**SLOVENSKI STANDARD**
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**Železniške naprave - Ocenjevanje odpornosti proti utrujenosti konstrukcije železniških vozil na podlagi kumulativnega poškodovanja**

Railway Applications - Fatigue strength assessment of railway vehicle structures based on cumulative damage

Bahnanwendungen - Betriebsfestigkeitsnachweis von Schienenfahrzeugstrukturen



Applications ferroviaires - Évaluation de la résistance à la fatigue des structures de véhicule ferroviaire basée sur la méthode des dommages cumulés



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# Railway Applications - Fatigue strength assessment of railway vehicle structures based on cumulative damage

Applications ferroviaires - Évaluation de la résistance à la fatigue des structures de véhicule ferroviaire basée sur la méthode des dommages cumulés

Bahnanwendungen - Betriebsfestigkeitsnachweis von Schienenfahrzeugstrukturen

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# European foreword

This document (prEN 17149:2017) has been prepared by Technical Committee CEN/TC 256 “Railway applications”, the secretariat of which is held by DIN.

This document is currently submitted to the CEN Enquiry.

# Introduction

For railway vehicle structures the fatigue strength assessment is necessary. In some cases it is sufficient to apply an endurance limit approach, i.e. assessing just against the peak stress level and not taking into account the number of cycles and spectrum shapes of the stress history. Traditionally this endurance limit approach is used in combination with the normative loads such as those defined in EN 12663 series or EN 13749.

A more detailed evaluation may be obtained using a cumulative damage fatigue assessment taking into consideration stress spectra with varying amplitudes and cycle numbers or stress time histories.

This European Standard provides the basic procedure and criteria to be applied for fatigue strength assessment based on cumulative damage approach.

The bibliography lists relevant documents that may be used for reference purposes.

The main body of the standard is based on the nominal stress approach, but the consideration of variable amplitudes and cycles counts according to methods described in this standard may equally be applied with the structural stress and the notch stress approach (additional information is included as informative annexes). A combination of these approaches may be appropriate.

This Standard defines a pragmatic methodology for undertaking fatigue assessments based on cumulative damage approach. In the application of this standard the use of more detailed information or other validated methods is permissible under the precondition of a valid justification.

# 1 Scope

The purpose of this European standard is to specify the procedure for fatigue strength assessment of railway vehicle structures based on cumulative damage.

This document is applicable to all rail vehicle structures, which are covered by EN 12663 series (car body) and EN 13749 (bogie frame).

It considers materials used for design of car bodies and bogie frames (steel, aluminium, castings and forgings) and the manufacturing according to the standards valid for railway applications.

NOTE As a manufacturing standard, EN 15085 series covers the welding of rail vehicle structures.

It is applicable for variable amplitude load data with total number of cycles higher than 10000 cycles.

This document is not applicable for:

— Corrosive conditions or

— Elevated temperature operation in the creep range.

A static strength assessment is outside the scope of this European Standard.

# 2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.



EN 15085-3:2007/AC:2009, *Railway applications - Welding of railway vehicles and components - Part 3: Design requirements*



BS 7608:2014+A1:2015, *Guide to fatigue design and assessment of steel products*

EN 755-2:2016, *Aluminium and aluminium alloys - Extruded rod/bar, tube and profiles - Part 2: Mechanical properties*

EN 485-2:2016, *Aluminium and aluminium alloys - Sheet, strip and plate - Part 2: Mechanical properties*

EN 586-2:1994, *Aluminium and aluminium alloys - Forgings - Part 2: Mechanical properties and additional property requirements*

EN 1706:2010, *Aluminium and aluminium alloys - Castings - Chemical composition and mechanical properties*

# 3 Terms, definitions, symbols and abbreviations

For the purposes of this document, the following terms and definitions apply.

## 3.1 Terms and definitions

**3.1.1**
**fatigue**
damage of a structural part by the process of initiation and gradual propagation of cracks caused by time varying repeated applications of stress

**3.1.2**
**fatigue action**
time varying repeated loading events which introduces a stress into a structural component

**3.1.3**
**fatigue stress**
stress caused by fatigue action

**3.1.4**
**fatigue resistance**
structural detail's resistance to fatigue actions expressed in terms of a S-N curve

**3.1.5**
**fatigue strength**
magnitude of stress range leading to a particular fatigue life

**3.1.6**
**component fatigue strength**
fatigue strength considering the specific design details

**3.1.7**
**design loads**
loads caused by fatigue action under the consideration of partial factor for loads

**3.1.8**
**stress spectrum**
fatigue stresses including the partial factor for actions (e.g. loads) and relevant to the fatigue strength assessment



**3.1.9**
**design value of fatigue strength**
strength of a structural detail under the consideration of partial factor for component fatigue strength and relevant to the fatigue strength assessment



**3.1.10**
**endurance limit**
constant amplitude fatigue below which no fatigue damage will occur

**3.1.11**
**nominal stress**
stress in a component adjacent to a potential crack location calculated in accordance with elasticity theory excluding all stress concentration effects (e.g. welds, openings, thickness changes)

**3.1.12**
**modified nominal stress**
nominal stress including macro-geometric effects

Note 1 to entry: The macro-geometric effects are the stress raising effects caused by the macro-geometry in the vicinity of the welded joints (e.g. concentrated load effects, misalignment, eccentricity} but disregarding stress raising effects of the weld joint itself.

**3.1.13**
**structural stress**
surface value of linearly distributed stress across the section thickness adjacent to a welded detail taking into account the effects of a structural discontinuity

Note 1 to entry: Structural stress is also referred to as geometric stress.

Note 2 to entry: The linear stress distribution includes the effects of gross structural discontinuities (e.g. presence of an attachment, aperture, change of cross-section, misalignment, intersection of members) and distortion-induced bending moments. However it excludes the notch effects of local structural discontinuities (e.g. weld toe, weld end) which give rise to nonlinear stress distributions across the section thickness.

**3.1.14**
**notch stress**
calculated stress for a notch of welded joint with a certain assumed notch radius

**3.1.15**
**reference values of fatigue strength**
fatigue strength for a particular welded structure detail related to $N_C$ = 2×10$^6$ cycles for a survival probability of $P_s$ = 97,5 %

**3.1.16**
**mean stress**
mean value of the algebraic sum of maximum and minimum alternating stress in a cycle



**3.1.17**
**residual stress**
permanent stresses in a structure caused by manufacture processes (e.g. rolling, cutting or welding) and with static equilibrium to itself



**3.1.18**
**membrane stress**
average normal stress which is uniform across the thickness of a plate or shell

**3.1.19**
**bending stress**
stress in a shell or plate-like part of a component with linear distribution across the thickness

**3.1.20**
**stress range**
algebraic difference between the maximum and minimum stresses in a cycle

**3.1.21**
**constant stress range**
constant magnitude stress fluctuation between a maximum and minimum value in a stress cycle

**3.1.22**
**variable stress range**
variable magnitude stress fluctuation between a maximum and minimum value in a stress cycle caused by an irregular load time history

**3.1.23**
**stress ratio**
ratio of minimum to maximum algebraic value of the stress in a particular stress cycle

**3.1.24**
**partial factor**
factor taking into account uncertainties of loads (forces), material, model and geometry

Note 1 to entry: In some of the referred documents the partial factor described with terms as "safety factor" as in EN 12663 series and EN 13749 or partial factor for variable actions (e.g. loads or forces) and for material, model and geometric uncertainties as in ISO 2394.

**3.1.25**
**stress cycle**
pattern of variation of stress at a point defined by the cycle counting method and consisting of a change in stress between a minimum (trough) and maximum (peak) values and back again

**3.1.26**
**S-N curve**
quantative relationship between the fatigue strength and the number of the cycles corresponding to a specific survival probability of the failure for a detail, derived from test data

**3.1.27**
**stress (range) spectrum**
tabular or graphical presentation of the number of occurrences (cumulative frequency) of different magnitudes produced by the load spectrum in the design life of a structure detail

**3.1.28**
**stress range block**
part of stress spectrum with constant stress range



**3.1.29**
**cut off limit**
fatigue strength under variable stress ranges below which the stress cycles are considered to be non-damaging

**3.1.30**
**damage equivalent stress range**
constant stress range which produces an equivalent fatigue damage to that resulted from a variable amplitude stress spectrum

**3.1.31**
**damage sum**
sum of fatigue damage produced by a variable amplitude stress spectrum

**3.1.32**
**cumulative damage sum**
linear cumulative damage summation based on the rule devised by Palmgren and Miner of the fatigue damage due to all cycles in a stress-range spectrum

**3.1.33**
**cumulative damage rule**
method for estimating fatigue life under variable amplitude loading from the constant S-N curve

Note 1 to entry: Often referred to as damage accumulation hypothesis, Miner's rule or Palmgren-Miner rule.

**3.1.34**
**proportional stresses**
principal stresses or stress components with constant directions and constant ratios of their values for time varying loads

**3.1.35**
**non-proportional stresses**
principal stresses or stress components with non-constant directions and non-constant ratios of their values for time varying loads

**3.1.36**
**degree of utilisation**
relationship between the design values of fatigue stress and of component fatigue strength expressed as a ratio of applied stress to component fatigue strength

**3.1.37**
**damage equivalent degree of utilisation**
relationship between the design values of fatigue stress and of component fatigue strength for an extrapolation of stress spectra with compliance to the assessment criteria

**3.1.38**
**misalignment**
axial and angular deformation (offset) of welded joints caused by detail design or/and by manufacture process



**3.1.39**
**NDT**
non-destructive test



**3.1.40**
**safety category**
consequences of failure of the single welded joint in respect to the effects on persons, facilities and the environment according to EN 15085-3

**3.1.41**
**weld performance class**
performance requirements of the welded joint with respect to weld quality requirements and weld inspection requirements as defined in EN 15085-3

Note 1 to entry: The weld performance class is abbreviated by “CP” (class of performance)

**3.1.42**
**weld inspection class**
inspections to be carried out for a given weld with respect to the frequency and the type of inspection (e.g. volumetric, surface or visual) as defined by the weld performance class according to EN 15085-3

Note 1 to entry: The weld inspection class is abbreviated by “CT” (class of testing)

### 3.2 Symbols and abbreviations

| | |
|---|---|
| A | ultimate elongation according to material standards |
| $A_{eq}$ | stress spectrum shape factor |
| a | throat thickness of fillet weld |
| $a_c$ | degree of utilisation for stress component |
| $a_f$ | degree of utilisation for plain axial stress state according to von Mises criterion |
| $a_m$ | mean stress sensitivity parameter |
| b | exponent in correction term for thickness in case of membrane and bending loading (e.g. in F.3) |
| $b_{EP}$ | distance from weld toe or root to the stress assessment location (evaluation point) for a nominal stress, modified nominal stress or structural stress assessment |
| $b_m$ | mean stress sensitivity parameter |
| $C_\sigma$ | constant in equation of S-N curve for normal stresses |
| $C_\tau$ | constant in equation of S-N curve for shear stresses |
| c | root gap length |
| $D_{it}$ | cumulative damage sum of stress spectrum |
| $D_m$ | admissible damage sum |
| $D_{m,min}$ | damage sum limit |
| $e$ | eccentricity between midpoint of weld throat and connected plates (amount of offset to misalignment) |
| $f_A$ | anisotropy factor for rolled sheets and extrusions with different strength in rolling or extrusion and transverse directions |
| $f_{bend}$ | enhancement factor for bending |
| $f_C$ | fatigue strength factor for casting |
| $f_{M,NDT}$ | enhancement factor for NDT-level during manufacture |
| $f_{m,\sigma}$ | mean stress factor for normal stress |
| $f_{m,\tau}$ | mean stress factor for shear stress |
| $f_{post}$ | enhancement factor for post weld improvement |
| $f_{R,\sigma}$ | fatigue strength factor for normal stresses |
| $f_{R,\tau}$ | ratio between fatigue strength of shear stress and of normal stress |
| $f_{res,\sigma}$ | residual stress factor for normal stress for stress difference between $R_\sigma = -1$ and $R_\sigma = 0{,}5$ under consideration of residual stress state |
| $f_{res,\tau}$ | residual stress factor for shear stress for stress difference between $R_\tau = -1$ and $R_\tau = 0{,}5$ under consideration of residual stress state |
| $f_{SR}$ | surface roughness factor |
| $f_{SR,\sigma}$ | surface roughness factor for normal stress assessment |
| $f_{SR,\tau}$ | surface roughness factor for shear stress assessment |
| $f_{struc}$ | factor for fatigue strength related to structural stress defined in Annex H |

$f_{thick}$ thickness correction factor

$h$ depth of partial penetration of butt weld

i number of blocks of stress spectrum

j total number of blocks of stress spectrum for which additionally holds: $x_{it} \times \Delta\sigma_i > \Delta\sigma_L$

$j_D$ basic partial factor according to [2]

$K_f$ fatigue notch factor

$K_t$ stress concentration factor

$K_w$ weld notch shape factor

L toe distance or sum of thickness or length of attachment and weld leg lengths

l length of attachment of welded structures or non-load carrying rectangular or circular pads or plates

$l_{SG}$ length of strain gauge measurement grid

$l_{SG,tot}$ total length of strain gauge including backing film

$M_\sigma$ mean stress sensitivity for normal stresses

$M_\tau$ mean stress sensitivity for shear stresses

m exponent of S-N curve

$m_1$ exponent of S-N curve before knee point



$m_2$ exponent of S-N curve beyond knee point

N number of cycles



$N_C$ number of cycles of reference value of fatigue strength

$N_D$ number of cycles of knee point of S-N curve

$N_{eq}$ number of cycles of damage equivalent stress spectrum

$N_L$ number of cycles of cut-off limit for stress range

$N_t$ total number of cycles in given stress spectrum with $\Delta\sigma_i > \Delta\sigma_{0M}$

n exponent in correction term for thickness in case of membrane loading

$n_i$ cycle number of stress range block *i* of stress spectrum

$P_s$ survival probability

R stress ratio

$R_{eH}$ upper yield strength

$R_m$ tensile strength relevant for determination of fatigue strength of non-welded structures

$R_{m,N}$ normative tensile strength according to material standards

$R_{m,S}$ nominal tensile strength according to drawing or to component specification

$R_{p0,2}$ 0,2 % proof strength

$R_z$ surface roughness

$R_\sigma$ stress ratio for normal stresses

$R_\tau$ stress ratio for shear stresses

r actual notch radius of weld toe or weld root

$r_{ref}$ reference notch radius of weld toe or weld root

t plate thickness

$t_{eff}$ effective plate thickness in correction term for thickness influence

$t_{ref}$ reference plate thickness relevant to reference values of the fatigue strength for welded structural details in Annex D and Annex E

$w$ width of loaded plates with welded longitudinal flat side gusset

$x_{Dm}$ scaling factor for stress range with iteration result $D_{it}(x_{Dm}) \equiv D_m$

$x_{it}$ scaling factor for stress range during iteration for determination of cumulative damage sum

$\gamma_L$ partial factor for stress spectrum based on design loads

$\gamma_M$ partial factor for design values of fatigue strength

$\gamma_{M,I}$ partial factor for inspection during maintenance

$\gamma_{M,S}$ partial factor for safety category

$\gamma_{M,V}$ partial factor for degree of validation process

$\gamma_{M,V,FT}$ partial factor considering validation of fatigue behaviour by fatigue testing

$\gamma_{M,V,ST}$ partial factor considering validation of calculated stress data by measured stress data

$\Delta\sigma$ normal stress range



$\Delta\sigma_b$ applied bending stress range



$\Delta\sigma_C$ reference value of fatigue strength of normal stress range for $N_C = 2 \times 10^6$ cycles, $R = 0,5$, $P_s = 97,5$ %



$\Delta\sigma_{C,e}$ reference value of fatigue strength for normal notch stress assessment

$\Delta\sigma_{C,S}$ reference value of fatigue strength for normal structural stress assessment

$\Delta\sigma_D$ normal stress range for component fatigue strength at knee point of S-N curve $N_D$

$\Delta\sigma_{D,C}$ normal stress range for reference value of fatigue strength at knee point of S-N curve $N_D$

$\Delta\sigma_e$ normal notch stress range transverse to weld line

$\Delta\sigma_{eq}$ normal stress range of damage equivalent stress spectrum

$\Delta\sigma_i$ normal stress range of stress spectrum block $i$ related to stress ratio $R = -1$

$\Delta\sigma_{i,RF}$ normal stress range of stress spectrum block $i$ as a result of rain flow counting

$\Delta\sigma_L$ cut-off limit for normal stress range at $N_L$

$\Delta\sigma_{OM}$ omission limit of normal stress range

$\Delta\sigma_{mem}$ applied membrane stress range

$\Delta\sigma_R$ component fatigue strength for normal stress range

$\Delta\sigma_{R,e}$ component fatigue strength for normal notch stress range

$\Delta\sigma_1$ largest normal stress range of stress spectrum

$\Delta\tau$ shear stress range

$\Delta\tau_C$ reference value of fatigue strength of shear stress range for $N_C = 2 \times 10^6$ cycles, $R = 0,5$, $P_s = 97,5$ %

$\Delta\tau_{,C,e}$ reference value of fatigue strength for shear notch stress assessment