

NOTE 2 The National Annex may give provisions for inspection programmes.

NOTE 3 Structures that are assessed to this part, the material of which is chosen according to EN 1993-1-10 and which are subjected to regular maintenance are deemed to be damage tolerant.

(3) The safe life method should provide an acceptable level of reliability that a structure will perform satisfactorily for its design life without the need for regular in-service inspection for fatigue damage. The safe life method should be applied in cases where local formation of cracks in one component could rapidly lead to failure of the structural element or structure.

(4) For the purpose of fatigue assessment using this part, an acceptable reliability level may be achieved by adjustment of the partial factor for fatigue strength γ_{Mf} taking into account the consequences of failure and the design assessment used.

(5) Fatigue strengths are determined by considering the structural detail together with its metallurgical and geometric notch effects. In the fatigue details presented in this part the probable site of crack initiation is also indicated.

(6) The assessment methods presented in this code use fatigue resistance in terms of fatigue strength curves for

- standard details applicable to nominal stresses
- reference weld configurations applicable to geometric stresses.

(7) The required reliability can be achieved as follows:

a) damage tolerant method

- selecting details, materials 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,
- provision of multiple load path
- provision of crack-arresting details,
- provision of readily inspectable details during regular inspections.

b) safe-life method

AC2) – selecting details and stress levels resulting in a fatigue life sufficient to achieve the β-values to be at least equal to those required for ultimate limit state verifications at the end of the design service life. (AC2

NOTE The National Annex may give the choice of the assessment method, definitions of classes of consequences and numerical values for γ_{Mf}. Recommended values for γ_{Mf} are given in Table 3.1.

Table 3.1: Recommended values for partial factors for fatigue strength

Assessment method	Consequence of failure	
	Low consequence	High consequence
Damage tolerant	1,00	1,15
Safe life	1,15	1,35

4 Stresses from fatigue actions

(1) Modelling for nominal stresses should take into account all action effects including distortional effects and should be based on a linear elastic analysis for members and connections

(2) For latticed girders made of hollow sections the modelling may be based on a simplified truss model with pinned connections. Provided that the stresses due to external loading applied to members between joints are taken into account the effects from secondary moments due to the stiffness of the connection can be allowed for by the use of k_1-factors AC2) (see Table 4.1 for circular hollow sections, Table 4.2 for rectangular hollow sections; these sections are subject to the geometrical restrictions according to Table 8.7).(AC2

Table 4.1: k_1-factors for circular hollow sections under in-plane loading

Type of joint		Chords	Verticals	Diagonals
Gap joints	K type	1,5	AC2) -	1,3
	N type / KT type	1,5	1,8	1,4
Overlap joints	K type	1,5	- (AC2	1,2
	N type / KT type	1,5	1,65	1,25

Table 4.2: k_1-factors for rectangular hollow sections under in-plane loading

Type of joint		Chords	Verticals	Diagonals
Gap joints	K type	1,5	AC1 - AC1	1,5
	N type / KT type	1,5	2,2	1,6
Overlap joints	K type	1,5	AC1 - AC1	1,3
	N type / KT type	1,5	2,0	1,4

AC2 **NOTE 1** For the definition of joint types see EN 1993-1-8.

NOTE 2 Ranges of geometric validity:

For CHS planar joints (K-, N-, KT-joints):

$$0,30 \leq \beta \leq 0,60$$
$$12,0 \leq \gamma \leq 30,0$$
$$0,25 \leq \tau \leq 1,00$$
$$30° \leq \theta \leq 60°$$

For SHS joints (K-, N-, KT-joints):

$$0,40 \leq \beta \leq 0,60$$
$$6,25 \leq \gamma \leq 12,5$$
$$0,25 \leq \tau \leq 1,00$$
$$30° \leq \theta \leq 60°$$ AC2

5 Calculation of stresses

(1) Stresses should be calculated at the serviceability limit state.

(2) Class 4 cross sections are assessed for fatigue loads according to EN 1993-1-5.

NOTE 1 For guidance see EN 1993-2 to EN 1993-6.

NOTE 2 The National Annex may give limitations for class 4 sections.

(3) Nominal stresses should be calculated at the site of potential fatigue initiation. Effects producing stress concentrations at details other than those included in Table 8.1 to Table 8.10 should be accounted for by using a stress concentration factor (SCF) according to 6.3 to give a modified nominal stress.

(4) When using geometrical (hot spot) stress methods for details covered by Table B.1, the stresses should be calculated as shown in 6.5.

(5) The relevant stresses for details in the parent material are:

- nominal direct stresses σ
- nominal shear stresses τ

AC2 **NOTE** For effects of combined nominal stresses see 8(3). AC2

(6) The relevant stresses in the welds are (see Figure 5.1)

- normal stresses σ_{wf} transverse to the axis of the weld: $\sigma_{wf} = \sqrt{\sigma_{\perp f}^2 + \tau_{\perp f}^2}$
- shear stresses τ_{wf} longitudinal to the axis of the weld: $\tau_{wf} = \tau_{\| f}$

for which two separate checks should be performed.

NOTE The above procedure differs from the procedure given for the verification of fillet welds for the ultimate limit state, given in EN 1993-1-8.

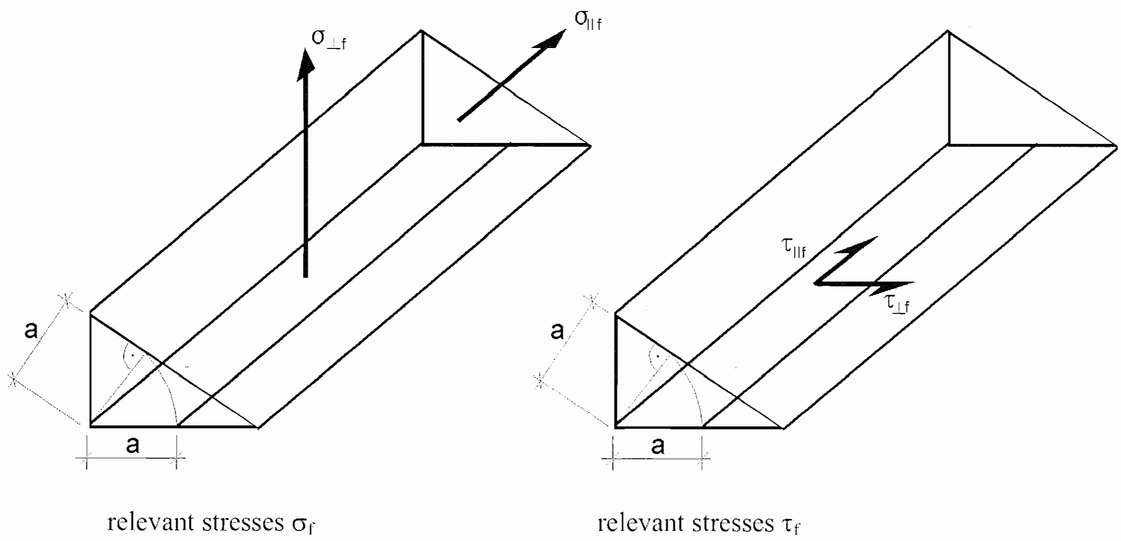


Figure 5.1: Relevant stresses in the fillet welds

6 Calculation of stress ranges

6.1 General

(1) The fatigue assessment should be carried out using

- nominal stress ranges for details shown in Table 8.1 to Table 8.10,
- modified nominal stress ranges where, e.g. abrupt changes of section occur close to the initiation site which are not included in Table 8.1 to Table 8.10 or
- geometric stress ranges where high stress gradients occur close to a weld toe in joints covered by Table B.1

NOTE The National Annex may give information on the use of the nominal stress ranges, modified nominal stress ranges or the geometric stress ranges. For detail categories for geometric stress ranges see Annex B.

(2) The design value of stress range to be used for the fatigue assessment should be the stress ranges $\gamma_{Ff}\,\Delta\sigma_{E,2}$ corresponding to $N_C = 2\times10^6$ cycles.

6.2 Design value of nominal stress range

(1) The design value of nominal stress ranges $\gamma_{Ff}\,\Delta\sigma_{E,2}$ and $\gamma_{Ff}\,\Delta\tau_{E,2}$ should be determined as follows:

$$\gamma_{Ff}\,\Delta\sigma_{E,2} = \lambda_1 \times \lambda_2 \times \lambda_i \times \ldots \times \lambda_n \times \Delta\sigma(\gamma_{Ff}\,Q_k)$$

$$\gamma_{Ff}\,\Delta\tau_{E,2} = \lambda_1 \times \lambda_2 \times \lambda_i \times \ldots \times \lambda_n \times \Delta\tau(\gamma_{Ff}\,Q_k) \tag{6.1}$$

where $\Delta\sigma(\gamma_{Ff}\,Q_k)$, $\Delta\tau(\gamma_{Ff}\,Q_k)$ is the stress range caused by the fatigue loads specified in EN 1991

λ_i are damage equivalent factors depending on the spectra as specified in the relevant parts of EN 1993.

(2) Where no appropriate data for λ_i are available the design value of nominal stress range may be determined using the principles in Annex A.

NOTE The National Annex may give informations supplementing Annex A.

6.3 Design value of modified nominal stress range

(1) The design value of modified nominal stress ranges $\gamma_{Ff}\,\Delta\sigma_{E,2}$ and $\gamma_{Ff}\,\Delta\tau_{E,2}$ should be determined as follows:

$$\gamma_{Ff}\,\Delta\sigma_{E,2} = k_f \times \lambda_1 \times \lambda_2 \times \lambda_i \times \ldots \times \lambda_n \times \Delta\sigma(\gamma_{Ff}\,Q_k)$$
$$\gamma_{Ff}\,\Delta\tau_{E,2} = k_f \times \lambda_1 \times \lambda_2 \times \lambda_i \times \ldots \times \lambda_n \times \Delta\tau(\gamma_{Ff}\,Q_k) \qquad (6.2)$$

where k_f is the stress concentration factor to take account of the local stress magnification in relation to detail geometry not included in the reference $\Delta\sigma_R$-N-curve

NOTE k_f-values may be taken from handbooks or from appropriate finite element calculations.

6.4 Design value of stress range for welded joints of hollow sections

(1) Unless more accurate calculations are carried out the design value of modified nominal stress range $\gamma_{Ff}\Delta\sigma_{E,2}$ should be determined as follows using the simplified model in 4(2):

$$\gamma_{Ff}\,\Delta\sigma_{E,2} = k_1\left(\gamma_{Ff}\,\Delta\sigma^*_{E,2}\right) \qquad (6.3)$$

where $\gamma_{Ff}\,\Delta\sigma^*_{E,2}$ is the design value of stress range calculated with a simplified truss model with pinned joints

k_1 is the magnification factor according to Table 4.1 and Table 4.2.

6.5 Design value of stress range for geometrical (hot spot) stress

(1) The design value of geometrical (hot spot) stress range $\gamma_{Ff}\,\Delta\sigma_{E,2}$ should be determined as follows:

$$\gamma_{Ff}\,\Delta\sigma_{E,2} = k_f\left(\gamma_{Ff}\,\Delta\sigma^*_{E,2}\right) \qquad (6.4)$$

where k_f is the stress concentration factor

7 Fatigue strength

7.1 General

(1) The fatigue strength for nominal stress ranges is represented by a series of (log $\Delta\sigma_R$) – (log N) curves and (log $\Delta\tau_R$) – (log N) curves (S-N-curves), which correspond to typical detail categories. Each detail category is designated by a number which represents, in N/mm^2, the reference value $\Delta\sigma_C$ and $\Delta\tau_C$ for the fatigue strength at 2 million cycles.

AC2 (2) For constant amplitude nominal stress ranges the fatigue strength can be obtained as follows: AC2

$\Delta\sigma_R^m\,N_R = \Delta\sigma_C^m\,2\times10^6$ with $m = 3$ for $N \le 5\times10^6$, **see**

Figure 7.1

$\Delta\tau_R^m\,N_R = \Delta\tau_C^m\,2\times10^6$ with $m = 5$ for $N \le 10^8$, see Figure 7.2

$\Delta\sigma_D = \left(\frac{2}{5}\right)^{1/3}\Delta\sigma_C = 0{,}737\Delta\sigma_C$ **is the constant amplitude fatigue limit, see**

Figure 7.1, and

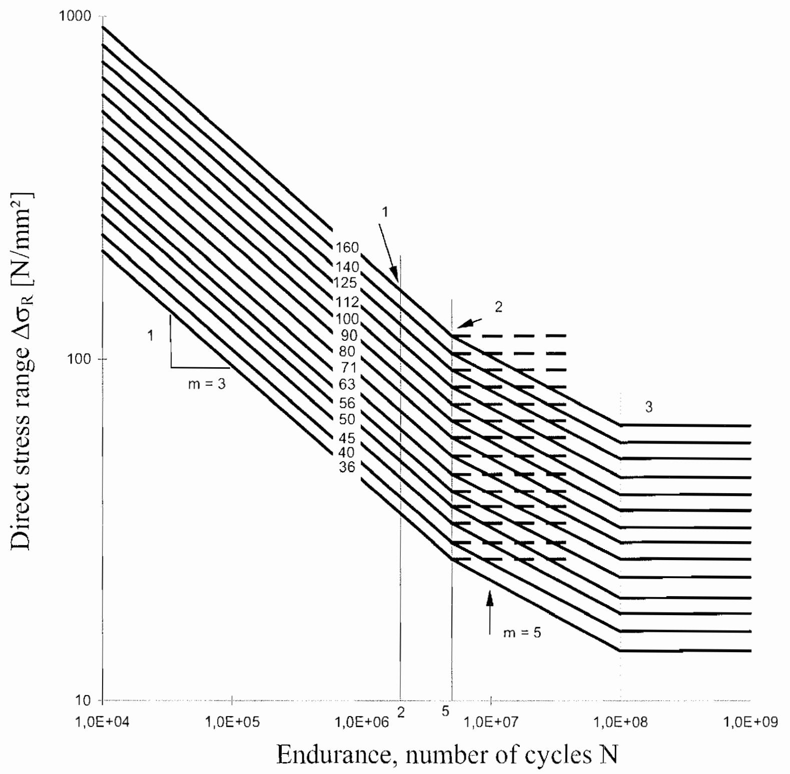
$$\Delta\tau_L = \left(\frac{2}{100}\right)^{1/5} \Delta\tau_C = 0{,}457\Delta\tau_C \quad \text{is the cut off limit, see Figure 7.2.}$$

(3) For nominal stress spectra with stress ranges above and below the constant amplitude fatigue limit $\Delta\sigma_D$ the fatigue strength should be based on the extended fatigue strength curves as follows:

$$\Delta\sigma_R^m\, N_R = \Delta\sigma_C^m\, 2\times10^6 \quad \text{with } m = 3 \text{ for } N \leq 5\times10^6$$
$$\Delta\sigma_R^m\, N_R = \Delta\sigma_D^m\, 5\times10^6 \quad \text{with } m = 5 \text{ for } 5\times10^6 \leq N \leq 10^8$$

$$\Delta\sigma_L = \left(\frac{5}{100}\right)^{1/5} \Delta\sigma_D = 0{,}549\Delta\sigma_D$$ **is the cut off limit, see**

Figure 7.1.



1 Detail category $\Delta\sigma_C$

2 Constant amplitude fatigue limit $\Delta\sigma_D$

3 Cut-off limit $\Delta\sigma_L$

Figure 7.1: Fatigue strength curves for direct stress ranges

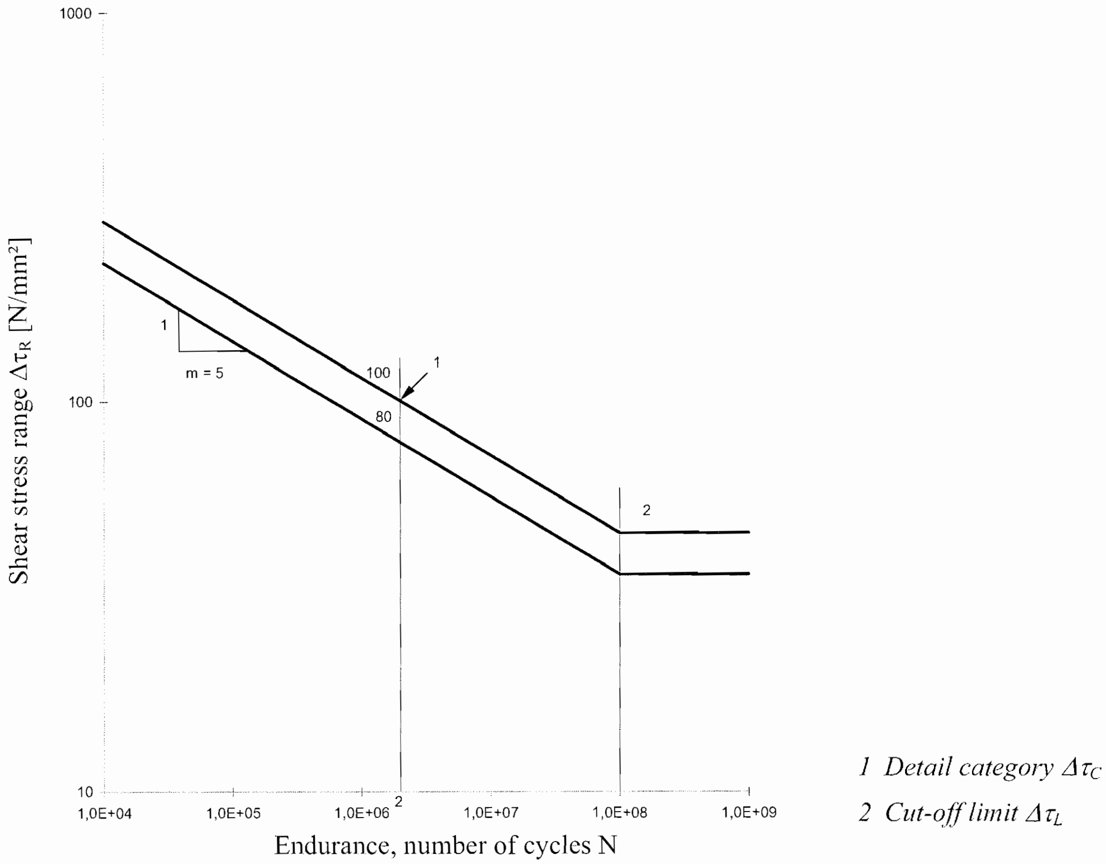


Figure 7.2: Fatigue strength curves for shear stress ranges

NOTE 1 When test data were used to determine the appropriate detail category for a particular constructional detail, the value of the stress range $\Delta\sigma_C$ corresponding to a value of N_C = 2 million cycles were calculated for a 75% confidence level of 95% probability of survival for log N, taking into account the standard deviation and the sample size and residual stress effects. The number of data points (not lower than 10) was considered in the statistical analysis, see annex D of EN 1990.

NOTE 2 The National Annex may permit the verification of a fatigue strength category for a particular application provided that it is evaluated in accordance with NOTE 1.

NOTE 3 **Test data for some details do not exactly fit the fatigue strength curves in**

Figure 7.1. In order to ensure that non conservative conditions are avoided, such details, marked with an asterisk, are located one detail category lower than their fatigue strength at 2×10^6 cycles would require. An alternative assessment may increase the classification of such details by one detail category provided that the constant amplitude fatigue limit $\Delta\sigma_D$ is defined as the fatigue strength at 10^7 cycles for m=3 (see Figure 7.3).

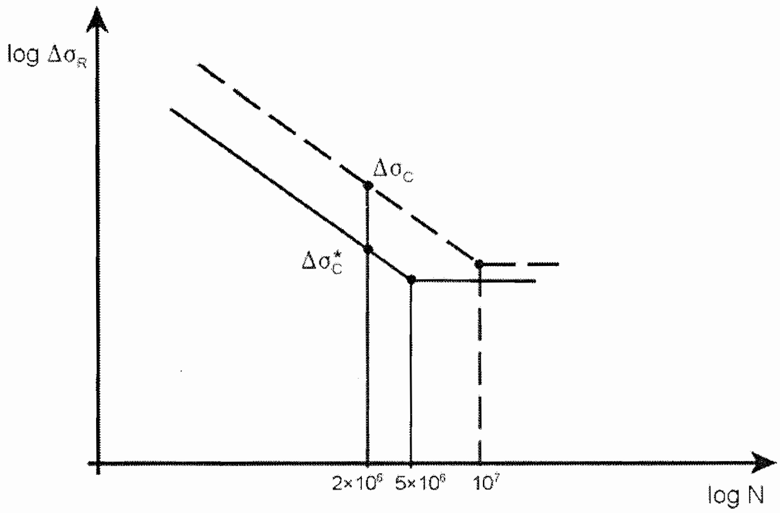


Figure 7.3: Alternative strength $\Delta\sigma_C$ for details classified as $\Delta\sigma_C^*$

(4) Detail categories $\Delta\sigma_C$ and $\Delta\tau_C$ for nominal stresses are given in

Table 8.1 for plain members and mechanically fastened joints

Table 8.2 for welded built-up sections

Table 8.3 for transverse butt welds

Table 8.4 for weld attachments and stiffeners

Table 8.5 for load carrying welded joints

Table 8.6 for hollow sections

Table 8.7 for lattice girder node joints

Table 8.8 for orthotropic decks – closed stringers

Table 8.9 for orthotropic decks – open stringers

Table 8.10 for top flange to web junctions of runway beams

(5) The fatigue strength categories $\Delta\sigma_C$ for geometric stress ranges are given in Annex B.

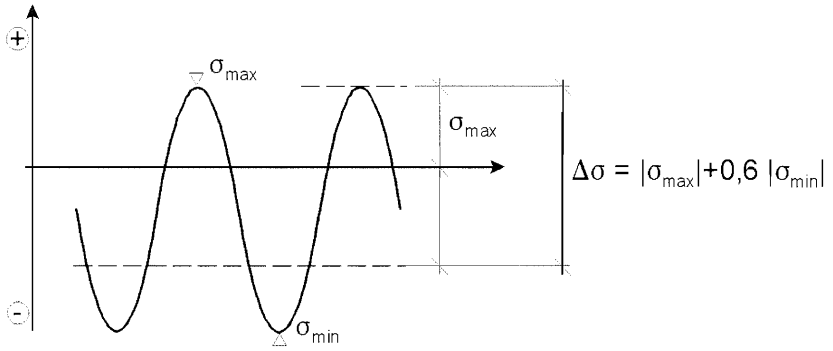
NOTE The National Annex may give fatigue strength categories $\Delta\sigma_C$ and $\Delta\tau_C$ for details not covered by Table 8.1 to Table 8.10 and by Annex B.

7.2 Fatigue strength modifications

7.2.1 Non-welded or stress-relieved welded details in compression

(1) In non-welded details or stress-relieved welded details, the mean stress influence on the fatigue strength may be taken into account by determining a reduced effective stress range $\Delta\sigma_{E,2}$ in the fatigue assessment when part or all of the stress cycle is compressive.

(2) The effective stress range may be calculated by adding the tensile portion of the stress range and 60% of the magnitude of the compressive portion of the stress range, see Figure 7.4.



+ *tension*
– *compression*

Figure 7.4: Modified stress range for non-welded or stress relieved details

7.2.2 Size effect

(1) The size effect due to thickness or other dimensional effects should be taken into account as given in Table 8.1 to Table 8.10. The fatigue strength then is given by:

$$\Delta\sigma_{C,red} = k_s \Delta\sigma_C \tag{7.1}$$

8 Fatigue verification

(1) Nominal, modified nominal or geometric stress ranges due to frequent loads ψ_1 Q_k (see EN 1990) should not exceed

$$\begin{aligned} &\Delta\sigma \leq 1{,}5\ f_y && \text{for direct stress ranges} \\ &\Delta\tau \leq 1{,}5\ f_y / \sqrt{3} && \text{for shear stress ranges} \end{aligned} \tag{8.1}$$

(2) It should be verified that under fatigue loading

$$\frac{\gamma_{Ff}\ \Delta\sigma_{E,2}}{\Delta\sigma_C / \gamma_{Mf}} \leq 1{,}0$$

and (8.2)

$$\frac{\gamma_{Ff}\ \Delta\tau_{E,2}}{\Delta\tau_C / \gamma_{Mf}} \leq 1{,}0$$

NOTE Table 8.1 to Table 8.9 require stress ranges to be based on principal stresses for some details.

(3) Unless otherwise stated in the fatigue strength categories in Table 8.8 and Table 8.9, in the case of combined stress ranges $\Delta\sigma_{E,2}$ and $\Delta\tau_{E,2}$ it should be verified that:

$$\left(\frac{\gamma_{Ff}\ \Delta\sigma_{E,2}}{\Delta\sigma_C / \gamma_{Mf}}\right)^3 + \left(\frac{\gamma_{Ff}\ \Delta\tau_{E,2}}{\Delta\tau_C / \gamma_{Mf}}\right)^5 \leq 1{,}0 \tag{8.3}$$

(4) When no data for $\Delta\sigma_{E,2}$ or $\Delta\tau_{E,2}$ are available the verification format in Annex A may be used.

AC2) **NOTE 1** Annex A is presented for stress ranges in longitudinal direction. This presentation may be adopted also for shear stress ranges. (AC2

NOTE 2 The National Annex may give information on the use of Annex A.

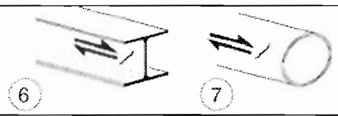
Table 8.1: Plain members and mechanically fastened joints

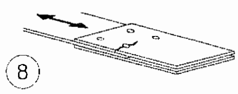
<table>
<tr><th>Detail category</th><th>Constructional detail</th><th>Description</th><th colspan="2">Requirements</th></tr>
<tr><td>160</td><td>NOTE The fatigue strength curve associated with category 160 is the highest. No detail can reach a better fatigue strength at any number of cycles.
</td><td>[AC2⟩ <u>Rolled or extruded products:</u>

1) Plates and flats with as rolled edges;
2) Rolled sections with as rolled edges; ⟨AC2]
3) Seamless hollow sections, either rectangular or circular.</td><td colspan="2"><u>Details 1) to 3):</u>

Sharp edges, surface and rolling flaws to be improved by grinding until removed and smooth transition achieved.</td></tr>
<tr><td>140</td><td></td><td rowspan="2"><u>Sheared or gas cut plates:</u>

4) Machine gas cut or sheared material with subsequent dressing.

5) Material with machine gas cut edges having shallow and regular drag lines or manual gas cut material, subsequently dressed to remove all edge discontinuities.
Machine gas cut with cut quality according to EN 1090.</td><td colspan="2" rowspan="2">4) All visible signs of edge discontinuities to be removed.
The cut areas are to be machined or ground and all burrs to be removed.
Any machinery scratches for example from grinding operations, can only be parallel to the stresses.
<u>Details 4) and 5):</u>
- Re-entrant corners to be improved by grinding (slope ≤ ¼) or evaluated using the appropriate stress concentration factors.
- No repair by weld refill.</td></tr>
<tr><td>125</td><td></td></tr>
<tr><td>100
m = 5</td><td></td><td>[AC2⟩ 6) and 7)
Rolled or extruded products as in details 1), 2), 3) ⟨AC2]</td><td colspan="2"><u>Details 6) and 7):</u>

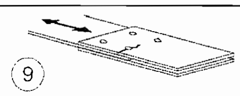
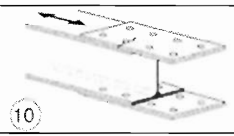
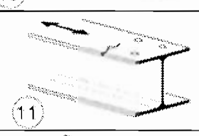
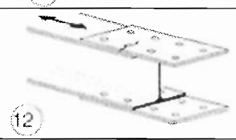
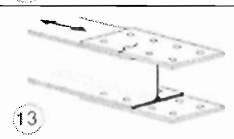
Δτ calculated from: $\tau = \frac{V\,S(t)}{I\,t}$</td></tr>
<tr><td colspan="5">For detail 1 – 5 made of weathering steel use the next lower category.</td></tr>
<tr><td rowspan="2">112</td><td rowspan="2"></td><td>8) Double covered symmetrical joint with preloaded high strength bolts.</td><td>8) Δσ to be calculated on the gross cross-section.</td><td rowspan="10"><u>For bolted connections (Details 8) to 13)) in general:</u>

End distance:
$e_1 \geq 1{,}5\ d$

Edge distance:
$e_2 \geq 1{,}5\ d$

Spacing:
$p_1 \geq 2{,}5\ d$

Spacing:
$p_2 \geq 2{,}5\ d$

Detailing to EN 1993-1-8, Figure 3.1</td></tr>
<tr><td>8) Double covered symmetrical joint with preloaded injection bolts.</td><td>8) ... gross cross-section.</td></tr>
<tr><td rowspan="5">90</td><td rowspan="2"></td><td>9) Double covered joint with fitted bolts.</td><td>9) ... net cross-section.</td></tr>
<tr><td>9) Double covered joint with non preloaded injection bolts.</td><td>9) ... net cross-section.</td></tr>
<tr><td rowspan="2"></td><td>10) One sided connection with preloaded high strength bolts.</td><td>10) ... gross cross-section.</td></tr>
<tr><td>10) One sided connection with preloaded injection bolts.</td><td>10) ... gross cross-section.</td></tr>
<tr><td></td><td>11) Structural element with holes subject to bending and axial forces</td><td>11) ... net cross-section.</td></tr>
<tr><td rowspan="2">80</td><td rowspan="2"></td><td>12) One sided connection with fitted bolts.</td><td>12) ... net cross-section.</td></tr>
<tr><td>12) One sided connection with non-preloaded injection bolts.</td><td>12) ... net cross-section.</td></tr>
<tr><td>50</td><td></td><td>13) One sided or double covered symmetrical connection with non-preloaded bolts in normal clearance holes.
No load reversals.</td><td>13) ... net cross-section.</td></tr>
<tr><td>50</td><td>size effect for $t > 30$mm:

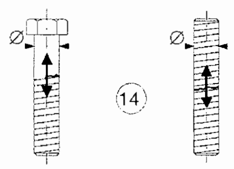
$k_s=(30/t)^{0.25}$
</td><td>14) Bolts and rods with rolled or cut threads in tension.
For large diameters (anchor bolts) the size effect has to be taken into account with k_s.</td><td colspan="2">14) Δσ to be calculated using the tensile stress area of the bolt.
Bending and tension resulting from prying effects and bending stresses from other sources must be taken into account.
For preloaded bolts, the reduction of the stress range may be taken into account.</td></tr>
</table>

Table 8.1 (continued): Plain members and mechanically fastened joints

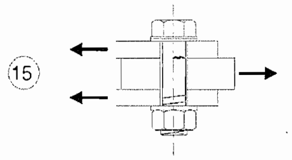
Detail category	Constructional detail	Description	Requirements
100 m=5		Bolts in single or double shear Thread not in the shear plane 15) - Fitted bolts - normal bolts without load reversal (bolts of grade 5.6, 8.8 or 10.9)	15) Δτ calculated on the shank area of the bolt.

Table 8.2: Welded built-up sections

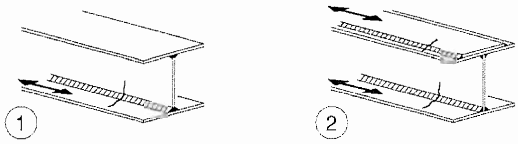
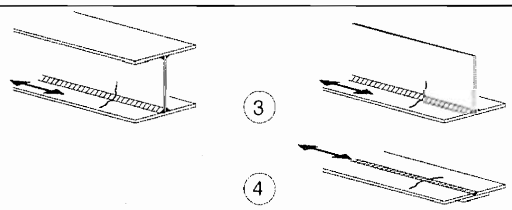
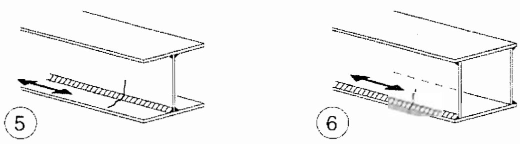
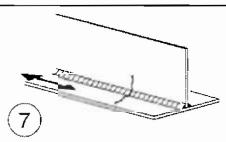
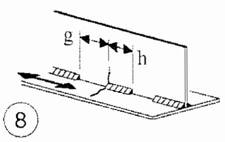
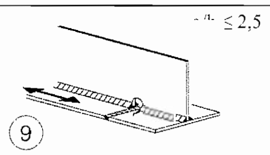
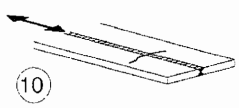
Detail category	Constructional detail	AC2 Description	Requirements
125		Continuous longitudinal welds: 1) Automatic or fully mechanized butt welds carried out from both sides. 2) Automatic or fully mechanized fillet welds. Cover plate ends to be checked using detail 6) or 7) in Table 8.5.	Details 1) and 2): No stop/start position is permitted except when the repair is performed by a specialist and inspection is carried out to verify the proper execution of the repair.
112		3) Automatic or fully mechanized fillet or butt weld carried out from both sides but containing stop/start positions. 4) Automatic or fully mechanized butt welds made from one side only, with a continuous backing bar, but without start/stop positions.	4) When this detail contains stop/start positions category 100 to be used.
100		5) Manual fillet or butt weld. 6) Manual or automatic or fully mechanized butt welds carried out from one side only, particularly for box girders	5), 6) A very good fit between the flange and web plates is essential. The web edge to be prepared such that the root face is adequate for the achievement of regular root penetration without break-out.
100		7) Repaired automatic or fully mechanized or manual fillet or butt welds for categories 1) to 6).	7) Improvement by grinding performed by specialist to remove all visible signs and adequate verification can restore the original category.
80		8) Intermittent longitudinal fillet welds.	8) Δσ based on direct stress in flange.
71		9) Longitudinal butt weld, fillet weld or intermittent weld with a cope hole height not greater than 60 mm. For cope holes with a height > 60 mm see detail 1) in Table 8.4	9) Δσ based on direct stress in flange.
125		10) Longitudinal butt weld, both sides ground flush parallel to load direction, 100% NDT	
112		10) No grinding and no start/stop	
90		10) with start/stop positions	
140		11) Automatic or fully mechanized longitudinal seam weld without stop/start positions in hollow sections	11) Wall thickness t ≤ 12,5 mm.
125		11) Automatic or fully mechanized longitudinal seam weld without stop/start positions in hollow sections	11) Wall thickness t > 12,5 mm. AC2
90		11) with stop/start positions	
For details 1 to 11 made with fully mechanized welding the categories for automatic welding apply.			

Table 8.3: Transverse butt welds

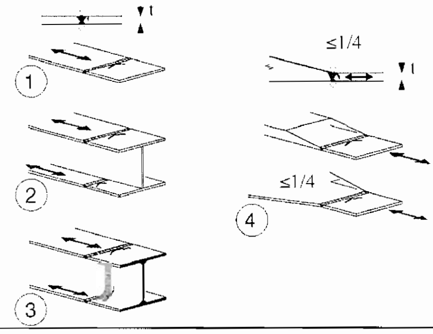
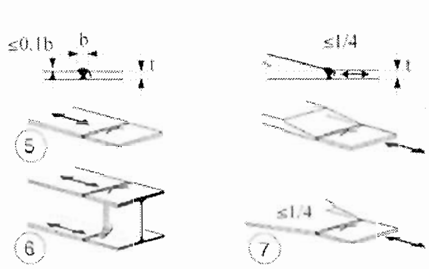
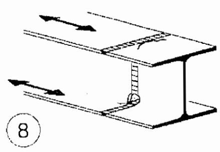
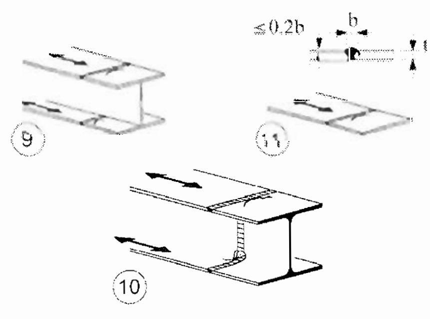
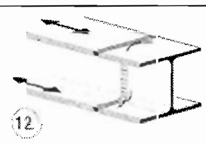
Detail category	Constructional detail		Description	Requirements
112	size effect for t>25mm: $k_s=(25/t)^{0.2}$		Without backing bar: 1) Transverse splices in plates and flats. 2) Flange and web splices in plate girders before assembly. 3) Full cross-section butt welds of rolled sections without cope holes. 4) Transverse splices in plates or flats tapered in width or in thickness, with a slope ≤ ¼.	- All welds ground flush to plate surface parallel to direction of the arrow. - Weld run-on and run-off pieces to be used and subsequently removed, plate edges to be ground flush in direction of stress. - Welded from both sides; checked by NDT. Detail 3): Applies only to joints of rolled [AC2> sections, cut and welded. <AC2]
90	size effect for t>25mm: $k_s=(25/t)^{0.2}$		5) Transverse splices in plates or flats. 6) Full cross-section butt welds of rolled sections without cope holes. 7) Transverse splices in plates or flats tapered in width or in thickness with a slope ≤ ¼. Translation of welds to be machined notch free.	- The height of the weld convexity to be not greater than 10% of the weld width, with smooth transition to the plate surface. - Weld run-on and run-off pieces to be used and subsequently removed, plate edges to be ground flush in direction of stress. - Welded from both sides; checked by NDT. Details 5 and 7: Welds made in flat position.
90	size effect for t>25mm: $k_s=(25/t)^{0.2}$		8) As detail 3) but with cope holes.	- All welds ground flush to plate surface parallel to direction of the arrow. - Weld run-on and run-off pieces to be used and subsequently removed, plate edges to be ground flush in direction of stress. - Welded from both sides; checked by NDT. - Rolled sections with the same dimensions without tolerance differences
80	size effect for t>25mm: $k_s=(25/t)^{0.2}$		9) Transverse splices in welded plate girders without cope hole. 10) Full cross-section butt welds of rolled sections with cope holes. 11) Transverse splices in plates, flats, rolled sections or plate girders.	- The height of the weld convexity to be not greater than 20% of the weld width, with smooth transition to the plate surface. - Weld not ground flush - Weld run-on and run-off pieces to be used and subsequently removed, plate edges to be ground flush in direction of stress. - Welded from both sides; checked by NDT. Detail 10: The height of the weld convexity to be not greater than 10% of the weld width, with smooth transition to the plate surface.
63			12) Full cross-section butt welds of rolled sections without cope hole.	- Weld run-on and run-off pieces to be used and subsequently removed, plate edges to be ground flush in direction of stress. - Welded from both sides.

Table 8.3 (continued): Transverse butt welds

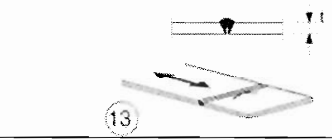
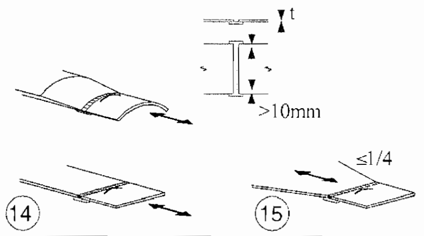
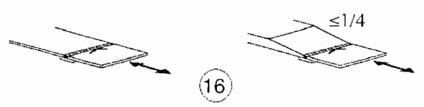
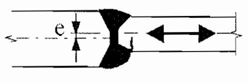
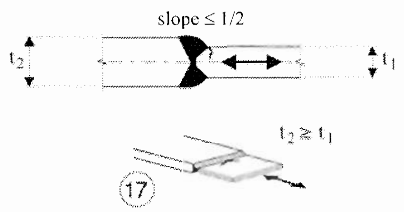
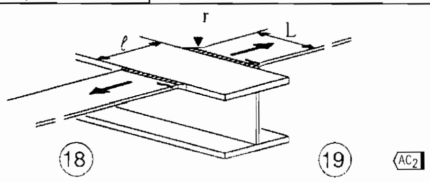
Detail category	Constructional detail		Description	Requirements
36			13) Butt welds made from one side only.	13) Without backing strip.
71	size effect for t>25mm: $k_s=(25/t)^{0.2}$		13) Butt welds made from one side only when full penetration checked by appropriate NDT.	
71	size effect for t>25mm: $k_s=(25/t)^{0.2}$		With backing strip: 14) Transverse splice. 15) Transverse butt weld tapered in width or thickness with a slope ≤ ¼. Also valid for curved plates.	Details 14) and 15): Fillet welds attaching the backing strip to terminate ≥ 10 mm from the edges of the stressed plate. Tack welds inside the shape of butt welds.
50	size effect for t>25mm: $k_s=(25/t)^{0.2}$		16) Transverse butt weld on a permanent backing strip tapered in width or thickness with a slope ≤ ¼. Also valid for curved plates.	16) Where backing strip fillet welds end < 10 mm from the plate edge, or if a good fit cannot be guaranteed.
71	size effect for t>25mm and/or generalization for eccentricity: $k_s = \left(\frac{25}{t_1}\right)^{0.2} \Big/ \left(1+\frac{6e}{t_1}\frac{t_1^{1.5}}{t_1^{1.5}+t_2^{1.5}}\right)$ 		17) Transverse butt weld, different thicknesses without transition, centrelines aligned.	
AC2 40		 AC2	18) Transverse butt weld at intersecting flanges.	Details 18) and 19) The fatigue strength of the continuous component has to be checked with Table 8.4, detail 4 or detail 5.
As detail 4 in Table 8.4			19) With transition radius according to Table 8.4, detail 4	

Table 8.4: Weld attachments and stiffeners

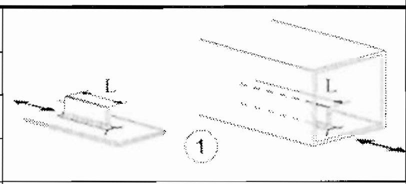
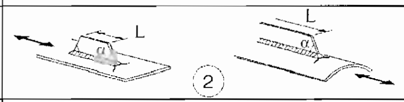
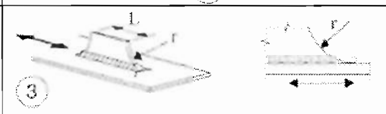
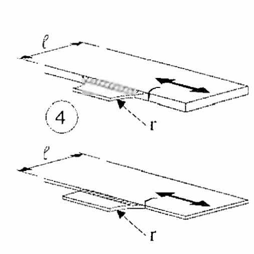
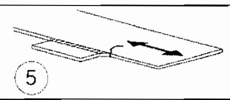
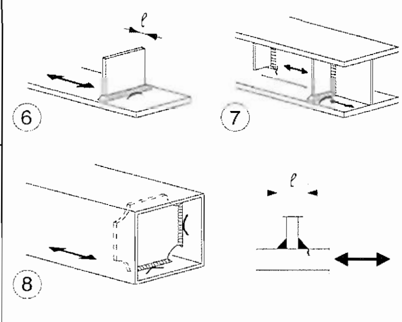
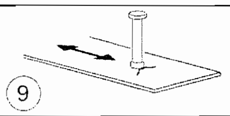
Detail category	Constructional detail		Description	Requirements
80	$L \leq 50mm$		Longitudinal attachments: 1) The detail category varies according to the length of the attachment L.	The thickness of the attachment must be less than its height. If not see Table 8.5, details 5 or 6.
71	$50 < L \leq 80mm$			
63	$80 < L \leq 100mm$			
56	$L > 100mm$			
71	$L > 100mm$ $\alpha < 45°$		2) Longitudinal attachments to plate or tube.	
80	$r > 150mm$	 reinforced	3) Longitudinal fillet welded gusset with radius transition to plate or tube; end of fillet weld reinforced (full penetration); length of reinforced weld > r.	Details 3) and 4): Smooth transition radius r formed by initially machining or gas cutting the gusset plate before welding, then subsequently grinding the weld area parallel to the direction of the arrow so that the transverse weld toe is fully removed.
AC2⟩ 90	$\frac{r}{\ell} \geq \frac{1}{3}$ or $r > 150mm$	 ⟨AC2	4) Gusset plate, welded to the edge of a plate or beam flange.	
71	$\frac{1}{6} \leq \frac{r}{\ell} \leq \frac{1}{3}$			
50	$\frac{r}{\ell} < \frac{1}{6}$			
40			5) As welded, no radius transition.	
80	$\ell \leq 50mm$		Transverse attachments: 6) Welded to plate. 7) Vertical stiffeners welded to a beam or plate girder. 8) Diaphragm of box girders welded to the flange or the web. May not be possible for small hollow sections. The values are also valid for ring stiffeners.	Details 6) and 7): Ends of welds to be carefully ground to remove any undercut that may be present. 7) $\Delta\sigma$ to be calculated using principal stresses if the stiffener terminates in the web, see left side.
71	$50 < \ell \leq 80mm$			
80			9) The effect of welded shear studs on base material.	

Table 8.5: Load carrying welded joints

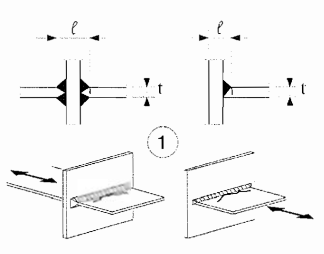
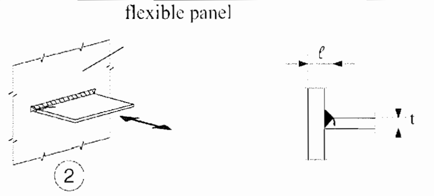
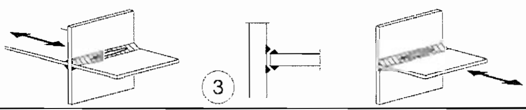
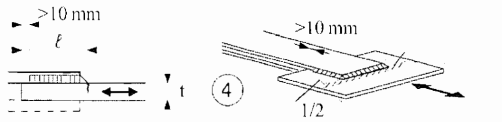
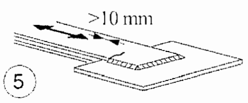
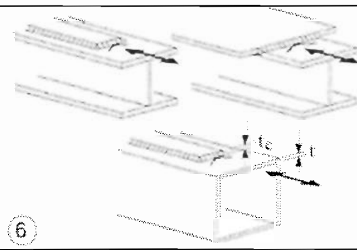
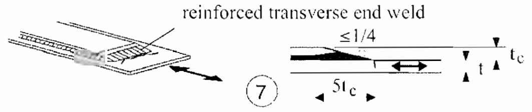
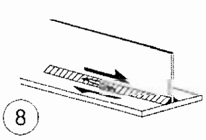
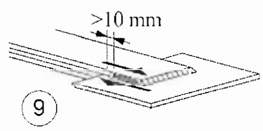
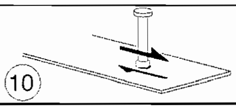
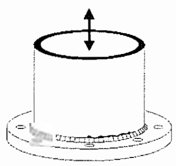
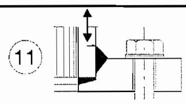
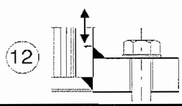
[AC2⟩ Detail category	Constructional detail			Description	Requirements
80	ℓ<50 mm	all t [mm]		Cruciform and Tee joints: 1) Toe failure in full penetration butt welds and all partial penetration joints.	1) Inspected and found free from discontinuities and misalignments outside the tolerances of EN 1090. 2) For computing Δσ, use modified nominal stress. 3) In partial penetration joints two fatigue assessments are required. Firstly, root cracking evaluated according to stresses defined in section 5, using category 36* for $\Delta\sigma_w$ and category 80 for $\Delta\tau_w$. Secondly, toe cracking is evaluated by determining Δσ in the load-carrying plate. Details 1) to 3): The misalignment of the load-carrying plates should not exceed 15 % of the thickness of the intermediate plate.
71	50<ℓ≤80	all t			
63	80<ℓ≤100	all t			
56	100<ℓ≤120	all t			
56	ℓ>120	t≤20			
50	120<ℓ≤200 ℓ>200	t>20 20<t≤30			
45	200<ℓ≤300 ℓ>300	t>30 30<t≤50			
40	ℓ>300	t>50			
As detail 1 in Table 8.5	flexible panel 			2) Toe failure from edge of attachment to plate, with stress peaks at weld ends due to local plate deformations.	
36*				3) Root failure in partial penetration Tee-butt joints or fillet welded joint and in Tee-butt weld, according to Figure 4.6 in EN 1993-1-8:2005.⟨AC2]	
As detail 1 in Table 8.5	 stressed area of main panel: slope = 1/2			Overlapped welded joints: 4) Fillet welded lap joint.	4) Δσ in the main plate to be calculated on the basis of area shown in the sketch. 5) Δσ to be calculated in the overlapping plates. Details 4) and 5): - Weld terminations more than 10 mm from plate edge. - Shear cracking in the weld should be checked using detail 8).
45*				Overlapped: 5) Fillet welded lap joint.	
	t_c<t	t_c≥t		Cover plates in beams and plate girders: 6) End zones of single or multiple welded cover plates, with or without transverse end weld.	6) If the cover plate is wider than the flange, a transverse end weld is needed. This weld should be carefully ground to remove undercut. The minimum length of the cover plate is 300 mm. For shorter attachments size effect see detail 1).
56*	t≤20	-			
50	20<t≤30	t≤20			
45	30<t≤50	20<t≤30			
40	t>50	30<t≤50			
36	-	t>50			
56	reinforced transverse end weld 			7) Cover plates in beams and plate girders. $5t_c$ is the minimum length of the reinforcement weld.	7) Transverse end weld ground flush. In addition, if t_c>20mm, front of plate at the end ground with a slope < 1 in 4.
80 m=5	 			8) Continuous fillet welds transmitting a shear flow, such as web to flange welds in plate girders. 9) Fillet welded lap joint.	8) Δτ to be calculated from the weld throat area. 9) Δτ to be calculated from the weld throat area considering the total length of the weld. Weld terminations more than 10 mm from the plate edge, see also 4) and 5) above.
see EN 1994-2 (90 m=8)				Welded stud shear connectors: 10) For composite application	10) Δτ to be calculated from the nominal cross section of the stud.
71	 			11) Tube socket joint with 80% full penetration butt welds.	11) Weld toe ground. Δσ computed in tube.
40				12) Tube socket joint with fillet welds.	12) Δσ computed in tube.

Table 8.6: Hollow sections ($t \leq 12{,}5$ mm)

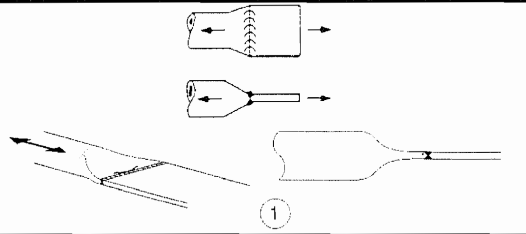
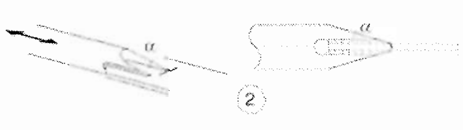
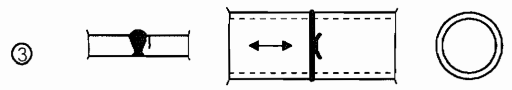
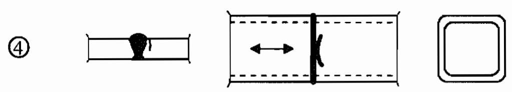
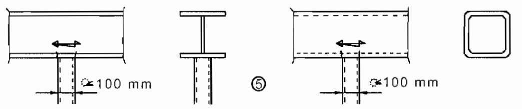
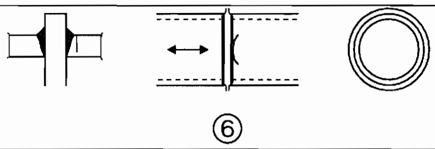
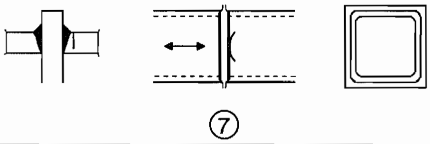
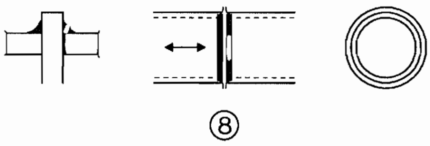
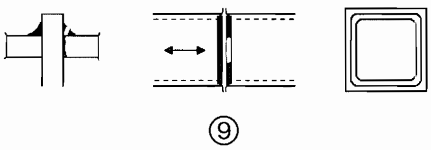
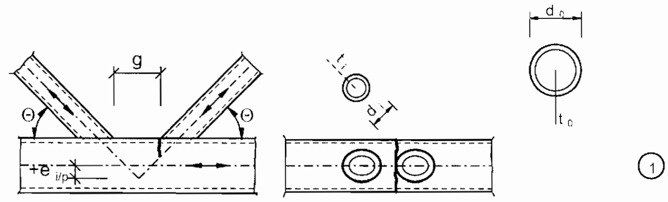
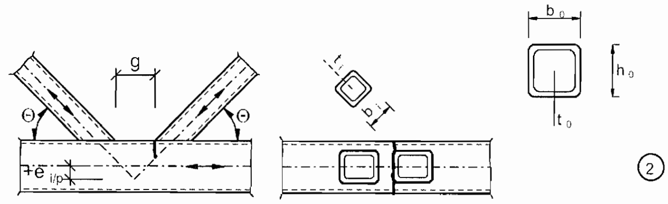
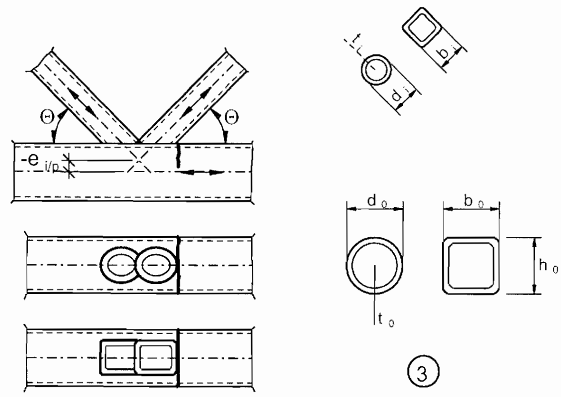
Detail category	Constructional detail	Description	Requirements
71		1) Tube-plate joint, tubes flatted, butt weld (X-groove)	1) $\Delta\sigma$ computed in tube. Only valid for tube diameter less than 200 mm.
71	$\alpha \leq 45°$ 	2) Tube-plate joint, tube slitted and welded to plate. Holes at end of slit.	2) $\Delta\sigma$ computed in tube. Shear cracking in the weld should be verified using Table 8.5, detail 8).
63	$\alpha > 45°$		
71		Transverse butt welds: 3) Butt-welded end-to-end connections between circular structural hollow sections.	Details 3) and 4): - Weld convexity $\leq$ 10% of weld width, with smooth transitions. - Welded in flat position, inspected and found free from defects outside the tolerances EN 1090. - Classify 2 detail categories higher if $t > 8$ mm.
56		4) Butt-welded end-to-end connections between rectangular structural hollow sections.	
71		Welded attachments: 5) Circular or rectangular structural hollow section, fillet-welded to another section.	5) - Non load-carrying welds. - Width parallel to stress direction $\ell \leq 100$ mm. - Other cases see Table 8.4.
50		Welded splices: 6) Circular structural hollow sections, butt-welded end-to-end with an intermediate plate.	Details 6) and 7): - Load-carrying welds. - Welds inspected and found free from defects outside the tolerances of EN 1090. - Classify 1 detail category higher if $t > 8$ mm.
45		7) Rectangular structural hollow sections, butt welded end-to-end with an intermediate plate.	
40		8) Circular structural hollow sections, fillet-welded end-to-end with an intermediate plate.	Details 8) and 9): - Load-carrying welds. - Wall thickness $t \leq 8$ mm.
36		9) Rectangular structural hollow sections, fillet-welded end-to-end with an intermediate plate.	

Table 8.7: Lattice girder node joints

<table>
<tr><th>Detail category</th><th colspan="2">Constructional detail</th><th>Requirements</th></tr>
<tr><td>90
m=5</td><td>$\frac{t_0}{t_i} \geq 2{,}0$</td><td rowspan="2">Gap joints: Detail 1): K and N joints, circular structural hollow sections:

</td><td rowspan="4"><u>Details 1) and 2):</u>
- Separate assessments needed for the chords and the braces.
- For intermediate values of the ratio t_0/t_i interpolate linearly between detail categories.
- Fillet welds permitted for braces with wall thickness $t \leq 8$ mm.
- t_0 and $t_i \leq 8$mm
- $35° \leq \theta \leq 50°$
- $b_0/t_0 \times t_0/t_i \leq 25$
- $d_0/t_0 \times t_0/t_i \leq 25$
- $0{,}4 \leq b_i/b_0 \leq 1{,}0$
- $0{,}25 \leq d_i/d_0 \leq 1{,}0$
- $b_0 \leq 200$ mm
- $d_0 \leq 300$ mm
- $-0{,}5h_0 \leq e_{i/p} \leq 0{,}25h_0$
- $-0{,}5d_0 \leq e_{i/p} \leq 0{,}25d_0$
- $e_{o/p} \leq 0{,}02b_0$ or $\leq 0{,}02d_0$

[$e_{o/p}$ is out-of-plane eccentricity]

<u>Detail 2):</u>
$0{,}5(b_0 - b_i) \leq g \leq 1{,}1(b_0 - b_i)$
and $g \geq 2t_0$</td></tr>
<tr><td>45
m=5</td><td>$\frac{t_0}{t_i} = 1{,}0$</td></tr>
<tr><td>71
m=5</td><td>$\frac{t_0}{t_i} \geq 2{,}0$</td><td rowspan="2">Gap joints: Detail 2): K and N joints, rectangular structural hollow sections:

</td></tr>
<tr><td>36
m=5</td><td>$\frac{t_0}{t_i} = 1{,}0$</td></tr>
<tr><td>71
m=5</td><td>$\frac{t_0}{t_i} \geq 1{,}4$</td><td rowspan="2">Overlap joints: Detail 3): K joints, circular or rectangular structural hollow sections:

</td><td rowspan="4"><u>Details 3) and 4):</u>
- 30 % ≤ overlap ≤ 100 %
- overlap = (q/p) × 100 %
- Separate assessments needed for the chords and the braces.
- For intermediate values of the ratio t_0/t_i interpolate linearly between detail categories.
- Fillet welds permitted for braces with wall thickness $t \leq 8$ mm.
- t_0 and $t_i \leq 8$mm
- $35° \leq \theta \leq 50°$
- $b_0/t_0 \times t_0/t_i \leq 25$
- $d_0/t_0 \times t_0/t_i \leq 25$
- $0{,}4 \leq b_i/b_0 \leq 1{,}0$
- $0{,}25 \leq d_i/d_0 \leq 1{,}0$
- $b_0 \leq 200$ mm
- $d_0 \leq 300$ mm
- $-0{,}5h_0 \leq e_{i/p} \leq 0{,}25h_0$
- $-0{,}5d_0 \leq e_{i/p} \leq 0{,}25d_0$
- $e_{o/p} \leq 0{,}02b_0$ or $\leq 0{,}02d_0$

[$e_{o/p}$ is out-of-plane eccentricity]

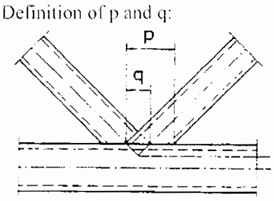
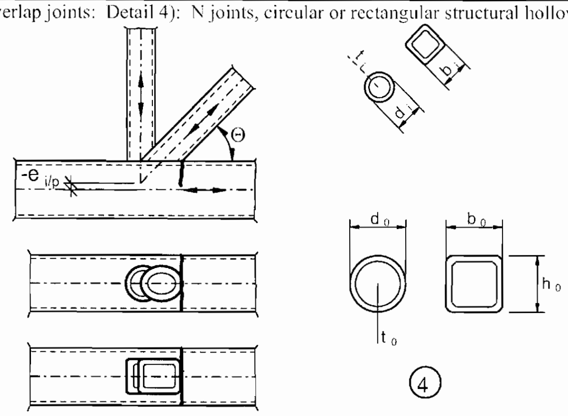
Definition of p and q:

</td></tr>
<tr><td>56
m=5</td><td>$\frac{t_0}{t_i} = 1{,}0$</td></tr>
<tr><td>71
m=5</td><td>$\frac{t_0}{t_i} \geq 1{,}4$</td><td rowspan="2">Overlap joints: Detail 4): N joints, circular or rectangular structural hollow sections:

</td></tr>
<tr><td>50
m=5</td><td>$\frac{t_0}{t_i} = 1{,}0$</td></tr>
</table>

Table 8.8: Orthotropic decks – closed stringers

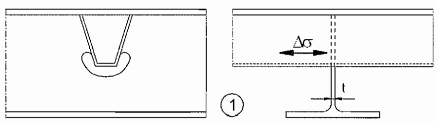
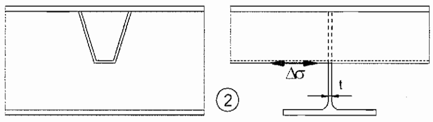
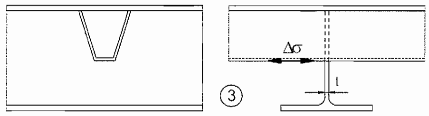
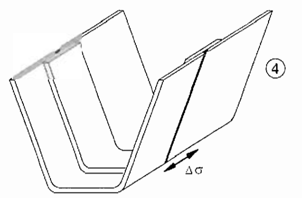
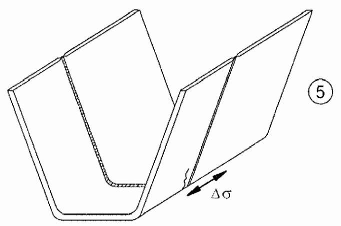
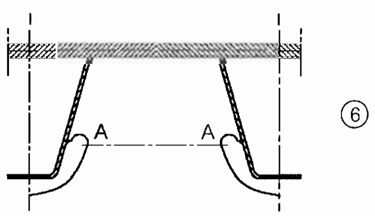
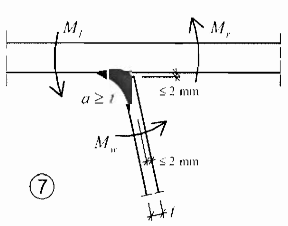
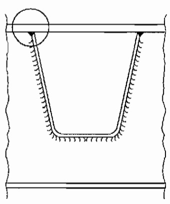
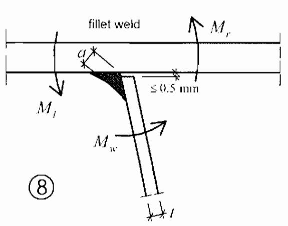
Detail category	Constructional detail		Description	Requirements
80	t≤12mm		1) Continuous longitudinal stringer, with additional cutout in cross girder.	1) Assessment based on the direct stress range Δσ in the longitudinal stringer.
71	t>12mm			
80	t≤12mm		2) Continuous longitudinal stringer, no additional cutout in cross girder.	2) Assessment based on the direct stress range Δσ in the stringer.
71	t>12mm			
36			3) Separate longitudinal stringer each side of the cross girder.	3) Assessment based on the direct stress range Δσ in the stringer.
71			4) Joint in rib, full penetration butt weld with steel backing plate.	4) Assessment based on the direct stress range Δσ in the stringer.
112	As detail 1, 2, 4 in Table 8.3		5) Full penetration butt weld in rib, welded from both sides, without backing plate.	5) Assessment based on the direct stress range Δσ in the stringer. Tack welds inside the shape of butt welds.
90	As detail 5, 7 in Table 8.3			
80	As detail 9, 11 in Table 8.3			
71			6) Critical section in web of cross girder due to cut outs.	6) Assessment based on stress range in critical section taking account of Vierendeel effects. **NOTE** In case the stress range is determined according to EN 1993-2, 9.4.2.2(3), detail category 112 may be used.
71		$\Delta\sigma = \frac{\Delta M_w}{W_w}$ 	<u>Weld connecting deck plate to trapezoidal or V-section rib</u> 7) Partial penetration weld with $a \geq t$	7) Assessment based on direct stress range from bending in the plate.
50			8) Fillet weld or partial penetration welds out of the range of detail 7)	8) Assessment based on direct stress range from bending in the plate.

Table 8.9: Orthotropic decks – open stringers

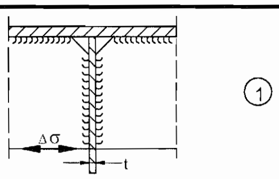
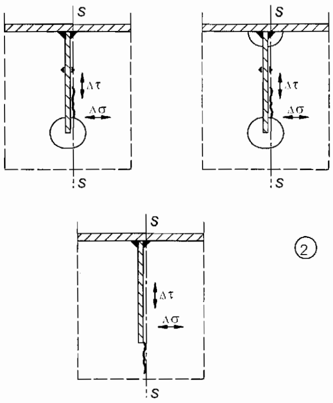
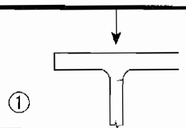
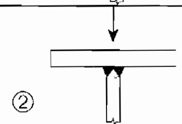
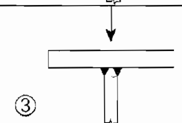
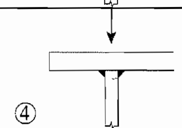
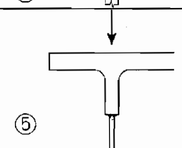
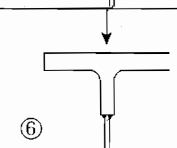
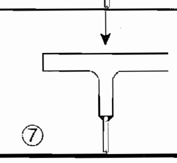
Detail category	Constructional detail		Description	Requirements
80	t≤12mm		1) Connection of longitudinal stringer to cross girder.	1) Assessment based on the direct stress range $\Delta\sigma$ in the stringer.
71	t>12mm			
56			2) Connection of continuous longitudinal stringer to cross girder. $\Delta\sigma = \frac{\Delta M_s}{W_{net,s}}$ $\Delta\tau = \frac{\Delta V_s}{A_{w,net,s}}$ Check also stress range between stringers as defined in EN 1993-2.	2) Assessment based on combining the shear stress range $\Delta\tau$ and direct stress range $\Delta\sigma$ in the web of the cross girder, as an equivalent stress range: $\Delta\sigma_{eq} = \frac{1}{2}\left(\Delta\sigma + \sqrt{\Delta\sigma^2 + 4\Delta\tau^2}\right)$

Table 8.10: Top flange to web junction of runway beams

Detail category	Constructional detail	Description	Requirements
160		1) Rolled I- or H-sections	1) Vertical compressive stress range $\Delta\sigma_{vert.}$ in web due to wheel loads
71		2) Full penetration tee-butt weld	2) Vertical compressive stress range $\Delta\sigma_{vert.}$ in web due to wheel loads
36*		3) Partial penetration tee-butt welds, or effective full penetration tee-butt weld conforming with EN 1993-1-8	3) Stress range $\Delta\sigma_{vert.}$ in weld throat due to vertical compression from wheel loads
36*		4) Fillet welds	4) Stress range $\Delta\sigma_{vert.}$ in weld throat due to vertical compression from wheel loads
71		5) T-section flange with full penetration tee-butt weld	5) Vertical compressive stress range $\Delta\sigma_{vert.}$ in web due to wheel loads
36*		6) T-section flange with partial penetration tee-butt weld, or effective full penetration tee-butt weld conforming with EN 1993-1-8	6) Stress range $\Delta\sigma_{vert.}$ in weld throat due to vertical compression from wheel loads
36*		7) T-section flange with fillet welds	7) Stress range $\Delta\sigma_{vert.}$ in weld throat due to vertical compression from wheel loads

Annex A [normative] – Determination of fatigue load parameters and verification formats

A.1 Determination of loading events

(1) Typical loading sequences that represent a credible estimated upper bound of all service load events expected during the fatigue design life should be determined using prior knowledge from similar structures, see Figure A.1 a).

A.2 Stress history at detail

(1) A stress history should be determined from the loading events at the structural detail under consideration taking account of the type and shape of the relevant influence lines to be considered and the effects of dynamic magnification of the structural response, see Figure A.1 b).

(2) Stress histories may also be determined from measurements on similar structures or from dynamic calculations of the structural response.

A.3 Cycle counting

(1) Stress histories may be evaluated by either of the following cycle counting methods:

- rainflow method
- reservoir method, see Figure A.1 c).

to determine

- stress ranges and their numbers of cycles
- mean stresses, where the mean stress influence needs to be taken into account.

A.4 Stress range spectrum

(1) The stress range spectrum should be determined by presenting the stress ranges and the associated number of cycles in descending order, see Figure A.1 d).

(2) Stress range spectra may be modified by neglecting peak values of stress ranges representing less than 1% of the total damage and small stress ranges below the cut off limit.

(3) Stress range spectra may be standardized according to their shape, e.g. with the coordinates $\overline{\Delta\sigma} = 1{,}0$ and $\overline{\Sigma n} = 1{,}0$.

A.5 Cycles to failure

(1) When using the design spectrum the applied stress ranges $\Delta\sigma_i$ should be multiplied by γ_{Ff} and the fatigue strength values $\Delta\sigma_C$ divided by γ_{Mf} in order to obtain the endurance value N_{Ri} for each band in the spectrum. The damage D_d during the design life should be calculated from:

$$D_d = \sum_i^n \frac{n_{Ei}}{N_{Ri}} \quad \text{(A.1)}$$

where n_{Ei} is the number of cycles associated with the stress range $\gamma_{Ff}\Delta\sigma_i$ for band i in the factored spectrum

N_{Ri} is the endurance (in cycles) obtained from the factored $\frac{\Delta\sigma_C}{\gamma_{Mf}} - N_R$ curve for a stress range of $\gamma_{Ff}\,\Delta\sigma_i$

(2) On the basis of equivalence of D_d the design stress range spectrum may be transformed into any equivalent design stress range spectrum, e.g. a constant amplitude design stress range spectrum yielding the fatigue equivalent load Q_e associated with the cycle number $n_{max} = \sum n_i$ or $Q_{E,2}$ associated with the cycle number $N_C = 2\times10^6$.

A.6 Verification formats

(1) The fatigue assessment based on damage accumulation should meet the following criteria:

- based on damage accumulation:

$$D_d \leq 1{,}0 \quad \text{(A.2)}$$

- based on stress range:

$$\gamma_{Ff}\Delta\sigma_{E,2} \leq \sqrt[m]{D_d}\,\frac{\Delta\sigma_C}{\gamma_{Mf}} \quad \text{where } m = 3 \quad \text{(A.3)}$$

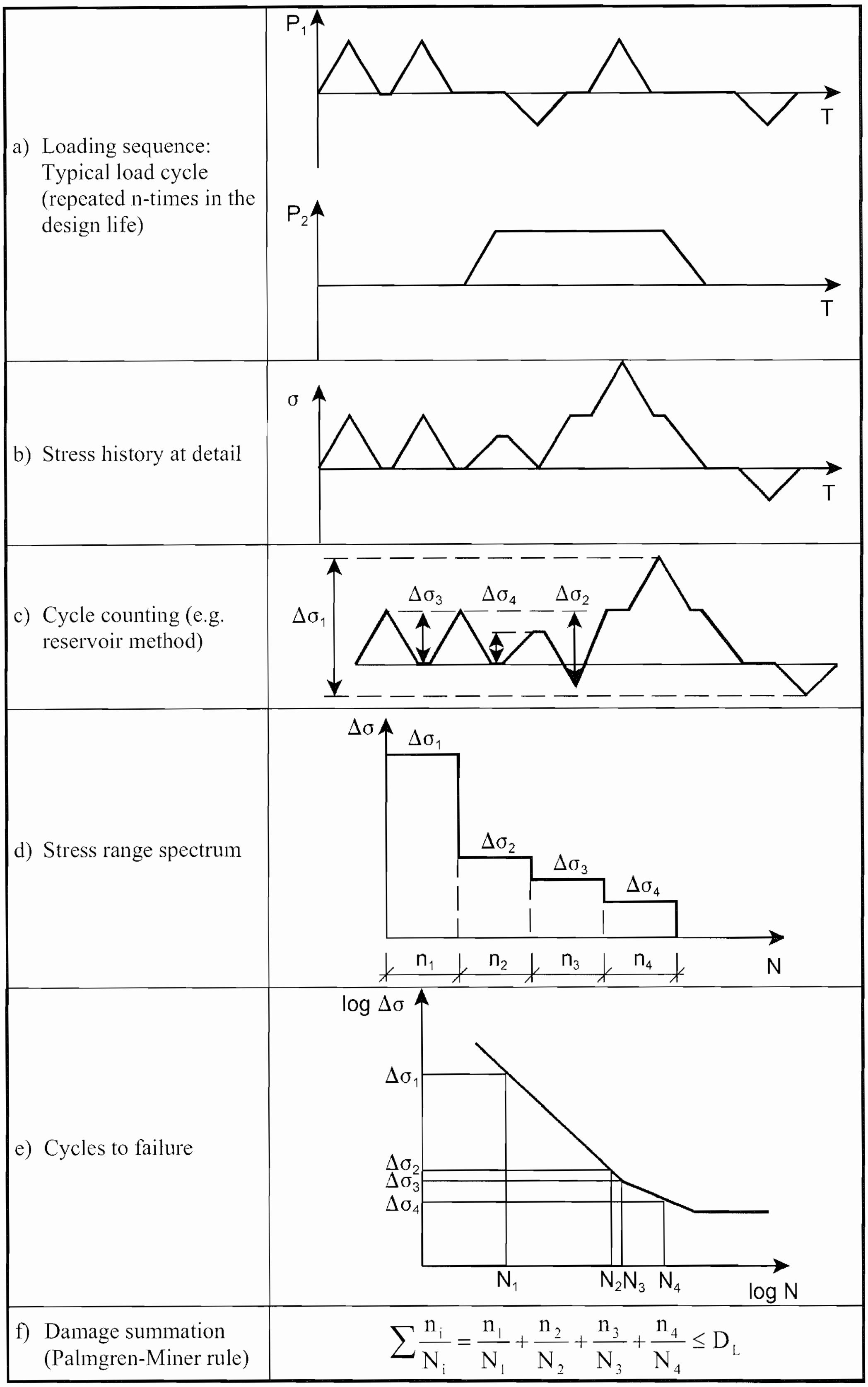


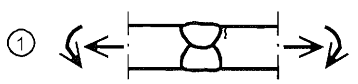
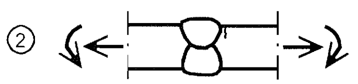
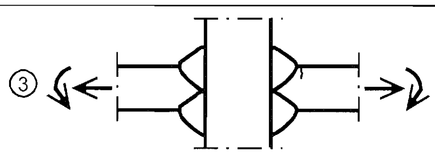
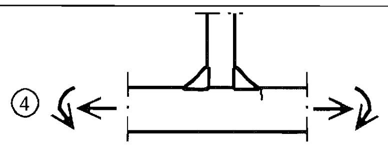
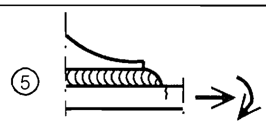
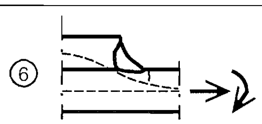
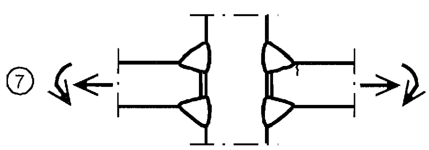
Figure A.1: Cumulative damage method

Annex B [normative] – Fatigue resistance using the geometric (hot spot) stress method

(1) For the application of the geometric stress method detail categories are given in Table B.1 for cracks initiating from

- toes of butt welds,
- toes of fillet welded attachments,
- toes of fillet welds in cruciform joints.

Table B.1: Detail categories for use with geometric (hot spot) stress method

Detail category	Constructional detail	Description	Requirements
112		1) Full penetration butt joint.	1) - All welds ground flush to plate surface parallel to direction of the arrow. - Weld run-on and run-off pieces to be used and subsequently removed, plate edges to be ground flush in direction of stress. - Welded from both sides, checked by NDT. - For misalignment see NOTE 1.
100		2) Full penetration butt joint.	2) - Weld not ground flush - Weld run-on and run-off pieces to be used and subsequently removed, plate edges to be ground flush in direction of stress. - Welded from both sides. - For misalignment see NOTE 1.
100		3) Cruciform joint with full penetration K-butt welds.	3) - Weld toe angle $\leq 60°$. - For misalignment see NOTE 1.
100		4) Non load-carrying fillet welds.	4) - Weld toe angle $\leq 60°$. - See also NOTE 2.
100		5) Bracket ends, ends of longitudinal stiffeners.	5) - Weld toe angle $\leq 60°$. - See also NOTE 2.
100		6) Cover plate ends and similar joints.	6) - Weld toe angle $\leq 60°$. - See also NOTE 2.
90		7) Cruciform joints with load-carrying fillet welds.	7) - Weld toe angle $\leq 60°$. - For misalignment see NOTE 1. - See also NOTE 2.

NOTE 1 Table B.1 does not cover effects of misalignment. They have to be considered explicitly in determination of stress.

NOTE 2 Table B.1 does not cover fatigue initiation from the root followed by propagation through the throat.

NOTE 3 For the definition of the weld toe angle see EN 1090.

blank