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Eurocode 3 : Design of steel structures

Part 1.11 : Design of structures with tension components

Calcul des structures en acier

Partie 1.11 :

Calcul des structures à câbles
ou éléments tendus

Bemessung und Konstruktion von Stahlbauten

Teil 1.11 :

Bemessung und Konstruktion von Stahlbauten
mit Zuggliedern

CEN

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National annex for EN 1993-1-11

This standard gives alternative procedures, values and recommendations for classes with notes indicating where national choices may have to be made. Therefore the National Standard implementing EN 1993-1-11 should have a National Annex containing all Nationally Determined Parameters to be used for the design of steel structures to be constructed in the relevant country.

National choice is allowed in EN 1993-1-11 through:

- 2.3.6(1)
- 2.3.6(2)
- 2.4.1(1)
- 3.1(1)
- 4.4(2)
- 4.5(4)
- 6.2(2)
- 6.3.2(1)
- 6.3.4(1)
- 6.4.1(1)
- 7.2(2)
- A.4.5.1(1)
- A.4.5.2(1)

1 General

1.1 Scope

(1) This Part 11 of prEN1993-1 gives design rules for structures with tension components made of steel which due to their connections with the structure are adjustable and replaceable.

NOTE Due to the requirement of adjustability and replaceability such tension components are mostly prefabricated products delivered to site and installed into the structure as a whole. Tension components that are not adjustable or replaceable, e.g. air spun cables of suspension bridges, are outside the scope of this part though rules of this part may be applicable.

(2) This part also gives rules for determining the technical requirements for prefabricated tension components for a structure and for assessing their safety, serviceability and durability.

(3) This part deals with tension components as given in Table 1.1.

Table 1.1: Groups of tension components

Group	Main tensile element	Component
A	rod (bar)	tension rod (bar) system, prestressing bar
B	circular wire	spiral strand rope
	circular and Z-wires	full-locked coil rope
	circular wire and stranded wire	strand rope
C	circular wire	parallel wire strand (PWS)
	circular wire	bundle of parallel wires (air spun)
	seven wire (prestressing) strand	bundle of parallel strands

NOTE 1 Group A products comprising tension rod systems and bars in general have a single solid round cross section connected to end terminations by threads. They are mainly used as

- bracings for roofs, walls, girders
- stays for roof elements, pylons
- inline tensioning for steel-wooden truss and steel structures, space frames

NOTE 2 Group B products comprising spiral strand, ropes, full locked coil ropes and strand ropes are composed of wires which are anchored in sockets or other end terminations.

Spiral strand ropes are mainly used as

- stay cables for aerials, smoke stacks, masts and bridges
- carrying cables and edge cables for light weight structures
- hangers or suspenders for suspension bridges
- stabilizing cables for cable nets and wood and steel trusses
- hand-rail cables for banisters, balconies, bridge rails and guardrails

They are fabricated mainly in the diameter range of 5 mm to ~160 mm.

Full locked coil ropes are mainly used as

- stay cables, suspension cables and hangers for bridge construction
- suspension cables and stabilizing cables in cable trusses
- edge cables for cable nets
- stay cables for pylons, masts, aerials

They are fabricated in the diameter range of 20 to ~180 mm.

Structural wire ropes are mainly used as

- stay cables for masts, aerials
- hangers for suspension bridges
- damper / spacer tie cables between stay cables
- edge cables for fabric membranes
- rail cables for banister, balcony, bridge and guide rails.

NOTE 3 For Group B see EN 12385-2.

NOTE 4 Group C products comprising bundles of parallel wires and bundles of parallel strands need individual or collective anchoring and individual or collective protection.

Bundles of parallel wires are mainly used as stay cables, main cables for suspension bridges and external tendons.

Bundles of parallel strands are mainly used as stay cables or external tendons for concrete, composite and steel bridges.

(4) The types of termination dealt with in this part for Group B and C products are

- metal and resin socketing, see EN 13411-4
- socketing with cement grout
- ferrules and ferrule securing, see EN 13411-3
- swaged sockets and swaged fitting
- U-bolt wire rope grips, see EN 13411-5
- anchoring for bundles with wedges, cold formed button heads for wires and nuts for bars.

NOTE For terminology see 1.3 and Annex C.

1.2 Normative references

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

NOTE The Eurocodes were published as European Prestandards. The following European Standards which are published or in preparation are cited in normative clauses:

EN 10138 Prestressing steels

Part 1 General requirements

Part 2 Wire

Part 3 Strand

Part 4 Bars

EN 10244 Steel wire and wire products – Non-ferrous metallic coatings on steel wire

Part 1 General requirements

Part 2 Zinc and zinc alloy coatings

Part 3 Aluminium coatings

EN 10264 Steel wire and wire products – Steel wire for ropes

Part 1 General requirements

Part 2 Cold drawn non alloyed steel wire for ropes for general applications

Part 3 Cold drawn and cold profiled non alloyed steel wire for high tensile applications

Part 4 Stainless steel wires

EN 12385 Steel wire ropes – safety

Part 1 General requirements

Part 2 Definitions, designation and classification

Part 3 Information for use and maintenance

Part 4 Stranded ropes for general lifting applications

Part 10 Spiral ropes for general structural applications

EN 13411 Terminations for steel wire ropes – safety

Part 3 Ferrules and ferrule-securing

Part 4 Metal and resin socketing

Part 5 U-bolt wire rope grips

1.3 Terms and definitions

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

1.3.1
strand
an element of rope normally consisting of an assembly of wires of appropriate shape and dimensions laid helically in the same or opposite direction in one or more layers around a centre

1.3.2
stranded rope
an assembly of several strands laid helically in one or more layers around a core (single layer rope) or centre (rotation-resistant or parallel-closed rope)

1.3.3
spiral rope
an assembly of at least two layers of wires laid helically over a centre, usually around a wire

1.3.4
spiral strand rope
spiral rope comprising only round wires

1.3.5
full-locked coil rope
spiral rope having an outer layer of full lock (Z-shaped) wires

1.3.6
fill factor f
the ratio of the sum of the nominal metallic cross sectional areas of all the wires in a rope (A) and the circumscribed area (A_u) of the rope based on its nominal diameter (d)

1.3.7
spinning loss factor k
reduction factor for rope construction included in the breaking force factor K

1.3.8

breaking force factor (K)

an empirical factor used in the determination of minimum breaking force of a rope and obtained from the product of fill factor (f) for the rope class or construction, spinning loss factor (k) for the rope class or construction and the constant $\pi / 4$

$$K = \frac{\pi \; f \; k}{4}$$

> **NOTE** K-factors for the more common rope classes and constructions are given in the appropriate part of EN 12385.

1.3.9

minimum breaking force (F_{min})

specified value in kN, below which the measured breaking force (F_{min}) is not allowed to fall in a prescribed breaking force test and normally obtained by calculation from the product of the square of the nominal diameter (d) [mm], the rope grade (R_r) [N/mm²] and the breaking force factor (K)

$$F_{min} = \frac{d^2 \; R_r \; K}{1000}$$

1.3.10

rope grade (R_r)

a level of requirement of breaking force which is designated by a number (e.g. 1770 [N/mm²], 1960 [N/mm²])

> **NOTE** This does not imply that the actual tensile strength grades of the wires in the rope are necessarily of this grade.

1.3.11

unit weight (w)

value of selfweight of rope (w) [kN/(m mm²)] related to the metallic cross section (A_m) [mm²] and the unit length [m] taking account of the weight densities of steel and the corrosion protection system

1.3.12

cable

main tension component in a structure (e.g. a stay cable bridge) which may consist of a rope, strand or bundles of parallel wires or strands

1.4 Symbols

(1) For the purpose of this standard the following symbols apply.

Draft note: Will be added later.

2 Basis of Design

2.1 General

(1) The design of structures with tensile components shall be in accordance with the general rules given in EN 1990.

(2) The supplementary provisions for tensile components given in this chapter should be applied.

(3) As durability is a main concern for the design of tension components the following distinction according to exposure classes may be applied:

Table 2.1: Exposure classes

fatigue action	corrosion action	
	not exposed to external climate	exposed to external climate (rain)
no significant fatigue action	class 1	class 2
mainly axial fatigue action	class 3	class 4
axial and lateral fatigue actions (wind and wind & rain)	–	class 5

(4) It is assumed that the connections of tensile components to the structure are such that the components are replaceable and adjustable.

2.2 Requirements

(1) The following limit states should be considered in choosing tensile components:

1. ULS: Fracture of the component by reaching the design tension resistance taking account of durability, see section 6.

   NOTE The design tension resistance is determined from testing including durability provisions.

2. SLS: Limitation of stress levels and strain levels in the component for controlling the durability behaviour, see section 7.

   NOTE Because of the dominant durability aspect serviceability checks may be relevant and may cover ULS-verifications.

3. Fatigue: Limitation of stress ranges from axial load fluctuations as well as oscillations from wind or wind-rain, see sections 8 and 9.

   NOTE Due to the model uncertainties concerning the excitement mechanisms and the fatigue resistance of cables the fatigue check also presupposes a SLS-check, see section 7.

(2) Depending on the type and system of the structure, and the effects of possible detension of a tensile component below a minimum stress (e.g. uncontrolled stability or fatigue or damages to structural or non structural parts), the tensile components are mostly preloaded by deformations imposed to the structure (prestressing).

As a consequence the permanent actions are composed of actions from gravity loads “G” and prestress “P”, that shall be considered as a single permanent action “G+P” to which the relevant partial factors γ_{Gi} should be applied, see section 5.

NOTE For other materials and ways of construction other rules for combination of “G” and “P” may apply.

(3) Any attachments to prefabricated tensile components as saddles or clamps shall be designed for ultimate limit states and serviceability limit states using the hypothetical occurrence of breaking strength or proof strength of cables as actions, see section 6. For fatigue see EN 1993-1-9

NOTE Fatigue action on the ropes is controlled by the minimum radius in the saddle or anchorage area.

2.3 Actions

2.3.1 Selfweight of tensile components

(1) The characteristic value of selfweight of tensile components and their attachments shall be determined from the cross-sectional make up and the density of the materials unless data are given in the relevant part of EN 12385.

(2) For spiral strands, locked coil strands or structural wire ropes the following approximate expression for the nominal selfweight g_k may be used:

$$g_k = w\, A_m \tag{2.1}$$

where A_m is the metallic cross-section in mm²

w [kN/(m mm²)] is the unit weight that takes the weight densities of steel and of the corrosion protection system into account, see Table 2.2

(3) A_m may be determined from

$$A_m = \frac{\pi\, d^2}{4} f \tag{2.2}$$

where d is the external diameter of rope or strand, including sheathing for corrosion protection if used

f is the fill-factor, see Table 2.2

Table 2.2: Unit weight w and fill-factors f

		Fill factor f							unit weight $w \times 10^{-4}$ $\left[\frac{kN}{m \times mm^2}\right]$
		Core wires + 1 layer z-wires	Core wires + 2 layer z-wires	Core wires + >2 layer z-wires	Number of wire layers around core wire				
					1	2	3-6	>6	
1	Spiral strand ropes				0,77	0,76	0,75	0,73	0,83
2	Full locked coil ropes	0,81	0,84	0,88					0,83
3	Strand wire ropes with CWR				0,56				0,93

(4) For parallel wire ropes or parallel strand ropes the metallic cross section may be determined from

$$A_m = n\, a_m \tag{2.3}$$

where n is the number of identical wires or strands of which the rope is constituted

a_m is the cross section of a wire (derived from its diameter) or a (prestressing) strand (derived from the appropriate standard)

(5) For group C tension components the self weight should be determined from the steel weight of individual wires or strands and the weight of the corrosion protection (HDPE, wax etc.)

2.3.2 Wind actions

(1) The wind effects taken into account shall include:

- the static effects of wind drag on the cables, see EN 1991-1-4, including deflections and possible resulting bending effects near the ends of the cable,
- aerodynamic and other excitation leading to possible oscillation of the cables, see section 8.

2.3.3 Ice loads

(1) For ice loading see Annex B to EN 1993-3-1.

2.3.4 Thermal actions

(1) The thermal actions to be taken into account shall include the effects of differential temperatures between the cables and the rest of the structure.

(2) For a cable in a structure exposed to weather conditions the actions from differential temperature according to EN 1991-1-5 should be used.

2.3.5 Prestressing

(1) The preloads in cables shall be determined such, that when all the permanent actions are applied, the structure adopts the required geometric profile and stress distribution.

(2) To ensure this objective, facilities for prestressing and for adjustment of the cables shall be provided and the characteristic value of the preload shall be taken as required to achieve the objective of (1) at the limit state under consideration.

(3) If adjustment of the cables is not provided allowance shall be made, in calculating the design values of the total effects of the permanent actions and preload for the range of error that may occur in the prestressing together with any errors that may arise in the precamber of the structure.

NOTE From a sensivity check tolerances may be derived.

2.3.6 Rope removal and replacement

(1) The replacement of any one rope should be taken into account in the design in a transient design situation.

NOTE The National Annex may define the transient loading conditions and partial factors for replacement.

(2) A sudden removal of any one rope should be taken into account in the design in an accidental design situation.

NOTE 1 The National Annex may define where such an accidental design situation applies and also give the protection aims and loading conditions.

NOTE 2 In the absence of a more exact analysis the dynamic effect of a sudden removal may conservatively be allowed by using the design effect

$$E_d = k\, E_{d2} - E_{d1} \qquad (2.4)$$

where k = 1,5 to 2,0

E_{d1} represents the design effects with all cables intact;

E_{d2} represents the design effects with the relevant cable removed.

2.3.7 Fatigue loads

(1) For fatigue loads see EN 1991.

2.4 Design situations and partial factors

2.4.1 Transient design situation during the construction phase

(1) For the construction phase the partial factor for permanent loads (G+P) may be adapted to the particular design situation and limit state model.

NOTE The National Annex may define partial factors γ_G for the construction phase. Recommended values γ_G are

$\gamma_G = 1,10$ for a short time period (only a few hours) for the instalment of first strand in strand by strand installations

$\gamma_G = 1,20$ for the instalment of other strands

$\gamma_G = 1,00$ for favourable effects.

2.4.2 Persistent situations during service

(1) For the assessment of ULS, SLS and fatigue partial factors γ_M may be dependant on

- the severeness of the test conditions for qualification tests
- the measures to suppress bending effects with model uncertainties.

NOTE Indications for γ_M values are given in section 6.

3 Material

3.1 Strength of steels and wires

(1) The characteristic values f_y and f_u for steels and $f_{0,2}$ or $f_{0,1}$ and f_u for wires shall be taken from the relevant technical specifications.

NOTE 1 For steels see EN1993-1-1 and EN1993-1-4.

NOTE 2 For wires see EN 10264, Part 1 to Part 4.

NOTE 3 For ropes see EN 12385, Part 4 and Part 10.

NOTE 4 For terminations see EN 13411-3.

NOTE 5 For strands see EN 10138-3.

NOTE 6 The National Annex may give a maximum value f_u for durability reasons. The following values are recommended:

– steel wires	round wires:	nominal tensile grade:	1770 N/mm²
	Z-wires:	nominal tensile grade:	1570 N/mm²
– stainless steel wires:	round wires:	nominal tensile grade:	1450 N/mm²

3.2 Modulus of elasticity

3.2.1 Tension rod systems (Group A)

(1) The modulus of elasticity for tension rod systems may be taken as E = 210000 N/mm² ; for tension rod systems made of stainless steels see EN 1993-1-4.

3.2.2 Ropes (Group B)

(1) The modulus of elasticity for locked coil strands, bundles of strands, bars and wires should be derived from tests.

NOTE 1 The modulus of elasticity can depend on the stress level and whether the cable is subject to first loading or repeated loading.

NOTE 2 The modulus of elasticity for locked coil strands, strands or bundles of strands, bars and wires is multiplied with the metallic cross section A_m to obtain the tension stiffness of the cable.

(2) The modulus of elasticity used for structural analysis for persistent design situations during service should be obtained for each cable type and diameter by measuring the secant modulus after a sufficient number (at least 5) load cycles between F_{inf} and F_{sup} to get stable values. Herein F_{inf} is the minimum cable force under characteristic permanent and variable actions. F_{sup} is the maximum cable force under characteristic permanent and variable actions.

(3) For short test samples (sample length ≤ 10 x lay length) a smaller creep than for long cables should be expected.

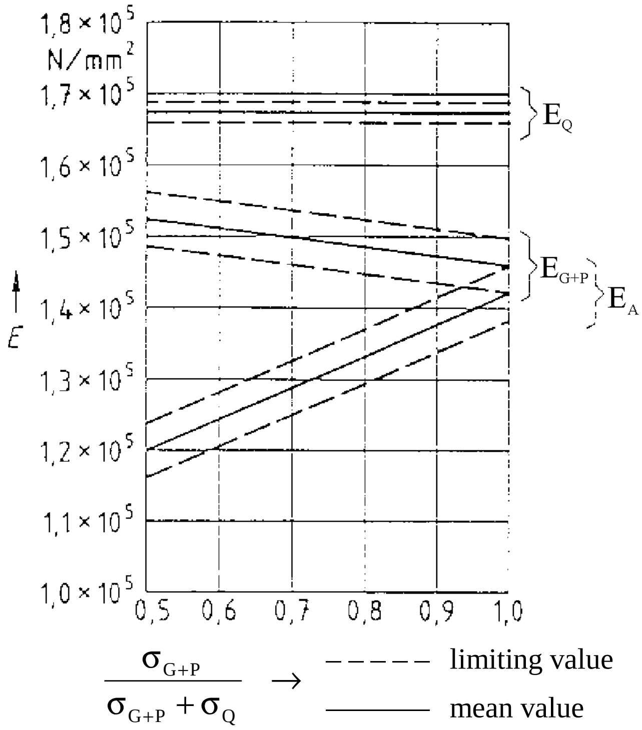
NOTE 1 In the absence of more accurate values this effect may be taken into account in cutting to length by applying an additional shortening of 0,15 mm/m.

NOTE 2 Notional values of moduli of elasticity for first estimations when test results are not available are given in Table 3.1. For further information see EN 10138.

Table 3.1: Notional values for the modulus of elasticity E_Q in the range of variable loads Q

	High strength tension component	E_Q [kN/mm²]	
		steel wires	stainless steel wires
1	Spiral strand ropes	150 ± 10	130 ± 10
2	Full locked coil ropes	160 ± 10	–
3	Strand wire ropes with CWR	100 ± 10	90 ± 10
4	Strand wire ropes with CF	80 ± 10	–
5	Bundle of parallel wires	205 ± 5	–
6	Bundle of parallel strands	195 ± 5	–

NOTE 3 Notional values for the modulus of elasticity E for the design of full locked coil ropes for bridges are given in Figure 3.1. These estimations apply to cyclic loading and unloading between 30 % and 40 % of the calculative breaking strength F_{uk}.



σ_{G+P} stress under characteristic permanent actions

σ_Q maximum stress under characteristic variable actions

E_Q modulus of elasticity for persistent design situations during service

E_{G+P} modulus of elasticity for an appropriate analysis for transient design situations during construction phase up to permanent load G+P

E_A modulus of elasticity for cutting to length

Figure 3.1: Notional values of modulus of elasticity E for the design of full locked coil ropes for bridges

NOTE 4 As non prestretched cables of group B exhibit both elastic and permanent deformations in the first loading it is recommended to prestretch such cables before or after installation by cyclic loading by up to $0{,}45\sigma_{uk}$. For cutting to length cables should be prestreched, with a precision depending on adjustment possiblities.

NOTE 5 For Figure 3.1 the following assumptions apply:

- the lay length is above 10 × the diameter
- the minimum value of stress is 100 N/mm²

The minimum value of stress is the lower bound of the elastic range.

3.2.3 Bundles of parallel wires or strands (Group C)

(1) The modulus of elasticity for bundles of parallel wires and strands may be taken from EN 10138 or Table 3.1.

3.3 Thermal expansion coefficient

(1) The thermal expansion coefficient shall be taken as

$$\alpha_T = 12 \times 10^{-6}\,K^{-1} \quad \text{for steel wires}$$
$$\alpha_T = 16 \times 10^{-6}\,K^{-1} \quad \text{for stainless steel wires} \qquad (3.1)$$

3.4 Cutting to length of tension components Group B

(1) Strands may be marked to length only for cutting at a prescribed cutting load.

(2) For an exact cutting to length the following data should be considered:

– measured values of the elongation between σ_A and σ_{G+P} after cyclic loading according to 3.2.2(2)
– difference between design temperature (normally 10°) and ambient temperature when cutting to length if the length is measured by temperature invariant measurement devices like fixed marks, invar measure tapes etc.
– long term cable creep under loads
– additional elongation of cable after installation of cable clamps
– setting of the pouring cone after cooling of molten metal and after initial load is applied.

NOTE The cable creep and cone setting will take place after a certain time and loading in the structure, so that higher loads may be needed during erection as the cable creep has not finished yet.

3.5 Lengths and fabrication tolerances

(1) The total length and all measuring points for the attachment of saddles and clamps should be marked under defined preload.

NOTE Additional control markings allows for a later check of exact length after parts have been installed.

(2) The fabrication tolerances shall be considered after prestretching and cyclic loading and unloading.

(3) When structures are sensitive to deviations from nominal geometrical values (e.g. by creep), adjusting devices should be provided.

3.6 Friction coefficients

(1) For the friction between full locked coil cables and steel attachments (clamps, saddles, fittings) the friction coefficient should be determined from tests. In the absence of tests $\mu = 0,1$ may be used.

(2) For other types of cables the friction coefficient should be determined from tests, see Annex A.

4 Durability for wires and ropes / strands

4.1 General

(1) Because of the crucial importance of corrosion protection for the safety of ropes with exposure classes 2, 4 and 5 according to Table 2.1 the corrosion protection barrier of a cable should be composed of the following measures:

1. Corrosion protection of each individual wire
2. Corrosion protection of the rope interior with inner filler to avoid the ingress of moisture.
3. Corrosion protection of rope surface

(2) The tension components of group C according to Table 1.1 should have two independent corrosion protection barriers with an interface or inner filler between the barriers.

(3) At clamps and anchorages additional corrosion measures should be applied at the structure to prevent water penetration.

(4) Also basic rules for transport, storage and handling should be observed.

NOTE See Annex B.

4.2 Corrosion protection of each individual wire

(1) All steel wires of group B and C should be coated with zinc or zinc alloy.

(2) For group B zinc or zinc alloy coating for round wires should be in accordance with EN 10264-2, class A. Shaped wires should comply with EN 10264-3, class A.

NOTE Z-shaped wires generally are heavy galvanized with a coating thickness up to 300g/m² to allow for thickness reduction on sharp corners.

(3) Zinc-aluminised wires (Zn95Al5) provide much improved corrosion protection than heavy galvanizing with the same coating thickness. Round and Z-shaped wires can be coated with a Zn95Al5 basis weight.

(3) For group C wires should comply with EN 10138.

4.3 Corrosion protection of the rope / strand / cable interior

(1) All interior voids of the cables should be filled with an active or passive inner filling that should not be displaced by water, heat or vibration.

NOTE 1 Active fillers are suspensions of zinc in polyurethane-oil.

NOTE 2 Passive inner fillers can be permanent elastic-plastic wax or aluminium flake in hydrocarbon resin.

NOTE 3 Inner filling applied during stranding of cable can extrude when cable is loaded (bleeding).

NOTE 4 When selecting the appropriate inner filling any possible incompatibility with other corrosion protection components applied to the cable later, should be checked.

4.4 Corrosion protection of the surface of single strands, cables or ropes and components

(1) After the installation of the cables and the erection of the structure in general an additional corrosion protection on ropes and cables need to be applied to compensate for damaging of the initial corrosion protection and for the expense of zinc.

NOTE This protection may consist of polyethylene sheathing or zinc loaded paint. For polyethylene, the minimum thickness is equal to the strand outer diameter divided by 15 and shall not by less than 3 mm.
The following minimum layer thicknesses may be applied to paints:

- 2 prime coats, Polyurethane with zinc dust 50 µm each
- 2 finishing coats. Polyurethane with iron mica, 125 µm each.

(2) The choice of cables with stainless steel wires and stainless steel terminations without additional corrosion protection should comply with the relevant corrosion resistance class.

NOTE 1 The National Annex may specify the corrosion resistance classes for stainless steel.

NOTE 2 The zinc-aluminium eutectoid of Zn95Al5-coated wires provides an up to 3 times better resistance compared with heavy zinc coated wires under equal conditions.

Draft note: To be coordinated with EN 1993-1-4 / EN ISO 12944-2.

4.5 Corrosion protection of bundles of parallel wires or bundles of parallel strands

(1) Cables formed as parallel wire strands should normally be sheathed using steel or polyethylene tube complying to relevant standards with the space between the inside of the sheath and the cable then filled with a suitable corrosion protection compound or cement grout.

(2) Alternatively polyethylene sheathing extruded directly or epoxy coating over the individual strands or cables may be used.

(3) The sheaths used for sheathed strand should be made completely impermeable at the connections to the anchorages. The joints shall be designed so that they do not break, when the sheath is subjected to tension.

(4) Void fillers should be

– continuous hydrophobic material with no detrimental interaction with the main tensile elements.

NOTE 1 Continuous hydrophobic materials are soft fillers as grease, wax or soft resin or hard fillers as cement if their suitability is proved by tests. The choice of materials may be given in the National Annex.

– circulation of dry air or nitrogen.

NOTE 2 Corrosion protection of main cables of suspension bridges requires a special approach. After compacting the main cable into a cross-sectional area as small as possible the cable gets a close wrapping with tensioned galvanized soft wire laid in a suitable paste sufficient to fill completely the voids between the outer cable wires and the wrapping wire. After removal of the surplus paste from outside of the wrapping wire the zinc coated surface is cleaned and subsequently painted. Special treatment is required for suspension bridge cable achorages where the wrapping wire is removed. Dehuminification of the air around the wires is a common method of protection.

4.6 Corrosion protection measures directly at the structure

(1) Provision should be taken to prevent rain water running down the cable from entering at clamps, saddles and anchorings.

(2) Therefore the transitions cable/component shall be sealed carefully with permanent elastic material. Also gaps between clamps should be sealed as well.

5 Structural analysis of cable structures

5.1 General

(1) The analysis should be made for the relevant design situations

1. for the transient construction phase
2. for the persistent service conditions after completion of the construction

for the limit states considered.

5.2 Transient design situations during the construction phase

(1) The confectioning of cables, the geometry of the structure, and the construction process with prestressing shall be planned such, that the conditions for prestress and selfweight satisfy the following conditions:

– attainment of the required geometric form

- attainment of a permanent stress situation that satisfied the serviceability and ultimate limit state conditions for all design situations.

(2) For complying with control measures (e.g. measurements of shape, gradients, deformations frequencies or forces) all calculations should be carried out with characteristic values of permanent loads, imposed deformations and any imposed action step by step to achieve the final required permanent stage.

(3) When nonlinear action effects from deformations are significant during construction these effects shall be taken into account, see 5.4.

(4) Where ultimate limit states during prestressing are controlled by differential effects of the action “G” and “P” (e.g. for concrete parts), the partial factor $\gamma_P = 1{,}00$ should be applied to “P”.

5.3 Persistent design situation during service

(1) For any persistent design situation during the service phase the permanent actions “G” from gravity and preloads or prestressing “P” shall be combined in a single permanent action “G + P” corresponding to the permanent shape of the structure.

(2) For the verification of serviceability limit states the action “G + P” shall be included in the relevant combination of action; for the verification of the ultimate limit states EQU or STR (see EN 1990) the permanent actions “G + P” shall be multiplied with the partial factor $\gamma_{G\ sup}$, when the effects of permanent action and of variable actions are unfavourable. In case the permanent actions “G + P” are favourable they should be multiplied with the partial factor $\gamma_{G\ inf}$.

(3) When nonlinear action effects from deformations are significant during service these effects shall be taken into account, see 5.4.

5.4 Nonlinear effects from deformations

5.4.1 General

(1) For structures with tension components the effects of deformations from catenary effects and shortening and lengthening of the components including creep shall be taken into account.

5.4.2 Catenary effects

(1) Catenary effects may be taken into account by applying to each cable or segment of cable the effective modulus

$$E_t = \frac{E}{1 + \dfrac{w^2\ \ell^2\ E}{12\ \sigma^3}} \tag{5.1}$$

E is the modulus of elasticity of the cable

w is the unit weight according to Table 2.2

ℓ is the horizontal span of the cable

σ is the stress in the cable. For situations according to 5.3 it is σ_{G+P} .

5.4.3 Effects of deformations on the structure

(1) For the application of 2nd order analysis deformations due to variable loads should refer to the initial geometrical form of the structure required for the permanent loading corresponding to “G + P” for a given temperature T_0.

(2) For the 2nd order calculations for serviceability limit states and for sublinear behaviour in ultimate limit states the characteristic load combination may be applied to determine the action effects.

(3) For 2nd order calculations for overlinear behaviour of structures in ultimate limit states the required permanent geometrical form of the structure at the reference temperature T_0 may be associated with the stress situation from "γ_G (G + P)" and design values of variable actions $\gamma_Q Q_{k1} + \gamma_Q \psi_2 Q_{k2}$ may be applied together with appropriate assumptions for imperfections of the structure.

6 Ultimate limit states

6.1 Tension rod systems

(1) Tension rod systems should be designed for ULS according to EN 1993-1-1 or EN 1993-1-4 depending on the steel used.

6.2 Ropes and prestressing bars

(1) For the ultimate limit state it shall be verified that

$$\frac{F_{Ed}}{F_{Rd}} \leq 1 \tag{6.1}$$

where F_{Ed} is the design value of the axial rope force

F_{Rd} is the design value of tension resistance.

(2) The design value of the tension resistance F_{Rd} shall be determined from the characteristic value of the breaking strength F_{uk} and the characteristic value of ther proof strength F_k.

$$F_{Rd} = \min \left\{ \frac{F_{uk}}{1,5\, \gamma_R} ; \frac{F_k}{\gamma_R} \right\} \tag{6.2}$$

where F_{uk} is the characteristic value of the breaking strength,

F_k is the characteristic value of the 0,2% proof strength $F_{0,2k}$ or of the 0,1% proof strength $F_{0,1k}$ determined according to the requirement of the standard relevant for the tension component, e.g. by testing for ropes or by calculation for bars,

γ_R is the partial factor.

NOTE 1 F_{uk} corresponds to the characteristic value of the ultimate tensile strength.

NOTE 2 Table 6.1 gives information on the proof strength F_k relevant for the tension component.

Table 6.1: Groups of tension components and relevant proof strength

Group	relevant standard	proof strength F_k
A	EN 10138-1	$F_{0,1k}$ *)
B	EN 10264	$F_{0,2k}$
C	EN 10138-1	$F_{0,1k}$
*) For prestressing bars see EN 1993-1-1 and EN 1993-1-4		

NOTE 3 F_k is not directly related to ULS. By the check against F_k it is verified that the rope will remain elastic even when the actions attain their design value. For ropes (e.g. full locked coil ropes) where $F_k \geq \frac{F_{uk}}{1,50}$ this check is not relevant.

NOTE 4 By tests on delivery it is demonstrated that the experimental values F_{uke} and F_{ke} satisfy the requirement

$F_{uke} > F_{uk}$,

$F_{ke} > F_k$,

see EN 12385, Part 1.

NOTE 5 The partial factor γ_R may be determined in the National Annex. It may be dependent on whether or not measures are applied at the rope ends to reduce bending moments from cable rotations, see 7.1(4). The values for γ_R in Table 6.2 are recommended.

Table 6.2: Recommended γ_R – values

Detailing measures to suppress bending stresses ahead of anchorage	γ_R
Yes	0,90
No	1,00

(3) For prestressing bars and group C tension components the characteristic value of the calculative breaking strength should be determined from

$$F_{uk} = A_m f_{uk} \qquad (6.3)$$

where A_m is the metallic cross-section, see 2.3.1

f_{uk} is the characteristic value of the tensile strength of rods, wires or (prestressing) strands of which the tension component is constituted according to the relevant standard

(4) For group B tension components F_{uk} should be calculated as

$$F_{uk} = F_{min} k_e \qquad (6.4)$$

where F_{min} is determined according to EN 12385-2 as

$$F_{min} = \frac{K\, d^2\, R_r}{1000} \; [KN] \qquad (6.5)$$

where K is the minimum breaking force factor taking account of the spinning loss,

d is the nominal diameter of the rope

R_r is the rope grade

k_e is given in Table 6.3 for some types of end terminations

NOTE K, d, R_r are specified for all ropes in the EN 12385-2.

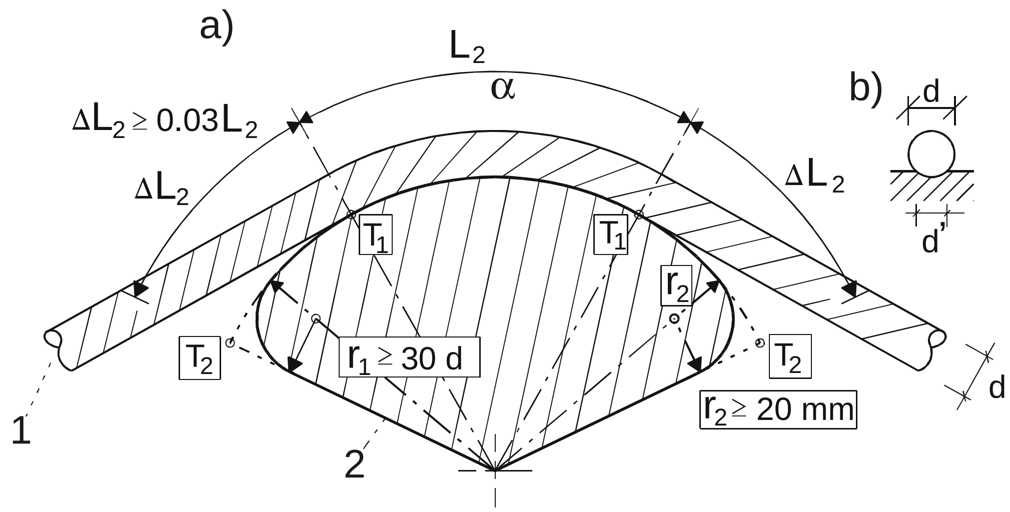
Table 6.3: Loss factors k_e

Type of termination	Loss factor k_e
Metal filled socket	1,0
Resin filled socket	1,0
Ferrule-secured eye	0,9
Swaged socket	0,9
U-bolt grip	0,8 *)
*) For U-bolt grip a reduction of preload is possible.	

6.3 Saddles

6.3.1 Geometrical conditions

(1) In order to reduce the characteristic breaking resistance of strand or rope by no more than 3%, the saddle should be proportioned as shown in Figure 6.1. Where the following conditions are satisfied stresses due to curvature of wires may be neglected in the design.



1 *cable*
2 *saddle*
L_2 *length of strand between the two theoretical points of tangency T_1 under unfavourable characteristic loads including catenary effects*
ΔL_2 *additional length of wrap*

Figure 6.1: Radii of saddle and definition of bedding

(2) The radius of the saddle should be $r_1 \geq 30d$ or $r_1 \geq 400\varnothing$, whichever is greater, where $\varnothing$ is the diameter of wire.

(3) The radius may be reduced to $r_1 \geq 20d$ when the bedding of the rope on at least 60% of the diameter is performed by soft metal or spray zinc coating with a minimum thickness of 1 mm.

(4) Smaller radii may be used for spiral ropes where justified by tests.

NOTE The position of the points T_1 and T_2 should be determined for the relevant load cases taking the movement of bearings and cables (catenary) into account.

6.3.2 Slipping of cables round saddles

(1) To ensure that slip does not occur it shall be verified that for the highest value of the ratio

$$\max\left\{\frac{F_{Ed1}}{F_{Ed2}}\right\} \tag{6.6}$$

where F_{Ed1} and F_{Ed2} are the design values of the greater and smaller force in the cable on either side of the saddle

the following equation is satisfied:

$$\max\left\{\frac{F_{Ed1}}{F_{Ed2}}\right\} \leq e^{\left\{\frac{\mu\alpha}{\gamma_{M,fr}}\right\}} \tag{6.7}$$

where μ is the coefficient of friction between cable and saddle

α is the angle in radians, of the cable passing over the saddle

$\gamma_{M,fr}$ is the partial factor for friction.

NOTE The partial factor γ_{Mfr} may be given in the National Annex. The value γ_{Mfr} = 1,65 is recommended.

(2) If (1) is not satisfied, an additional radial force F_r should be provided by clamps such that

$$\frac{F_{Ed1} - \dfrac{k\,F_r\,\mu}{\gamma_{Mfr}}}{F_{Ed2}} \leq e^{\left[\frac{\mu\alpha}{\gamma_{M,fr}}\right]} \tag{6.8}$$

where k is normally taken as 1,0 but may be taken as 2, if full friction can be guaranteed at both the saddle grooves and the clamp itself and F_r should not exceed the resistance of the cable to clamping forces, see 6.3.3

$\gamma_{M,fr}$ is the partial factor for friction resistance

(3) In determining F_r from preloaded bolts the following effects should be considered:

a) long term creep

b) reduction of diameter if tension is increased

c) compaction/bedding down of cable or ovalisation

d) reduction of preload in clamp bolts by external loads

e) differential temperature.

6.3.3 Transverse pressure

(1) The transverse pressure q due to the radial clamping force F_r should be limited to

$$\frac{q_{Ed}}{q_{Rd}} \leq 1 \tag{6.9}$$

where $q_{Ed} = \dfrac{F_r}{d^{/}L_2}$ with $0{,}6d \leq d^{/} \leq d$, see Figure 6.1b)

$q_{Rd} = \dfrac{q_{Rk}}{\gamma_{M,bed}}$ limit value of transverse pressure determined from tests

$\gamma_{M,bed}$ is the partial factor.

NOTE For calculating q the pressure from F_{Ed1} need not be considered as it is limited by the rules in 6.3.1.

(2) In the absence of tests values for q_R the limit values of transverse pressure q_{Rk} are given in Table 6.4.

NOTE 1 The limit values q_{Rk} in combination with γ_M = 1,00 would lead to a reduction of the breaking strength of the cable by no more than 3%.

Table 6.4: Limit values q_{Rk}

Type of cable	Limit pressure q_{Rk} [N/mm²]	
	Steel clamps and saddles	Cushioned clamps and saddles
Full locked coil rope	40	100
Spiral strand rope	25	60

NOTE 2 Cushioned clamps have a layer of soft metal or spray zinc coating with a minimum thickness of 1 mm.

6.3.4 Design of saddles

(1) Cable saddles should be designed for a cable force of k times the characteristic breaking strength F_{uk} of the cables.

NOTE The factor k may be specified in the National Annex. The value k = 1,05 is recommended.

6.4 Clamps

6.4.1 Slipping of clamps

(1) Where clamps shall transmit longitudinal forces to a cable and the parts are not mechanically keyed together, slipping shall be prevented by verifying

$$F_{Ed_{||}} \leq \frac{\left(F_{Ed_{\perp}} + F_r\right)\mu}{\gamma_{M,fr}} \tag{6.10}$$

where $F_{Ed_{||}}$ is the component of external design load parallel to the cable

$F_{Ed_{\perp}}$ is the component of the external design load perpendicular to the cable

F_r is the clamping force considered that may be reduced by items in 6.3.2(3)

μ is the coefficient of friction

$\gamma_{M,fr}$ is the partial factor for friction

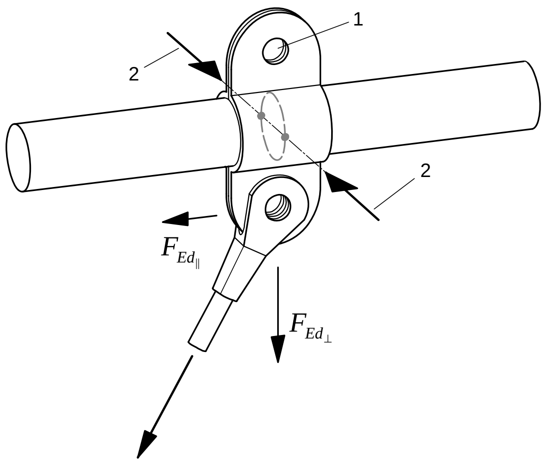
NOTE The partial factor $\gamma_{M,fr}$ may be determined in the National Annex. The partial factor $\gamma_{M,fr}$ = 1,65 is recommended.

6.4.2 Transverse pressure

(1) For $F_{Ed_{\perp}}$ or $F_{Ed_{\perp}} + F_r$ (whichever is greater) the transverse pressure should be limited according to 6.3.3.

6.4.3 Design of clamps

(1) Clamps and their fittings, anchoring secondary elements (e.g. hangers) on a main cable (e.g. a suspension cable) shall be designed as for end terminations for the secondary element for a hypothetical force equivalent to the proof force F_k of the secondary element clamped, see Figure 6.2.



1 preloaded bolts
2 preload F_r from preloaded bolts

Figure 6.2: Clamp

NOTE F_k is not directly related to ULS. By the use of F_k capacity design is applied.

7 Serviceability limit states

7.1 Serviceability criteria

(1) The following serviceability criteria should be considered.

1. Deformations or vibrations of the structure that may influence the design of the structure
2. The behaviour of high strength tension components themselves that are related to their elastic behaviour and durability

(2) Limits for deformations or vibrations may result in stiffness requirement governed by the structural system, the dimensions and the preloading of high strength tension components, and by the slipping resistance of attachments.

(3) Limits to retain elastic behaviours and durability are related to maximum and minimum values of stresses for serviceability load combinations.

(4) Bending stresses in the anchorage zone may be reduced by constructive measures (e.g. noeprene pads for transverse loading).

7.2 Recommendations for stress limits

(1) Stress limits may be introduced for rare load combinations for the following purposes:

– to keep stresses in the elastic range for the relevant design situations during construction and in the service phase,
– to limit strains controlling the durability behaviour and also cater for uncertainty in the fatigue design to sections 8 and 9,
– to cover ULS verifications for linear and sublinear (non linear) structural response to actions.

(2) Stress limits may be related to the breaking strength

$$\sigma_{uk} = \frac{F_{uk}}{A_m} \tag{7.1}$$

see equation (6.3).

NOTE 1 The National Annex may give values for stress limits f_{const} and f_{SLS}. Recommended values for stress limits f_{const} are given in Table 7.1 for the construction phase and for stress limits f_{SLS} in Table 7.2 for service conditions.

Table 7.1: Stress limits f_{const} for the construction phase

Conditions for erection using strand by strand installation	$f_{const.}$
First strand for only a few hours	$0{,}60\ \sigma_{uk}$
After instalment of other strands	$0{,}55\ \sigma_{uk}$

NOTE 2 The stress limits follow from

$$f_{const} = \frac{\sigma_{uk}}{1{,}50\gamma_R\gamma_F} = \frac{0{,}66\ \sigma_{uk}}{\gamma_R\gamma_F} \qquad (7.2)$$

with $\gamma_R \times \gamma_F = 1{,}0 \times 1{,}10 = 1{,}10$ for short term situations

$\gamma_R \times \gamma_F = 1{,}0 \times 1{,}20 = 1{,}20$ for long term situations

Table 7.2: Stress limits for service conditions

Model uncertainty for fatigue	f_{SLS}
Fatigue design including bending stresses *)	$0{,}50\ \sigma_{uk}$
Fatigue design without bending stresses	$0{,}45\ \sigma_{uk}$
*) Bending stresses may be reduced by detailing measures, see 7.1(4).	

NOTE 3 The stress limits follow from

$$f_{SLS} = \frac{\sigma_{uk}}{1{,}50\ \gamma_R\gamma_F} = \frac{0{,}66\ \sigma_{uk}}{\gamma_R\gamma_F} \qquad (7.3)$$

with $\gamma_R \times \gamma_F = 0{,}9 \times 1{,}48 = 1{,}33$ with consideration of bending stresses

$\gamma_R \times \gamma_F = 1{,}0 \times 1{,}48 = 1{,}48$ without consideration of bending stresses

where $\gamma_F \approx \gamma_Q = 1{,}50 \approx 1{,}48$

NOTE 4 The stress limit $f_{SLS} = 0{,}45\ \sigma_{uk}$ is used for testing, see Annex A.

8 Vibrations of cables

8.1 General

(1) For cables exposed to climatic conditions (e.g. for stay cables) the possibility of wind-induced vibrations during and after erection and their significance on the safety should be checked.

(2) Dynamic wind forces acting on the cable may be caused by

a) buffeting (from turbulence in the on-coming air flow)

b) vortex shedding (from von Karman vortexes in the wake behind the cable)

c) galloping (self induction)

d) wake galloping (fluid-elastic interaction of neighbouring cables)

e) interaction of wind, rain and cable

NOTE Gallopping is not possible on a cable with a circular cross section for symmetry reasons. This phenomenon may arise on cables with shapes altered, due to ice, dust, helical shapes of cable etc.

Forces due to c), d) and e) are a function of the motion of the cable (feedback) and due to ensuing aeroelastic instability lead to vibrations of large amplitudes starting at a critical wind speed. As the mechanism of dynamic excitation is not yet sufficiently modelled to make reliable predictions measures should be provided to limit unforeseen vibrations.

(3) Cable vibrations may also be caused by dynamic forces acting on other parts of the structure (girder, pylon).

NOTE This phenomenon is often referred to as “parametric excitation” and is responsible for vibrations of large amplitudes in case of overlapping between stay eigenfrequencies and structure eigenfrequencies.

8.2 Measures to limit vibrations of cables

(1) Cable structures should be monitored for excessive wind induced vibrations either by visual inspection or other methods that allow a more accurate determination of the involved amplitudes, modes and frequencies and the accompanying wind and rain characteristics.

(2) Provisions should be made in the design of a cable structure to enable implementation of vibration-suppressing measures during or after erection if unforeseen vibrations occur.

(3) Such measures are:

a) modification of cable surface (aerodynamic contour)

b) additional damping (e.g. by damping devices)

c) stabilizing cables (e.g. by tie-down cables with appropriate connections)

8.3 Estimation of risks

NOTE The complexity of the physical phenomena involved means it is not always possible to assess the risk of cable stay vibration. Conversely, economic constraints prohibit specifying “unnecessary” preventive measures. The following rules are guides intended to help to reach a trade-off.

(1) Rain-wind instability must systematically be prevented by design precautions; this involves cable stays with texturing.

(2) The risk of vibration increases with cable stay length. Short cable stays (less than about 70 – 80 m) generally involve no risk, other than of parametric resonance in the case of a particularly unstable structure (poorly shaped and flexible deck). There is therefore generally no need to make provisions for dampers on short cable stays.

(3) For long cable stays (more than 80 m), it is recommended that dampers be installed to obtain a damping ratio to critical greater that 0,5 %. It might be possible to dispense with dampers on the backspan cable stays if the spans are so short that there is likely no major displacement of anchorages.

(4) The risk of parametric resonance should be assessed at the design stage by means of a detailed study of the eigenmodes of the structure and cable stays, involving the ratio of angular frequencies and anchorage displacement for each mode.

(5) Everything should be done to avoid overlapping of frequencis, i.e. situations where the cable stay´s frequency of excitation Ω is close to (within 20 % of) the structure´s frequency ω_n or $2\omega_n$. If necessary, stability cables can be used to offset the modal angular frequencies of the cable stays.

(6) To ensure that users feel safe, the amplitude of cable stay vibration should be limited using a response criterion. E.g. with a moderate wind velocity of 15 m/s the amplitude of cable stay vibration shall not exceed L/500, where L is the cord length.

9 Fatigue

9.1 General

(1) The fatigue endurance of tension components according to classes 3, 4 or 5 to Table 2.1 shall be determined using the fatigue actions from EN 1991 and the appropriate category of structural detail.

(2) Fatigue failure of cable systems usually occurs at, or is governed by the effects at anchorages, saddles or clamps. The effective category should preferably be determined from tests representing the actual configuration used and reproducing any flexural effect or transverse stresses likely to occur in practice. The test evaluation should be carried out according to EN 1990 – Annex D.

9.2 Fluctuating axial loads

(1) In the absence of the tests described in 9.1(2) above, fatigue strength curves according to Figure 9.1 may be used and the fatigue category of detail be taken as given in Table 9.1.

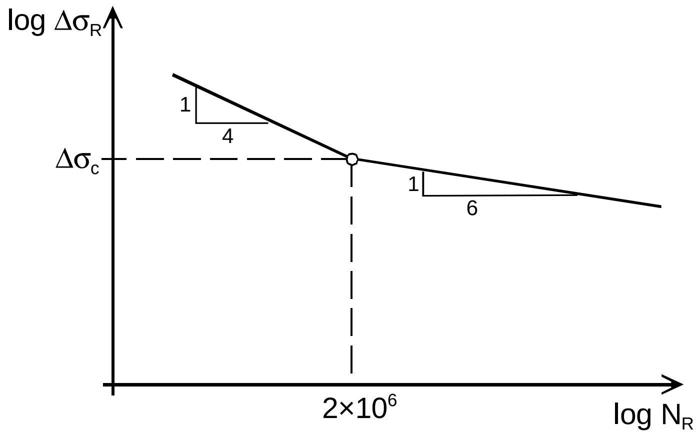


Figure 9.1: Fatigue strength curves for tension components

Table 9.1: Detail categories for fatigue strength according to the standard fatigue strength curves in EN 1993-1-9

Group		Tension element	Detail category $\Delta\sigma_c$ [N/mm²]
A	1	Prestressing bars	105
B	2	Fully locked coil rope with metal or resin socketing	150
	3	Spiral strands with metal or resin socketing	150
C	4	Parallel wire strands with epoxy socketing	160
	5	Bundle of parallel strands	160
	6	Bundle of parallel	160

NOTE The fatigue categories in Table 9.1 refer to exposure classes 3 and 4 according to Table 2.1 and to mainly axial fatigue action. For axial and lateral fatigue actions (exposure class 5 according to Table 2.1) additional constructive measures are required in order to minimise bending stresses in the anchorage zone.

(2) The categories given in (1) are not valid unless the following conditions apply:

a) cables with sockets comply with the basic requirements in Annex A

b) the design of cables, saddles and clamps complies with 6

c) serious aerodynamic oscillations of cables are prevented, see 8

d) adequate protection against corrosion is provided, see 4.

(3) For fatigue assessments see EN 1993-1-9.

Annex A [informative] – Product requirements for tension components

A.1 Scope

(1) This Annex gives the product requirements for tension components and their terminations to be used for buildings and civil engineering works.

(2) The requirements depend on the particular use of the prefabricated tension component (environmental and loading condition).

(3) The following types of prefabricated tension components are included

- Group A: tension rod systems, bars
- Group C: bundles of parallel wires, bundles of bars, bundles of parallel strands

A.2 Basic requirements

(1) Tension components should comply with the following basic points to be considered:

1. strength and ductility of the cable system and its terminations including durability,
2. fatigue resistance to axial load fluctuation plus bending stresses and angular deviations caused by catenary effects, wind forces and erection imperfections,
3. stable condition of axial and flexural stiffness of the cable system,
4. resistance to any corrosion action including environmental effects on corrosion barriers in the cable system and in particular in the region of anchorages,
5. resistance to fretting at any contact between steel parts.

(2) Terminations and anchorages of the tension components shall be designed such that

1. the ultimate resistance of the tension component would be reached before any gross yielding or other permanent deformation of the anchoring or any bearing elements would occur,
2. their fatigue resistance exceeds that of the components,
3. facilities are available for providing adequate adjustment of the component length to meet the requirements for preload, geometrical tolerances etc.,
4. sufficient articulation is provided in the anchorage to cater for manufacturing and erection imperfection,
5. the tension components are replaceable.

(3) These requirements shall be met by

- appropriate choice of materials as wires, strands, steels, protective materials,
- adequate make up and form of construction in view of strength, stiffness, ductility and durability as well as robustness for manufacturing, transport, handling and installation,
- quality control of termination fitting to ensure accurate alignment of cable.

(4) The fulfilment of the requirements shall be verified by initial tests for the system and test during the quality management.

A.3 Materials

(1) All materials used should comply with the relevant European technical specifications.

(2) The suitability of the corrosion protection system including the durability of filler and protection materials should be proved by appropriate testing.

NOTE The testing may prove the following basic functions:

- protection against aggressive agents (chemicals, environmental stress cracking, UV, mechanical impacts)
- watertightness (flexibilty and durability when cable bends)
- durability of colour (if required)

A.4 Requirements for tests

A.4.1 General

(1) The following tests on wire, strands, bars and complete cables shall ensure that they perform as required.

(2) $F_{0,1ke}$ and $F_{uk,e}$ (see 6.2) should be determined in a static tension tests. If necessary for cutting to length (see 3.4) and structural analysis (see 5) the test should follow the expected stress history of the cable in the structure for measuring all relevant data.

(3) To determine the fatigue strength curve (if necessary) a sufficient number of axial tests should be done at $\sigma_{sup} = 0,45\sigma_{uk}$ (see 7.2(2)) with different values of ΔF (force controlled, not $\Delta\ell$), see Table A.4.1.

Table A.4.1: Severity classes for fatigue load

	Type of test	Fatigue loading before fracture test
1	axial test (class 3 and 4)	$\sigma_{sup} = 0,45\sigma_{uk}$ $\Delta\sigma$ according to $\Delta\sigma_c$ given in Table 9.1 $\Delta\alpha = 0$ $n = 2\times10^6$ cycles
2	axial and flexural test (class 5)	$\sigma_{sup} = 0,45\sigma_{uk}$ $\Delta\sigma$ according to $\Delta\sigma_c$ given in Table 9.1 $\Delta\alpha$ = 0 – 10 milliradians (0 – 0,7 degrees) $n = 2\times10^6$ cycles

(4) If the tension component is used for a structure under fatigue loading and the fatigue resistance is verified according to 9.2(2) at least one test with each diameter should be carried out. It should be checked that in an axial test with $\sigma_{sup} = 0,45\ \sigma_{uk}$ and $\Delta\sigma = 1,25\ \Delta\sigma_c$ (see Table 9.1) after $2\cdot10^6$ cycles the number of broken wires is < 2% of all wires. No failure shall occur in the anchorage material or in any component of the anchorage during the fatigue tests. No failure is acceptable for bars.

(5) If the round out radius at the entrance of the cable in the socket is less than 30d the tests (2) and (3) have to be done as axial and flexural tests with the expected angle $\Delta\alpha$.

(6) After fatigue loading, the test specimen shall be reloaded and shall develop a minimum tensile force equal to 92% of the actual tensile strength of the cable or 95% of the minimum uultimate tensile strength of the cable, whichever is greater. The strain at resistance must be $\geq 1,5\%$.

(7) Fatigue tests in accordance with EN 10138 should be performed with single strands, wires or bars on samples taken from each manufactured length of prestressing steel.

A.4.2 Main tension elements

A.4.2.1 Wires

(1) Wires after zinc coating if applicable should be tested in an approved testing machine.

A.4.2.2 Strands

(1) Tests should be carried out for tensile strength, 0,1% proof force and elongation according to EN 10138.

(2) Deflective tensile strength: the reduction of tensile strength should be less than 20%.

A.4.2.3 Bars

(1) Tests should be carried out for tensile strength, 0,1% proof force and elongation according to EN 10138.

A.4.3 Strands and complete cables

(1) If different sizes of one type of strand / rope are used at least 3 representative tests are required. Cables shall be tested with all load-bearing appurtenances and the test load be applied in the same way as in the structure.

A.4.4 Coefficient of friction

(1) If the coefficient of friction between strands and surfaces of saddles, clamps etc. is determined by testing

- the effects of axial loads on the diameter of the strands,
- the creeping effects from transverse preloading (on filler material and zinc coating including possible ovalisation)

shall be taken into account.

(2) In the evaluation of the test results due account shall be taken of the fact, that friction can be beneficial or adverse to an effect being considered.

A.4.5 Corrosion protection

A.4.5.1 Waterproofing

(1) To prove the durability of the cable system a test set up with “accelerated ageing” for a complete sample of the lower end of the cable with all anchoring devices stay pipe etc. should be established in which cycles of axial loads and bending and temperature cycles can be simulated.

NOTE For test details see National Annex.

A.4.5.2 Corrosion protection barriers

NOTE For test details, e.g. salt fog tests, see National Annex.

Annex B [informative] – Transport, storage, handling

(1) Spiral strands and full locked coil cables are supplied in either coils or on reels.

(2) The minimum reeling diameter should not be below 30 times the rope diameter of full locked coil ropes, 24 times the rope diameter of spiral strand ropes and 16 times the diameter of stranded ropes to prevent possible tripping of the wire.

> **NOTE** The minimum diameter depends on the protection system, storage time and temperature. Caution for unreeling at temperatures below 5 °C.

(3) If cables are stored in coils each coil should be properly ventilated (no direct ground contact) to prevent any formation of white blister which may be caused by condensation water.

(4) Cables must be handled with utmost care when being installed. Coils require a turn-table for horizontal dereeling.

(5) The following general rules shall be observed:

– remove serving not before cable has been installed,

– have a bending radius not smaller than 30 × cable diameter,

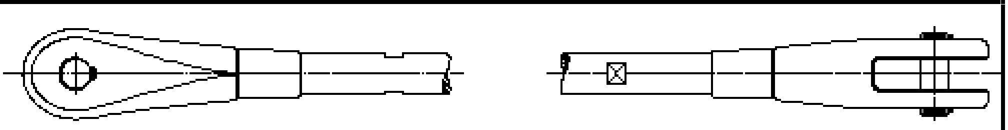
– do not bend cables, do not pull across sharp edges,

– neither twist or untwist cables (observe cable marking line).

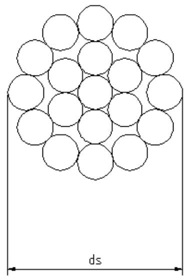
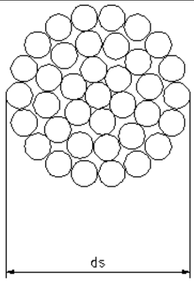
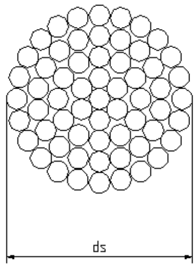
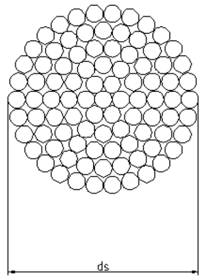
Annex C [informative] – Glossary

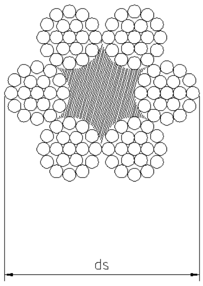
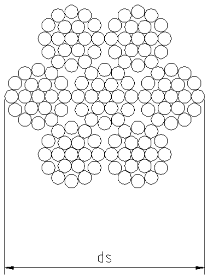
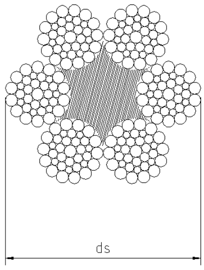
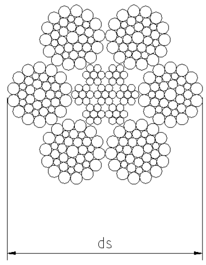
NOTE See EN 12385, Part 2.

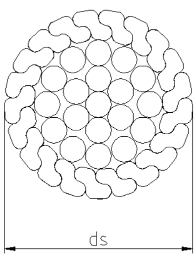
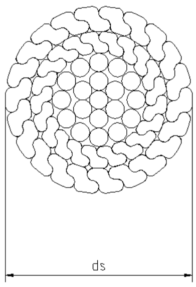
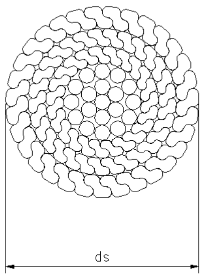
C.1 Products Group A

Tension rod system


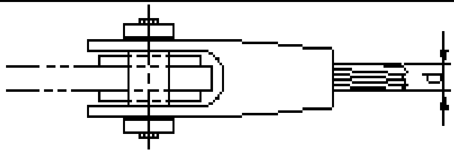
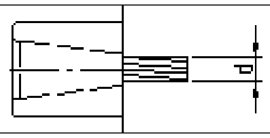
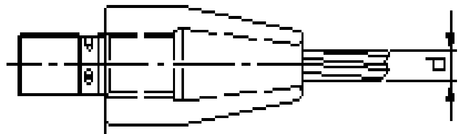
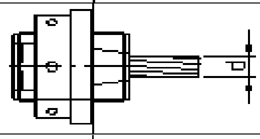
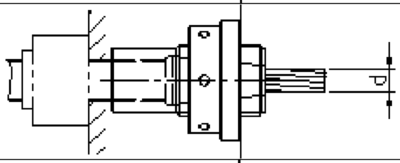
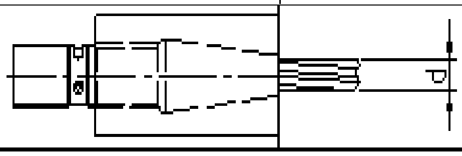
C.2 Products Group B

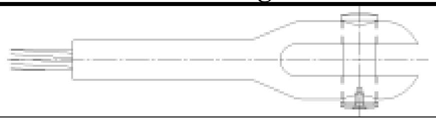
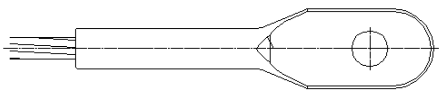
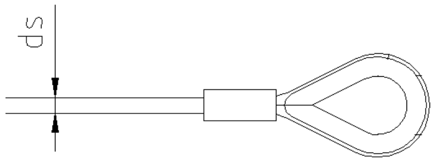
Spiral strand rope				
				
Construction	1 × 19	1 × 37	1 × 61	1 × 91
Diameter d_s [mm]	3 to 14	6 to 36	20 to 40	30 to 52
Strand	1	1	1	1
Wire per strand	19	37	61	91
Outer wire per strand	12	18	24	30
Nominal metallic area factor C	0,6	0,59	0,58	0,58
Breaking force factor K	0,525	0,52	0,51	0,51

Strand rope				
				
Construction	6 × 19 - CF	6 × 19 - CWS	6 × 36WS - CF	6 × 36 WS- CWR
Diameter d_s [mm]	6 to 40	6 to 40	6 to 40	6 to 40
Strand	6	6	6	6
Wire per strand	18	18	36	36
Outer wire per strand	12	12	14	14
Nominal metallic area factor C	0,357	0,414	0,393	0,455
Breaking force factor K	0,307	0,332	0,329	0,355

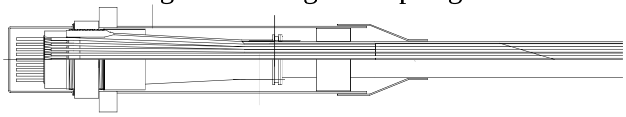
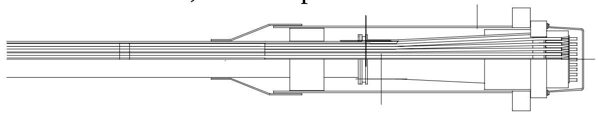
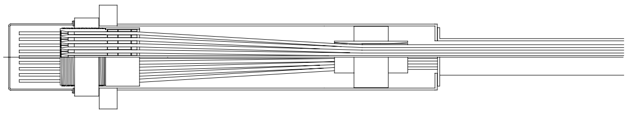
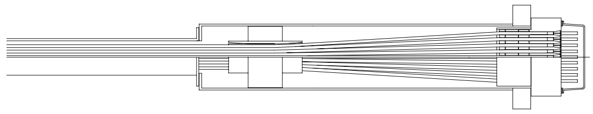
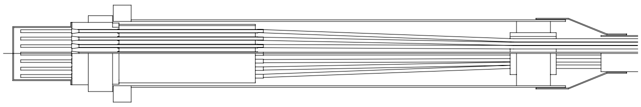
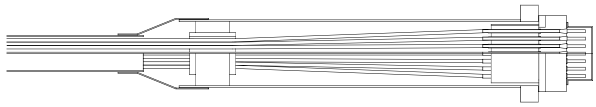
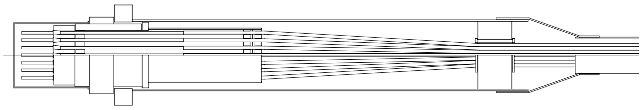
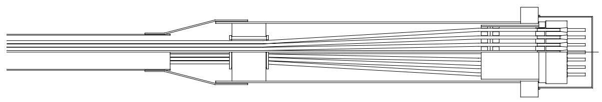
Full locked coil rope			
			
Construction	1 layer Z-wires	2 layer Z-wires	≥ 3 layer Z-wires
Diameter d_s [mm]	20 to 40	25 to 50	40 to 180
Tolerance d	+5%	+5%	+5%
Nominal metallic area factor C	0,636	0,660	0,700
breaking force factor K	0,585	0,607	0,643
NOTE Nominal metallic area factor and breaking force factor acc. EN 12385-2			

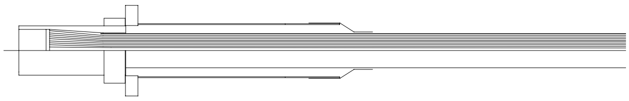
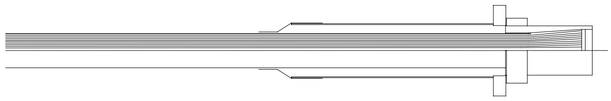
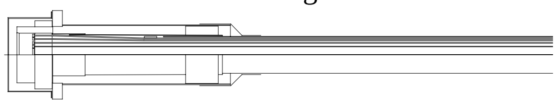
C.3 Wire rope end connectors

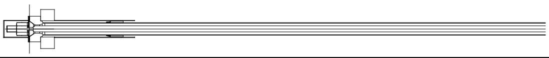
Wire rope end connectors - Metal or resin socketing acc. EN 13411-4	
Open spelter socket	
Cylindrical socket	
Conical socket with internal thread and tension rod	
Cylindrical socket with external thread and nut	
Cylindrical socket with internal and external thread and nut	
Cylindrical socket with internal thread and tension rod	

Wire rope end connectors swaged	
Open swaged socket	
Closed swaged socket	
Swaged fitting with thread	
Thimble with swaged aluminum ferrule acc. EN 13411-3	
U-bolt grip acc. EN 13411-5	*(to be added later ...)*

C.4 Product Group C

Bare strands, PE- or epoxy-coated strands	
Live end anchorage	Live end anchorage
Anchorage with wedges and postgrouted bond socket – bare strands, PE- or epoxi-coated strands	
	
Anchorage with wedges and sealing plates – PE-coated strands	
	
Anchorage with wedges and pregrouted pipe – PE-coated strands	
	
Anchorage with wedges and wax filled transition pipe – PE-coated strands	
	

Wires	
Live end anchorage	Live end anchorage
Anchorage with wires and compound filled socket	
	
Anchorage with wires and button heads filled with epoxy resin	
	

Bars	
Live end anchorage	Live end anchorage
Anchorage with single bar	
	
Anchorage with multiple bars and steel sheathing, grouted