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UDC

Descriptors:

English version

## **Eurocode 3 : Design of steel structures**

### **Part 1.9 : Fatigue**

Calcul des structures en acier

Bemessung und Konstruktion von Stahlbauten

Partie 1.9 :

Teil 1.9 :

Fatigue

Ermüdung

## **Stage 49 draft**

**CEN**

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## 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)

## 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 ( $> 150\text{ }^{\circ}\text{C}$ ) is not covered.

### 1.2 Definitions

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

#### 1.2.1 General

##### 1.2.1.1

##### **fatigue**

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

##### 1.2.1.2

##### **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.

### 1.2.1.3

#### **modified nominal stress**

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

### 1.2.1.4

#### **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.

### 1.2.1.5

#### **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.

## 1.2.2 Fatigue loading parameters

### 1.2.2.1

#### **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.

### 1.2.2.2

#### **stress history**

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

### 1.2.2.3

#### **rainflow method**

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

### 1.2.2.4

#### **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.

### 1.2.2.5

#### **stress range**

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

### 1.2.2.6

#### **stress-range spectrum**

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

### 1.2.2.7

#### **design spectrum**

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

### 1.2.2.8

#### **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.

#### 1.2.2.9

##### **fatigue life**

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

#### 1.2.2.10

##### **Miner's summation**

A linear cumulative damage calculation based on the Palmgren-Miner rule.

#### 1.2.2.11

##### **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.

#### 1.2.2.12

##### **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

- $Q_{\max}$ ,  $n_{\max}$ , standardised spectrum or
- $Q_{E, n_{\max}}$  related to  $n_{\max}$  or
- $Q_{E, 2}$  corresponding to  $n = 2 \times 10^6$  cycles.

Dynamic effects are included in these parameters unless otherwise stated.

#### 1.2.2.13

##### **equivalent constant amplitude fatigue loading**

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

### 1.2.3 Fatigue strength

#### 1.2.3.1

##### **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.

#### 1.2.3.2

##### **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/mm<sup>2</sup>).

#### 1.2.3.3

##### **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.

#### 1.2.3.4

##### cut-off limit

Limit below which stress ranges of the design spectrum do not contribute to the calculated cumulative damage.

#### 1.2.3.5

##### endurance

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

#### 1.2.3.6

##### reference fatigue strength

The constant amplitude stress range  $\Delta\sigma_C$ , for a particular detail category for an endurance  $N = 2 \times 10^6$  cycles

### 1.3 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
$\gamma_{Ff}$	partial factor for equivalent constant amplitude stress ranges $\Delta\sigma_E, \Delta\tau_E$
$\gamma_{Mf}$	partial factor for fatigue strength $\Delta\sigma_C, \Delta\tau_C$
$m$	slope of fatigue strength curve
$\lambda_i$	damage equivalent factors
$\psi_1$	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

## 2 Basic requirements and methods

(1) 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.

**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 shall 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 shall 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  $\gamma_{Mf}$  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

- selecting details and stress levels resulting in a fatigue life sufficient to achieve the  $\beta$  – values equal to those for ultimate limit state verifications at the end of the design service life.

**NOTE** The National Annex may give the choice of the assessment method, definitions of classes of consequences and numerical values for  $\gamma_{Mf}$ . Recommended values for  $\gamma_{Mf}$  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 shall 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 (see Table 4.1 for circular sections, Table 4.2 for rectangular sections).

**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	1,0	1,3
	N type / KT type	1,5	1,8	1,4
Overlap joints	K type	1,5	1,0	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	1,0	1,5
	N type / KT type	1,5	2,2	1,6
Overlap joints	K type	1,5	1,0	1,3
	N type / KT type	1,5	2,0	1,4

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

## 5 Calculation of stresses

- (1) Stresses shall 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.

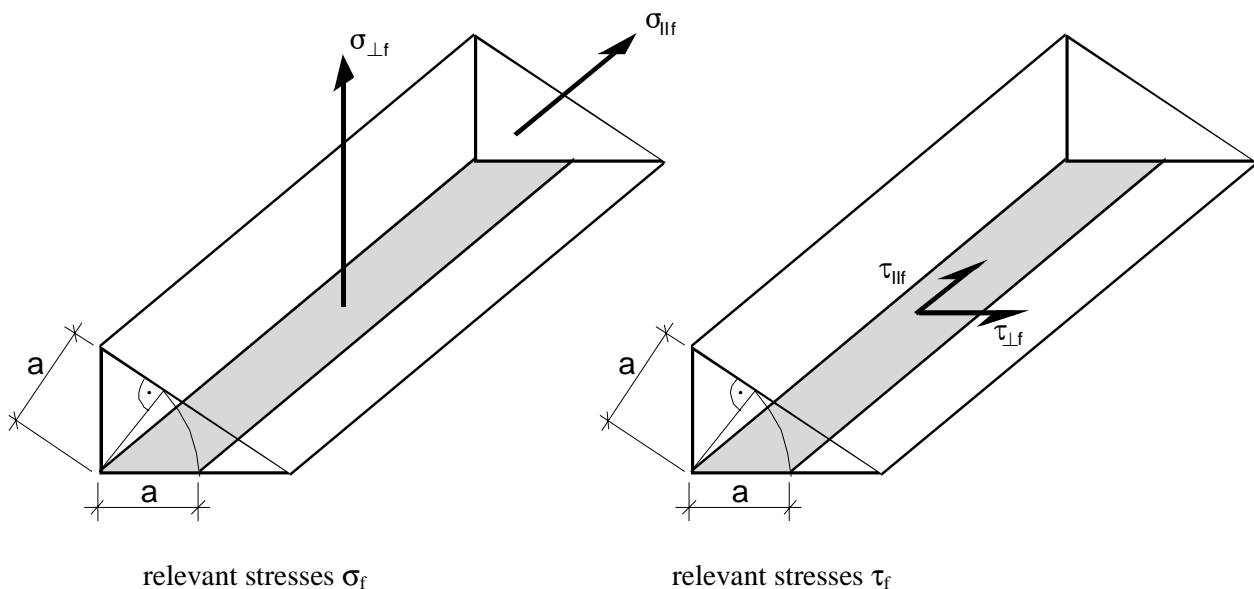
- (3) Nominal stresses should be calculated at the site of potential fatigue initiation. Effects producing stress concentrations at details other than those included in Table 8.1 to Table 8.10 shall be accounted for by using a stress concentration factor (SCF) according to 6.3 to give a modified nominal stress.
- (4) When using geometrical (hot spot) stress methods for details covered by Table B.1, the stresses shall be calculated as shown in 6.5.
- (5) The relevant stresses for details in the parent material are
  - nominal direct stresses  $\sigma$
  - nominal shear stresses  $\tau$

**NOTE** For effects of combined nominal stresses see 8(2).

- (6) The relevant stresses in the welds are (see Figure 5.1)
  - normal stresses  $\sigma_{wf}$  transverse to the axis of the weld:  $\sigma_{wf} = \sqrt{\sigma_{\perp f}^2 + \tau_{\perp f}^2}$
  - shear stresses  $\tau_{wf}$  longitudinal to the axis of the weld:  $\tau_{wf} = \tau_{\parallel f}$

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 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  $N_C = 2 \times 10^6$  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:

$$\gamma_{FF} \Delta\sigma_{E,2} = \lambda_1 \times \lambda_2 \times \lambda_i \times \dots \times \lambda_n \times \Delta\sigma(\gamma_{FF} Q_k) \quad (6.1)$$

$$\gamma_{FF} \Delta\tau_{E,2} = \lambda_1 \times \lambda_2 \times \lambda_i \times \dots \times \lambda_n \times \Delta\tau(\gamma_{FF} Q_k)$$

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

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

- (2) Where no appropriate data for  $\lambda_i$  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:

$$\gamma_{FF} \Delta\sigma_{E,2} = k_f \times \lambda_1 \times \lambda_2 \times \lambda_i \times \dots \times \lambda_n \times \Delta\sigma(\gamma_{FF} Q_k) \quad (6.2)$$

$$\gamma_{FF} \Delta\tau_{E,2} = k_f \times \lambda_1 \times \lambda_2 \times \lambda_i \times \dots \times \lambda_n \times \Delta\tau(\gamma_{FF} Q_k)$$

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  $\gamma_{\text{FF}} \Delta \sigma_{\text{E},2}$  should be determined as follows using the simplified model in 4(2):

$$\gamma_{\text{FF}} \Delta \sigma_{\text{E},2} = k_1 (\gamma_{\text{FF}} \Delta \sigma_{\text{E},2}^*) \quad (6.3)$$

where  $\gamma_{\text{FF}} \Delta \sigma_{\text{E},2}^*$  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  $\gamma_{\text{FF}} \Delta \sigma_{\text{E},2}$  should be determined as follows:

$$\gamma_{\text{FF}} \Delta \sigma_{\text{E},2} = k_f (\gamma_{\text{FF}} \Delta \sigma_{\text{E},2}^*) \quad (6.4)$$

where  $k_f$  is the stress concentration factor

# 7 Fatigue strength

## 7.1 General

(1) The fatigue strength for nominal stresses is represented by a series of  $(\log \Delta \sigma_{\text{R}}) - (\log N)$  curves and  $(\log \Delta \tau_{\text{R}}) - (\log N)$  curves (S-N-curves), which correspond to typical detail categories. Each detail category is designated by a number which represents, in  $\text{N/mm}^2$ , the reference value  $\Delta \sigma_{\text{C}}$  and  $\Delta \tau_{\text{C}}$  for the fatigue strength at 2 million cycles.

(2) For constant amplitude nominal stresses as shown in Figure 7.1 and Figure 7.2 fatigue strengths can be obtained as follows:

$$\Delta \sigma_{\text{R}}^m N_{\text{R}} = \Delta \sigma_{\text{C}}^m 2 \times 10^6 \quad \text{with } m = 3 \text{ for } N \leq 5 \times 10^6, \text{ see Figure 7.1}$$

$$\Delta \tau_{\text{R}}^m N_{\text{R}} = \Delta \tau_{\text{C}}^m 2 \times 10^6 \quad \text{with } m = 5 \text{ for } N \leq 10^8, \text{ see Figure 7.2}$$

$$\Delta \sigma_{\text{D}} = \left( \frac{2}{5} \right)^{1/3} \Delta \sigma_{\text{C}} = 0,737 \Delta \sigma_{\text{C}} \quad \text{is the constant amplitude fatigue limit, see Figure 7.1, and}$$

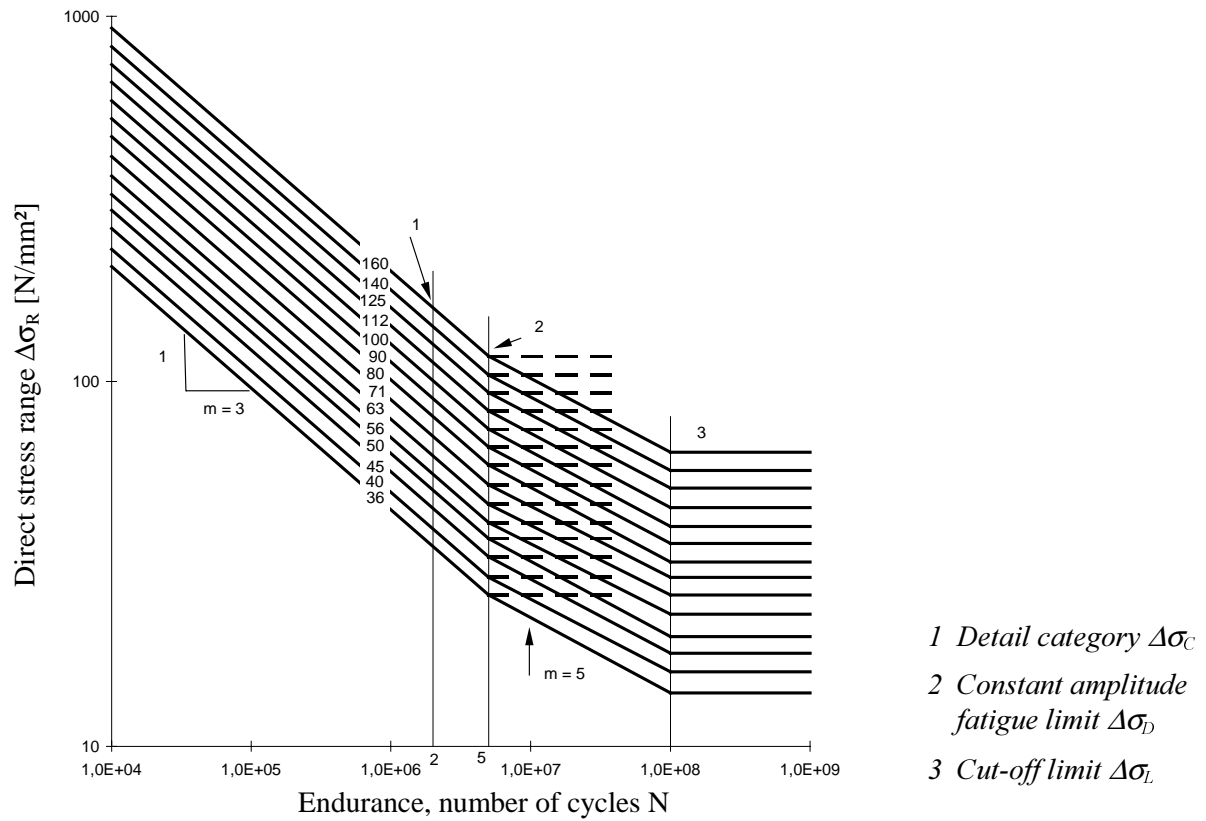
$$\Delta \tau_{\text{L}} = \left( \frac{2}{100} \right)^{1/5} \Delta \tau_{\text{C}} = 0,457 \Delta \tau_{\text{C}} \quad \text{is the cut off limit, see Figure 7.2.}$$

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

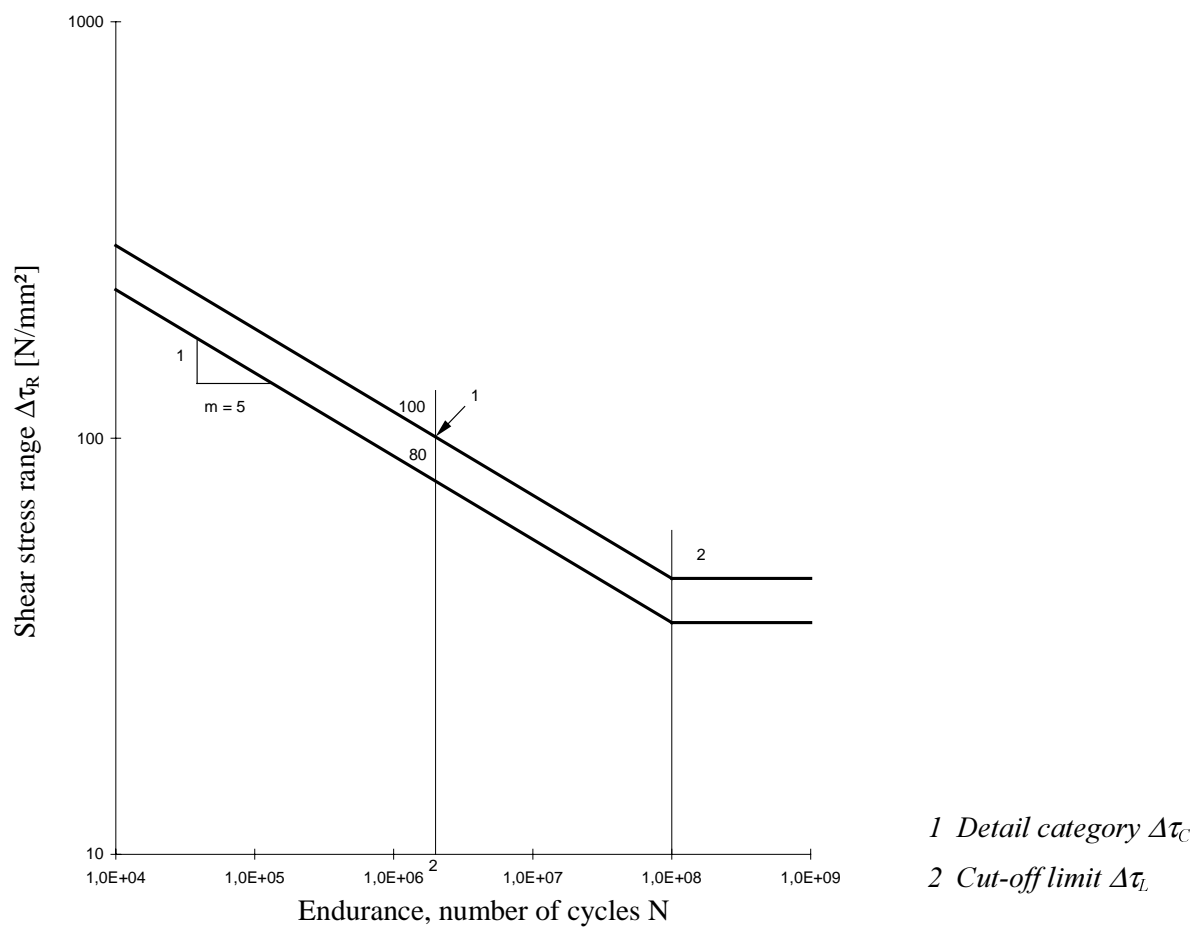
$$\Delta \sigma_{\text{R}}^m N_{\text{R}} = \Delta \sigma_{\text{C}}^m 2 \times 10^6 \quad \text{with } m = 3 \text{ for } N \leq 5 \times 10^6$$

$$\Delta \sigma_{\text{R}}^m N_{\text{R}} = \Delta \sigma_{\text{D}}^m 5 \times 10^6 \quad \text{with } m = 5 \text{ for } 5 \times 10^6 \leq N_{\text{R}} \leq 10^8$$

$$\Delta \sigma_{\text{L}} = \left( \frac{5}{100} \right)^{1/5} \Delta \sigma_{\text{D}} = 0,549 \Delta \sigma_{\text{D}} \quad \text{is the cut off limit, see Figure 7.1.}$$



**Figure 7.1: Fatigue strength curves for direct stress ranges**

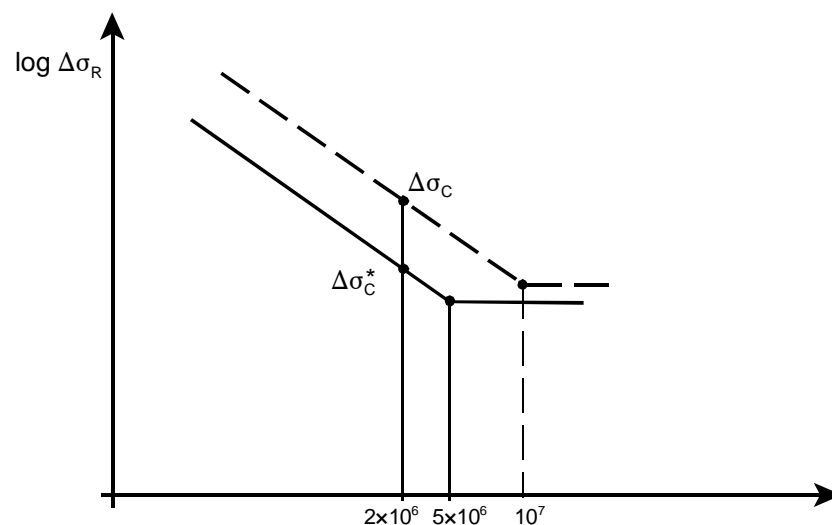


**Figure 7.2: Fatigue strength curves for shear stress ranges**

**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  $2 \times 10^6$  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  $\Delta\sigma_C^*$**

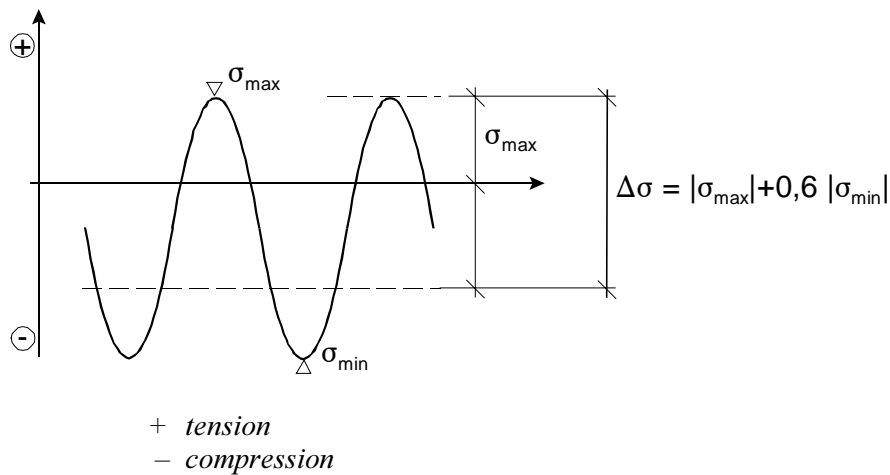
- (4) Detail categories  $\Delta\sigma_C$  and  $\Delta\tau_C$  for nominal stresses are given in
- Table 8.1 for plain members and mechanically fastened joints
  - Table 8.2 for welded built-up sections
  - Table 8.3 for transverse butt welds
  - Table 8.4 for weld attachments and stiffeners
  - Table 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.



**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:

$$\Delta\sigma_{C,red} = k_s \Delta\sigma_C \quad (7.1)$$

## 8 Fatigue verification

- (1) Nominal, modified nominal or geometric stress ranges due to frequent loads  $\psi_1 Q_k$  (see EN 1990) shall not exceed

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

- (2) It shall 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 shall be verified that:


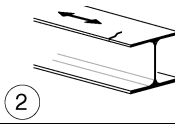
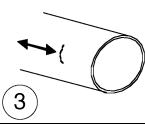


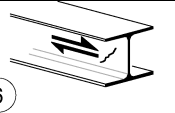
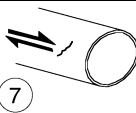
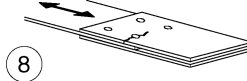
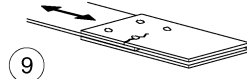
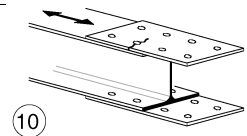
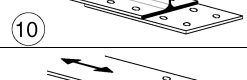
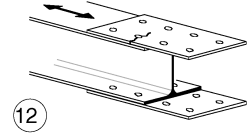
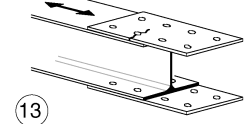
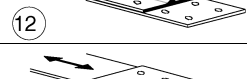
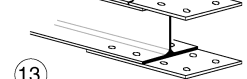
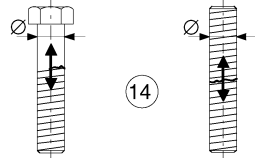
$$\left( \frac{\gamma_{Ff} \Delta\sigma_{E,2}}{\Delta\sigma_C / \gamma_{Mf}} \right)^3 + \left( \frac{\gamma_{Ff} \Delta\tau_{E,2}}{\Delta\tau_C / \gamma_{Mf}} \right)^5 \leq 1,0 \quad (8.3)$$

- (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.

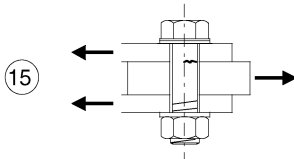
**NOTE** The National Annex may give information on the use of Annex A.



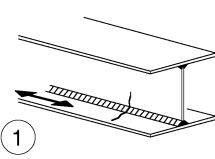
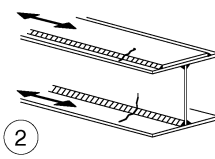
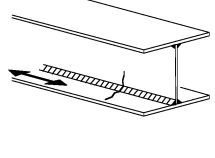
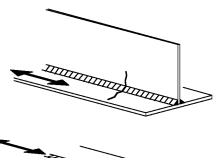
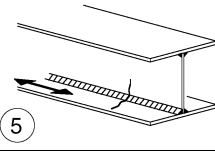
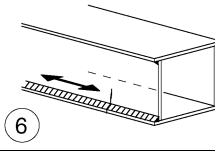

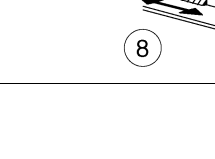

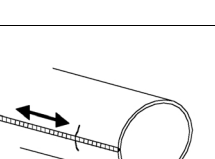
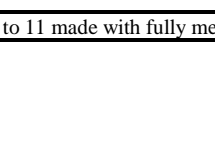
**Table 8.1: Plain members and mechanically fastened joints**

Detail category	Constructional detail	Description	Requirements
160	<p><b>NOTE</b> The fatigue strength curve associated with category 160 is the highest. No detail can reach a better fatigue strength at any number of cycles.</p>   	<p><u>Rolled and extruded products:</u></p> <p>1) Plates and flats; 2) Rolled sections; 3) Seamless hollow sections, either rectangular or circular.</p>	<p><u>Details 1) to 3):</u></p> <p>Sharp edges, surface and rolling flaws to be improved by grinding until removed and smooth transition achieved.</p>
140		<p><u>Sheared or gas cut plates:</u></p> <p>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.</p>	<p>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 <math>\leq 1/4</math>) or evaluated using the appropriate stress concentration factors. - No repair by weld refill.</p>
125			
100 m = 5	 	<p>6) and 7) Rolled and extruded products as in details 1), 2), 3)</p>	<p><u>Details 6) and 7):</u></p> <p><math>\Delta\tau</math> calculated from: <math>\tau = \frac{V S(t)}{I t}</math></p>
For detail 1 – 5 made of weathering steel use the next lower category.			
112		<p>8) Double covered symmetrical joint with preloaded high strength bolts. 8) Double covered symmetrical joint with preloaded injection bolts.</p>	<p>8) <math>\Delta\sigma</math> to be calculated on the gross cross-section. 8) ... gross cross-section.</p> <p><u>For bolted connections (Details 8) to 13)) in general:</u></p> <p>End distance: <math>e_1 \geq 1,5 d</math></p>
90		<p>9) Double covered joint with preloaded fitted bolts.</p>	<p>9) ... net cross-section.</p> <p>Edge distance: <math>e_2 \geq 1,5 d</math></p>
		<p>9) Double covered joint with non preloaded injection bolts. 10) One sided connection with preloaded high strength bolts.</p>	<p>9) ... net cross-section. 10) ... gross cross-section.</p> <p>Spacing: <math>p_1 \geq 2,5 d</math></p>
		<p>10) One sided connection with preloaded injection bolts.</p>	<p>10) ... gross cross-section.</p> <p>Spacing: <math>p_2 \geq 2,5 d</math></p>
		<p>11) Structural element with holes subject to bending and axial forces</p>	<p>11) ... net cross-section.</p> <p>Detailing to EN 1993-1-8, Figure 3.1</p>
80		<p>12) One sided connection with fitted bolts.</p>	<p>12) ... net cross-section.</p>
		<p>12) One sided connection with non-preloaded injection bolts.</p>	<p>12) ... net cross-section.</p>
50		<p>13) One sided or double covered symmetrical connection with non-preloaded bolts in normal clearance holes. No load reversals.</p>	<p>13) ... net cross-section.</p>
50	<p>size effect for <math>\varnothing &gt; 30\text{mm}</math>: <math>k_s = (30/\varnothing)^{0,25}</math></p> 	<p>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 <math>k_s</math>.</p>	<p>14) <math>\Delta\sigma</math> 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.</p>

**Table 8.1 (continued): Non-welded details**

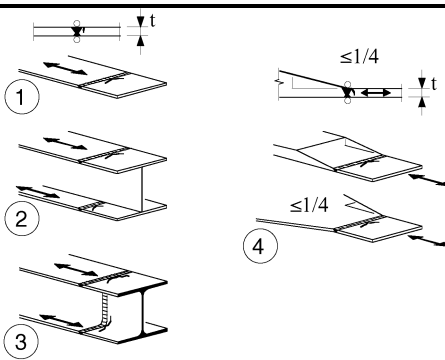
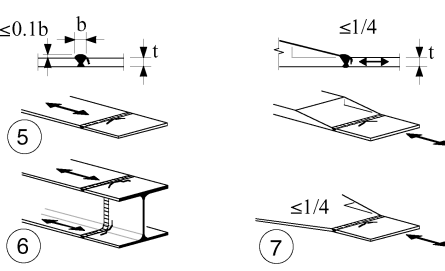
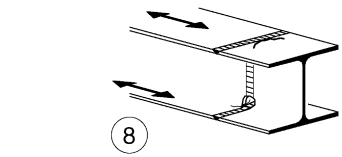
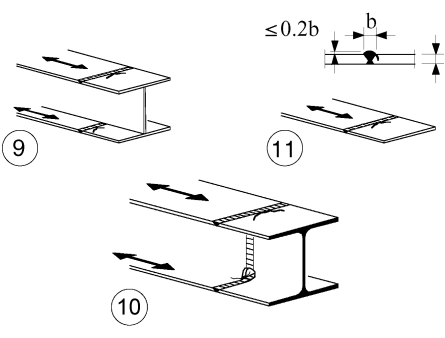
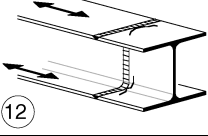
Detail category	Constructional detail	Description	Requirements
100 m=5		<u>Bolts in single or double shear</u> Thread not in the shear plane 15) - Fitted bolts - normal bolts without load reversal (bolts of grade 5.6, 8.8 or 10.9)	15) $\Delta\tau$ calculated on the shank area of the bolt.

**Table 8.2: Welded built-up sections**

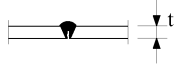

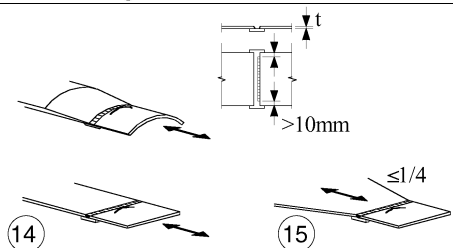
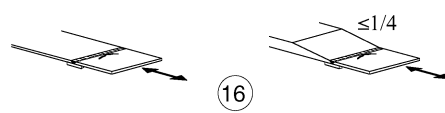
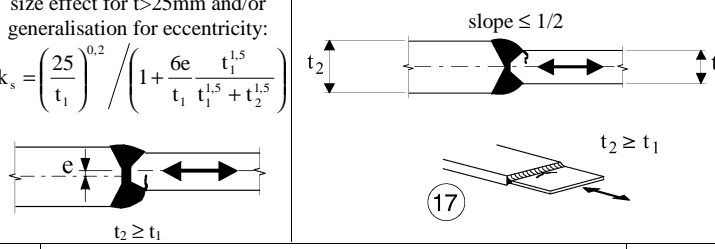
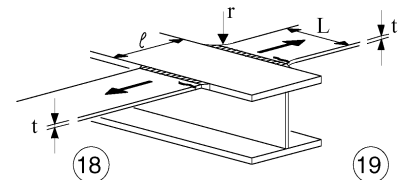
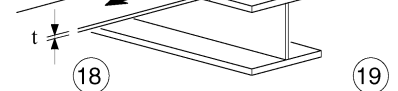
Detail category	Constructional detail	Description	Requirements
125		<u>Continuous longitudinal welds:</u> 1) Automatic butt welds carried out from both sides. 2) Automatic fillet welds. Cover plate ends to be checked using detail 6) or 7) in Table 8.5.	Details 1) and 2): No stop/start position is permitted except when the repair is performed by a specialist and inspection is carried out to verify the proper execution of the repair.
112			
112		3) Automatic fillet or butt weld carried out from both sides but containing stop/start positions. 4) Automatic butt welds made from one side only, with a continuous backing bar, but without stop/start positions.	4) When this detail contains stop/start positions category 100 to be used.
100			
100		5) Manual fillet or butt weld. 6) Manual or automatic 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			
100		7) Repaired automatic 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) $\Delta\sigma$ 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) $\Delta\sigma$ 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 longitudinal seam weld without stop/start positions in hollow sections	11) Free from defects outside the tolerances of EN 1090. Wall thickness $t \leq 12,5$ mm.
125		11) Automatic longitudinal seam weld without stop/start positions in hollow sections	11) Wall thickness $t > 12,5$ mm.
90		11) with stop/start positions	

For details 1 to 11 made with fully mechanized welding the categories for automatic welding apply.

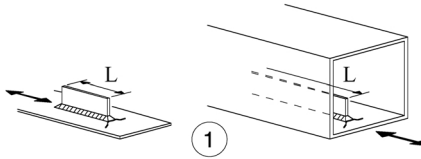
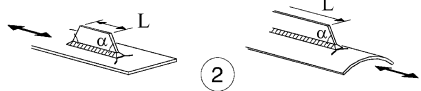
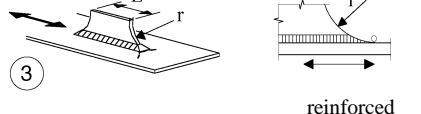
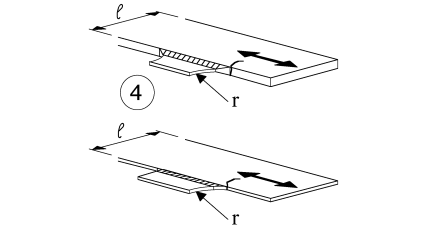
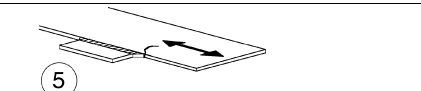
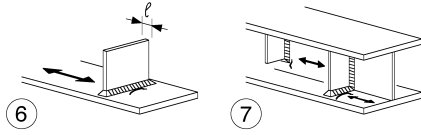
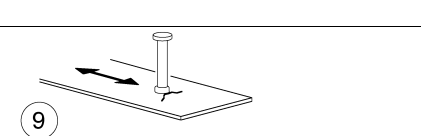
**Table 8.3: Transverse butt welds**

Detail category	Constructional detail	Description	Requirements
112	<p>size effect for <math>t &gt; 25\text{mm}</math>: <math>k_s = (25/t)^{0.2}</math></p> 	<p><u>Without backing bar:</u></p> <ol style="list-style-type: none"> <li>1) Transverse splices in plates and flats.</li> <li>2) Flange and web splices in plate girders before assembly.</li> <li>3) Full cross-section butt welds of rolled sections without cope holes.</li> <li>4) Transverse splices in plates or flats tapered in width or in thickness, with a slope <math>\leq 1/4</math>.</li> </ol>	<ul style="list-style-type: none"> <li>- All welds ground flush to plate surface parallel to direction of the arrow.</li> <li>- Weld run-on and run-off pieces to be used and subsequently removed, plate edges to be ground flush in direction of stress.</li> <li>- Welded from both sides; checked by NDT.</li> </ul> <p><u>Detail 3):</u> Applies only to joints of rolled sections, cut and rewelded.</p>
90	<p>size effect for <math>t &gt; 25\text{mm}</math>: <math>k_s = (25/t)^{0.2}</math></p> 	<ol style="list-style-type: none"> <li>5) Transverse splices in plates or flats.</li> <li>6) Full cross-section butt welds of rolled sections without cope holes.</li> <li>7) Transverse splices in plates or flats tapered in width or in thickness with a slope <math>\leq 1/4</math>. Translation of welds to be machined notch free.</li> </ol>	<ul style="list-style-type: none"> <li>- The height of the weld convexity to be not greater than 10% of the weld width, with smooth transition to the plate surface.</li> <li>- Weld run-on and run-off pieces to be used and subsequently removed, plate edges to be ground flush in direction of stress.</li> <li>- Welded from both sides; checked by NDT.</li> </ul> <p><u>Details 5 and 7:</u> Welds made in flat position.</p>
90	<p>size effect for <math>t &gt; 25\text{mm}</math>: <math>k_s = (25/t)^{0.2}</math></p> 	<ol style="list-style-type: none"> <li>8) As detail 3) but with cope holes.</li> </ol>	<ul style="list-style-type: none"> <li>- All welds ground flush to plate surface parallel to direction of the arrow.</li> <li>- Weld run-on and run-off pieces to be used and subsequently removed, plate edges to be ground flush in direction of stress.</li> <li>- Welded from both sides; checked by NDT.</li> <li>- Rolled sections with the same dimensions without tolerance differences</li> </ul>
80	<p>size effect for <math>t &gt; 25\text{mm}</math>: <math>k_s = (25/t)^{0.2}</math></p> 	<ol style="list-style-type: none"> <li>9) Transverse splices in welded plate girders without cope hole.</li> <li>10) Full cross-section butt welds of rolled sections with cope holes.</li> <li>11) Transverse splices in plates, flats, rolled sections or plate girders.</li> </ol>	<ul style="list-style-type: none"> <li>- The height of the weld convexity to be not greater than 20% of the weld width, with smooth transition to the plate surface.</li> <li>- Weld not ground flush</li> <li>- Weld run-on and run-off pieces to be used and subsequently removed, plate edges to be ground flush in direction of stress.</li> <li>- Welded from both sides; checked by NDT.</li> </ul> <p><u>Detail 10:</u> The height of the weld convexity to be not greater than 10% of the weld width, with smooth transition to the plate surface.</p>
63		<ol style="list-style-type: none"> <li>12) Full cross-section butt welds of rolled sections without cope hole.</li> </ol>	<ul style="list-style-type: none"> <li>- Weld run-on and run-off pieces to be used and subsequently removed, plate edges to be ground flush in direction of stress.</li> <li>- Welded from both sides.</li> </ul>

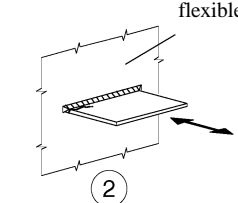
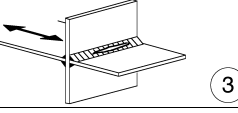
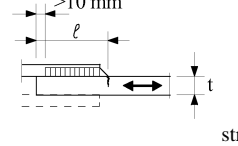

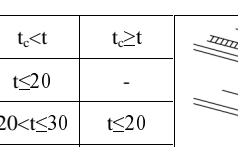
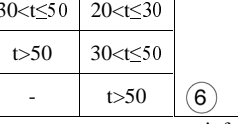
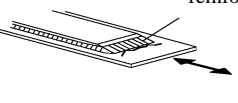

**Table 8.3 (continued): Transverse butt welds**

Detail category	Constructional detail		Description	Requirements
36			13) Butt welds made from one side only.	13) Without backing strip.
71	size effect for $t > 25\text{mm}$ : $k_s = (25/t)^{0.2}$		13) Butt welds made from one side only when full penetration checked by appropriate NDT.	
71	size effect for $t > 25\text{mm}$ : $k_s = (25/t)^{0.2}$		<u>With backing strip:</u> 14) Transverse splice. 15) Transverse butt weld tapered in width or thickness with a slope $\leq 1/4$ . Also valid for curved plates.	<u>Details 14) and 15):</u> Fillet welds attaching the backing strip to terminate $\geq 10\text{ mm}$ from the edges of the stressed plate. Tack welds inside the shape of butt welds.
50	size effect for $t > 25\text{mm}$ : $k_s = (25/t)^{0.2}$		16) Transverse butt weld on a permanent backing strip tapered in width or thickness with a slope $\leq 1/4$ . Also valid for curved plates.	16) Where backing strip fillet welds end $< 10\text{ mm}$ from the plate edge, or if a good fit cannot be guaranteed.
71	size effect for $t > 25\text{mm}$ and/or generalisation for eccentricity: $k_s = \left( \frac{25}{t_1} \right)^{0.2} \left/ \left( 1 + \frac{6e}{t_1} \frac{t_1^{1.5}}{t_1^{1.5} + t_2^{1.5}} \right) \right.$		17) Transverse butt weld, different thicknesses without transition, centrelines aligned.	
As detail 1 in Table 8.5			18) Transverse butt weld at intersecting flanges.	<u>Details 18) and 19)</u> 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	

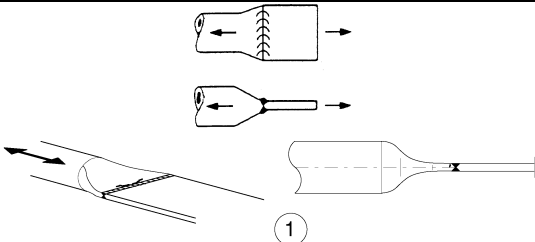
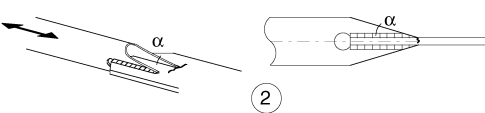
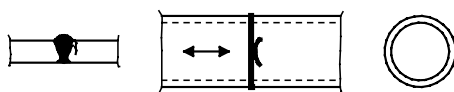
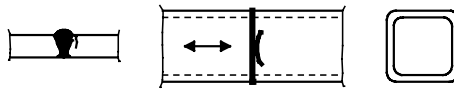
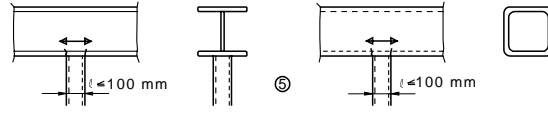
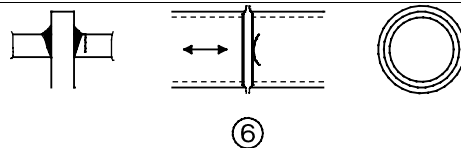
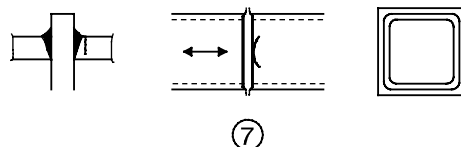
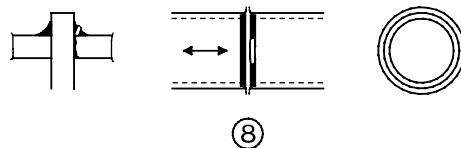
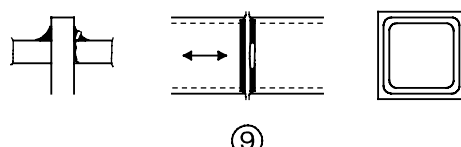
**Table 8.4: Weld attachments and stiffeners**

Detail category	Constructional detail		Description	Requirements
80	$L \leq 50\text{mm}$	 ①	<u>Longitudinal attachments:</u>  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	$50 < L \leq 80\text{mm}$			
63	$80 < L \leq 100\text{mm}$			
56	$L > 100\text{mm}$			
71	$L > 100\text{mm}$ $\alpha < 45^\circ$	 ②	2) Longitudinal attachments to plate or tube.	
80	$r > 150\text{mm}$	 ③ reinforced	3) Longitudinal fillet welded gusset with radius transition to plate or tube; end of fillet weld reinforced (full penetration); length of reinforced weld $> r$ .	<u>Details 3) and 4):</u>  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.
90	$\frac{r}{L} \geq \frac{1}{3}$ or $r > 150\text{mm}$	 ④  L: attachment length as above	4) Gusset plate, welded to the edge of a plate or beam flange.	
71	$\frac{1}{6} \leq \frac{r}{L} \leq \frac{1}{3}$			
50	$\frac{r}{L} < \frac{1}{6}$			
40		 ⑤	5) As welded, no radius transition.	
80	$\ell \leq 50\text{mm}$	 ⑥	<u>Transverse attachments:</u>  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.	<u>Details 6) and 7):</u>  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	$50 < \ell \leq 80\text{mm}$			
80		 ⑧	9) The effect of welded shear studs on base material.	

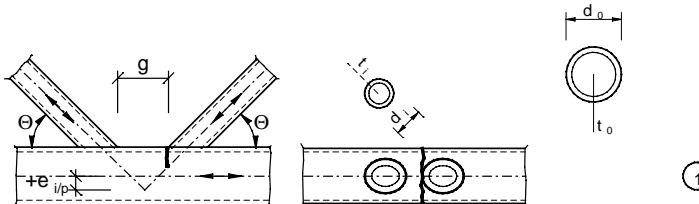
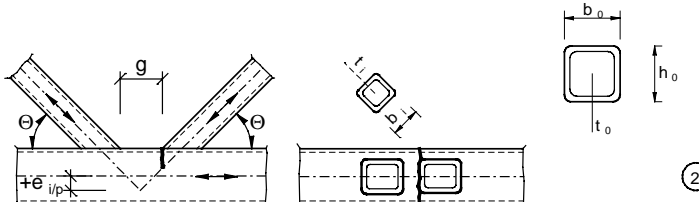
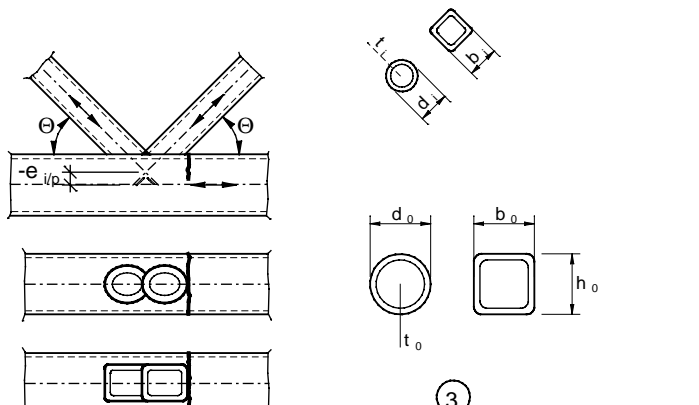
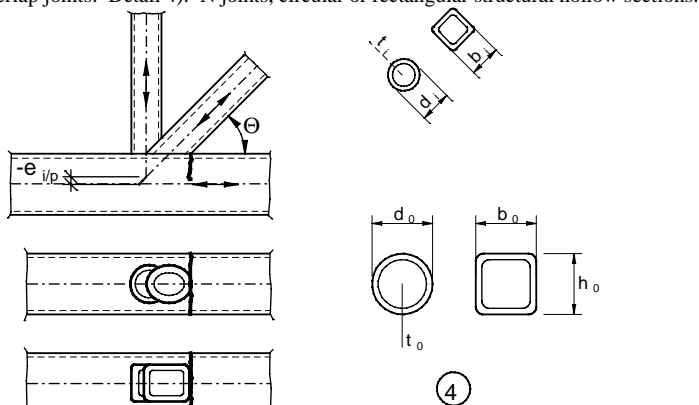
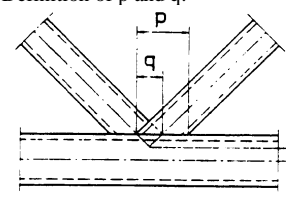
**Table 8.5: Load carrying welded joints**

Detail category	Constructional detail		Description	Requirements
80	$l < 50$ mm	all $t$ [mm]	<u>Cruciform and Tee joints:</u>  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 $\Delta\sigma$ , 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 $\Delta\sigma$ in the load-carrying plate.
71	$50 < l \leq 80$	all $t$		
63	$80 < l \leq 100$	all $t$		
56	$100 < l \leq 120$	all $t$		
56	$l > 120$	$t \leq 20$		
50	$120 < l \leq 200$	$t > 20$		
45	$200 < l \leq 300$	$20 < t \leq 30$		
45	$l > 300$	$t > 30$	2) Toe failure from edge of attachment to plate, with stress peaks at weld ends due to local plate deformations.	Details 1) to 3): The misalignment of the load-carrying plates should not exceed 15 % of the thickness of the intermediate plate.
40	$l > 300$	$t > 50$		
As detail 1 in Table 8.5	flexible panel		3) Root failure in partial penetration Tee-butt joints or fillet welded joint and effective full penetration in Tee-butt joint.	4) $\Delta\sigma$ in the main plate to be calculated on the basis of area shown in the sketch.  5) $\Delta\sigma$ to be calculated in the overlapping plates.
36*			Overlapped welded joints:	
As detail 1 in Table 8.5			4) Fillet welded lap joint.	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*			5) Fillet welded lap joint.	
56*	$t_c < t$	$t_c \geq t$	<u>Cover plates in beams and plate girders:</u>  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).
50	$t \leq 20$	-		
45	$20 < t \leq 30$	$t \leq 20$		
40	$30 < t \leq 50$	$20 < t \leq 30$		
36	$t > 50$	$30 < t \leq 50$		
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 $t_c > 20$ mm, front of plate at the end ground with a slope $< 1$ in 4.
80			8) Continuous fillet welds transmitting a shear flow, such as web to flange welds in plate girders.	8) $\Delta\tau$ to be calculated from the weld throat area.  9) $\Delta\tau$ 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.
m=5			9) Fillet welded lap joint.	
see EN 1994-2 (90 m=8)			<u>Welded stud shear connectors:</u> 10) For composite application	10) $\Delta\tau$ 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. $\Delta\sigma$ computed in tube.
40			12) Tube socket joint with fillet welds.	12) $\Delta\sigma$ computed in tube.

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

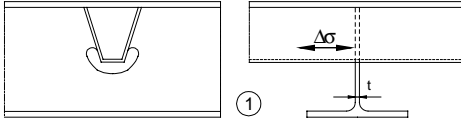
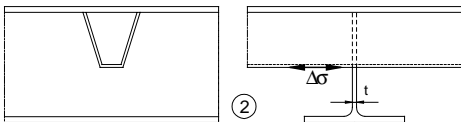
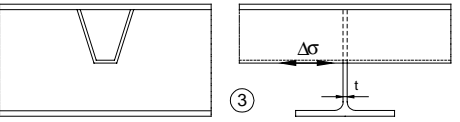
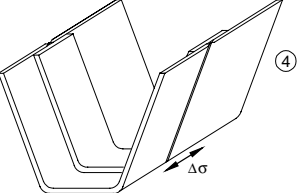
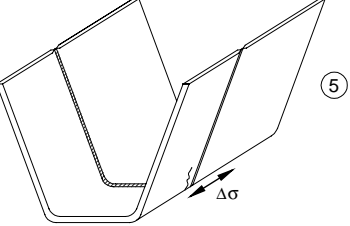
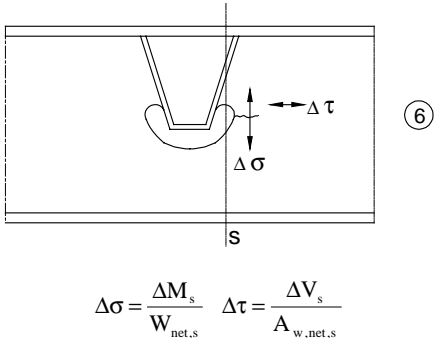
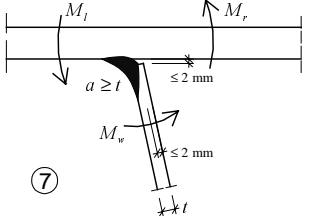
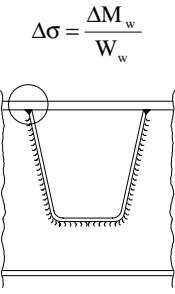
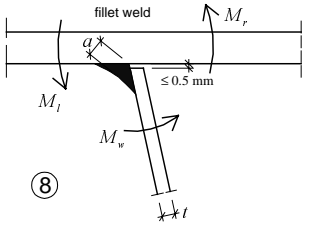
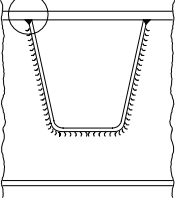
Detail category	Constructional detail		Description	Requirements
71			1) Tube-plate joint, tubes flattened, butt weld (X-groove)	1) $\Delta\sigma$ computed in tube. Only valid for tube diameter less than 200 mm.
71	$\alpha \leq 45^\circ$		2) Tube-plate joint, tube slitted and welded to plate. Holes at end of slit.	2) $\Delta\sigma$ computed in tube. Shear cracking in the weld should be verified using Table 8.5, detail 8).
63	$\alpha > 45^\circ$			
71	③		<u>Transverse butt welds:</u> 3) Butt-welded end-to-end connections between circular structural hollow sections.	<u>Details 3) and 4):</u> - 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.
56	④		4) Butt-welded end-to-end connections between rectangular structural hollow sections.	- Classify 2 detail categories higher if $t > 8$ mm.
71		⑤	<u>Welded attachments:</u> 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		⑥	<u>Welded splices:</u> 6) Circular structural hollow sections, butt-welded end-to-end with an intermediate plate.	<u>Details 6) and 7):</u> - Load-carrying welds. - Welds inspected and found free from defects outside the tolerances of EN 1090.
45		⑦	7) Rectangular structural hollow sections, butt welded end-to-end with an intermediate plate.	- Classify 1 detail category higher if $t > 8$ mm.
40		⑧	8) Circular structural hollow sections, fillet-welded end-to-end with an intermediate plate.	<u>Details 8) and 9):</u> - Load-carrying welds. - Wall thickness $t \leq 8$ mm.
36		⑨	9) Rectangular structural hollow sections, fillet-welded end-to-end with an intermediate plate.	

**Table 8.7: Lattice girder node joints**

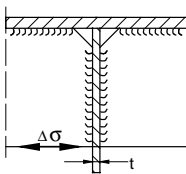
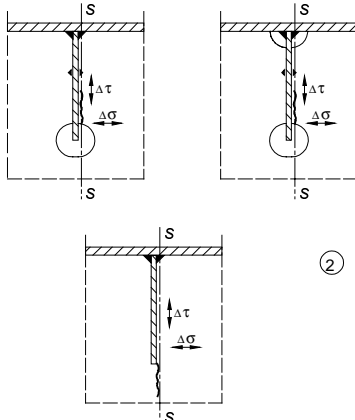
Detail category	Constructional detail		Requirements
90 m=5 $\frac{t_o}{t_i} \geq 2,0$	Gap joints: Detail 1): K and N joints, circular structural hollow sections: 		<u>Details 1) and 2):</u> - Separate assessments needed for the chords and the braces. - For intermediate values of the ratio $t_o/t_i$ interpolate linearly between detail categories. - Fillet welds permitted for braces with wall thickness $t \leq 8$ mm. - $t_o$ and $t_i \leq 8$ mm - $35^\circ \leq \theta \leq 50^\circ$ - $b_o/t_o \times t_o/t_i \leq 25$ - $d_o/t_o \times t_o/t_i \leq 25$ - $0,4 \leq b_i/b_o \leq 1,0$ - $0,25 \leq d_i/d_o \leq 1,0$ - $b_o \leq 200$ mm - $d_o \leq 300$ mm - $-0,5h_o \leq e_{i/p} \leq 0,25h_o$ - $-0,5d_o \leq e_{i/p} \leq 0,25d_o$ - $e_{o/p} \leq 0,02b_o$ or $\leq 0,02d_o$  <u>Detail 2):</u> $0,5(b_o - b_i) \leq g \leq 1,1(b_o - b_i)$ and $g \geq 2t_o$
45 m=5 $\frac{t_o}{t_i} = 1,0$			
71 m=5 $\frac{t_o}{t_i} \geq 2,0$	Gap joints: Detail 2): K and N joints, rectangular structural hollow sections: 		[e <sub>o/p</sub> is out-of-plane eccentricity]  <u>Detail 2):</u> $0,5(b_o - b_i) \leq g \leq 1,1(b_o - b_i)$ and $g \geq 2t_o$
36 m=5 $\frac{t_o}{t_i} = 1,0$			
71 m=5 $\frac{t_o}{t_i} \geq 1,4$	Overlap joints: Detail 3): K joints, circular or rectangular structural hollow sections: 		<u>Details 3) and 4):</u> - 30 % $\leq$ overlap $\leq$ 100 % - overlap = $(q/p) \times 100$ % - Separate assessments needed for the chords and the braces. - For intermediate values of the ratio $t_o/t_i$ interpolate linearly between detail categories. - Fillet welds permitted for braces with wall thickness $t \leq 8$ mm. - $t_o$ and $t_i \leq 8$ mm - $35^\circ \leq \theta \leq 50^\circ$ - $b_o/t_o \times t_o/t_i \leq 25$ - $d_o/t_o \times t_o/t_i \leq 25$ - $0,4 \leq b_i/b_o \leq 1,0$ - $0,25 \leq d_i/d_o \leq 1,0$ - $b_o \leq 200$ mm - $d_o \leq 300$ mm - $-0,5h_o \leq e_{i/p} \leq 0,25h_o$ - $-0,5d_o \leq e_{i/p} \leq 0,25d_o$ - $e_{o/p} \leq 0,02b_o$ or $\leq 0,02d_o$  [e <sub>o/p</sub> is out-of-plane eccentricity]
56 m=5 $\frac{t_o}{t_i} = 1,0$			
71 m=5 $\frac{t_o}{t_i} \geq 1,4$	Overlap joints: Detail 4): N joints, circular or rectangular structural hollow sections: 		[e <sub>o/p</sub> is out-of-plane eccentricity]  Definition of p and q: 
50 m=5 $\frac{t_o}{t_i} = 1,0$			



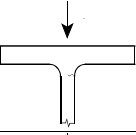
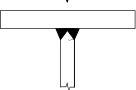
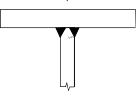
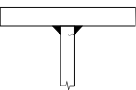
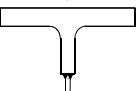
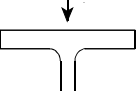
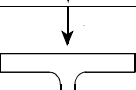
**Table 8.8: Orthotropic decks – closed stringers**

Detail category	Constructional detail		Description	Requirements
80	$\leq 12\text{mm}$		1) Continuous longitudinal stringer, with additional cutout in cross girder.	1) Assessment based on the direct stress range $\Delta\sigma$ in the longitudinal stringer.
71	$> 12\text{mm}$			
80	$\leq 12\text{mm}$		2) Continuous longitudinal stringer, no additional cutout in cross girder.	2) Assessment based on the direct stress range $\Delta\sigma$ in the stringer.
71	$> 12\text{mm}$			
36			3) Separate longitudinal stringer each side of the cross girder.	3) Assessment based on the direct stress range $\Delta\sigma$ in the stringer.
71			4) Joint in rib, full penetration butt weld with steel backing plate.	4) Assessment based on the direct stress range $\Delta\sigma$ 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 $\Delta\sigma$ 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			
36		 $\Delta\sigma = \frac{\Delta M_s}{W_{\text{net},s}} \quad \Delta\tau = \frac{\Delta V_s}{A_{w,\text{net},s}}$	6) Connection of continuous longitudinal rib to cross girder.	6) Assessment based on $\Delta\sigma_{\text{eq}}$ combining the shear stress range $\Delta\tau$ and direct stress range $\Delta\sigma$ in the web, as an equivalent stress range: $\Delta\sigma_{\text{eq}} = \frac{1}{2} \left( \Delta\sigma + \sqrt{\Delta\sigma^2 + 4\Delta\tau^2} \right)$
71		 $\Delta\sigma = \frac{\Delta M_w}{W_w}$	7) Weld connecting deck plate to trapezoidal or V-section rib 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	$t \leq 12 \text{ mm}$	 ①	1) Connection of continuous longitudinal stringer to cross girder.	1) Assessment based on the direct stress range $\Delta\sigma$ in the stringer.
71	$t > 12 \text{ mm}$			
56	 ②		2) Connection of continuous longitudinal stringer to cross girder. $\Delta\sigma = \frac{\Delta M_s}{W_{\text{net},s}}$ $\Delta\tau = \frac{\Delta V_s}{A_{w,\text{net},s}}$ 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: $\Delta\sigma_{\text{eq}} = \frac{1}{2} \left( \Delta\sigma + \sqrt{\Delta\sigma^2 + 4\Delta\tau^2} \right)$

**Table 8.10: Top flange to web junction of runway beams**

Detail category	Constructional detail		Description	Requirements
160	 <p>①</p>		1) Rolled I- or H-sections	1) Vertical compressive stress range $\Delta\sigma_{\text{vert.}}$ in web due to wheel loads
71	 <p>②</p>		2) Full penetration tee-butt weld	2) Vertical compressive stress range $\Delta\sigma_{\text{vert.}}$ in web due to wheel loads
36*	 <p>③</p>		3) Partial penetration tee-butt welds, or effective full penetration tee-butt weld conforming with EN 1993-1-8	3) Stress range $\Delta\sigma_{\text{vert.}}$ in weld throat due to vertical compression from wheel loads
36*	 <p>④</p>		4) Fillet welds	4) Stress range $\Delta\sigma_{\text{vert.}}$ in weld throat due to vertical compression from wheel loads
71	 <p>⑤</p>		5) T-section flange with full penetration tee-butt weld	5) Vertical compressive stress range $\Delta\sigma_{\text{vert.}}$ in web due to wheel loads
36*	 <p>⑥</p>		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 $\Delta\sigma_{\text{vert.}}$ in weld throat due to vertical compression from wheel loads
36*	 <p>⑦</p>		7) T-section flange with fillet welds	7) Stress range $\Delta\sigma_{\text{vert.}}$ 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 standardised 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  $\gamma_{Ff}$  and the fatigue strength values  $\Delta\sigma_c$  divided by  $\gamma_{Mf}$  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:

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

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  $N_C = 2 \times 10^6$ .

## A.6 Verification formats

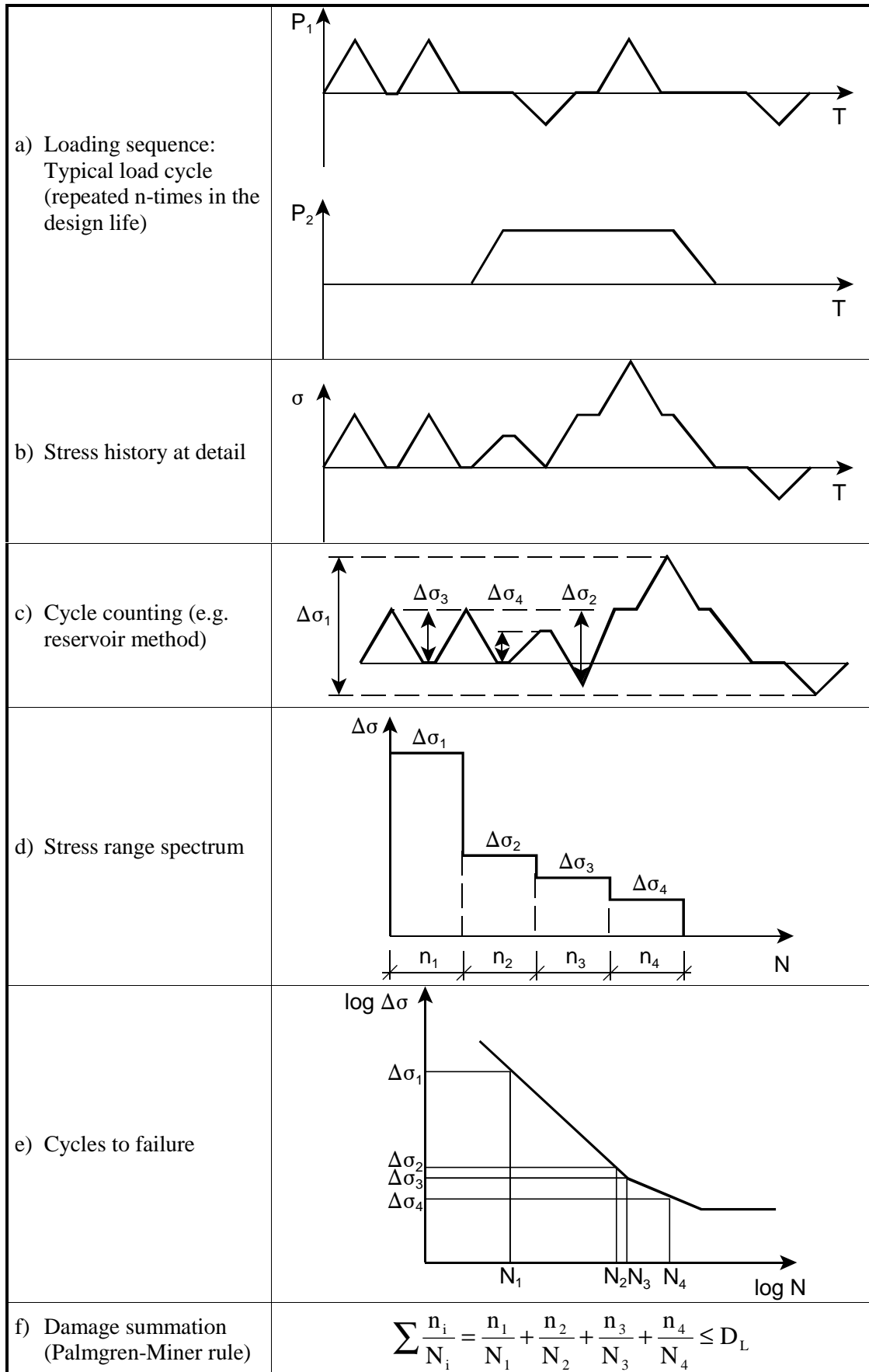
(1) The fatigue assessment based on damage accumulation shall meet the following criteria:

- based on damage accumulation:

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

- based on stress range:

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



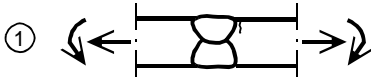
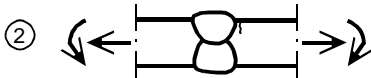
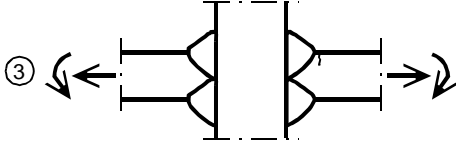
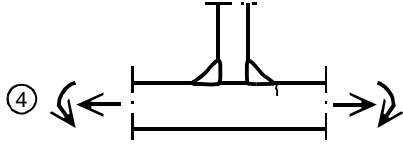
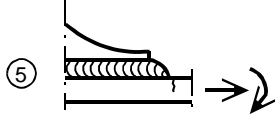
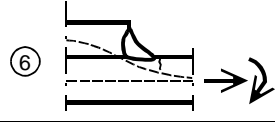
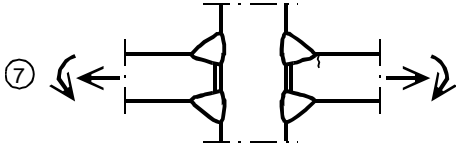
**Figure A.1: Cumulative damage method**

## 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 	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 	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 	3) Cruciform joint with full penetration K-butt welds.	3) - Weld toe angle $\leq 60^\circ$ . - For misalignment see NOTE 1.
100	④ 	4) Non load-carrying fillet welds.	4) - Weld toe angle $\leq 60^\circ$ . - See also NOTE 2.
100	⑤ 	5) Bracket ends, ends of longitudinal stiffeners.	5) - Weld toe angle $\leq 60^\circ$ . - See also NOTE 2.
100	⑥ 	6) Cover plate ends and similar joints.	6) - Weld toe angle $\leq 60^\circ$ . - See also NOTE 2.
90	⑦ 	7) Cruciform joints with load-carrying fillet welds.	7) - Weld toe angle $\leq 60^\circ$ . - 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.