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EC 2: Concrete Structures – Material Data

EC 2: Structures en béton – Propriétés des matériaux

EC 2: Betontragwerke – Baustoffkennwerte

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SUMMARY

Material data needed for design purposes are the subject of chapters 3 and 4.2 of EC 2 distinguishing between data for concrete, reinforcing steel, prestressing steel and prestressing devices. For material technology, general requirements, testing and quality control, reference is made in EC 2 to European Standards, in particular to ENV 206, prEN 10 080 and prEN 10 138. The main clauses of EC 2 and the above Standards are described in the present article.

RESUME

Les propriétés des matériaux requises pour le dimensionnement font l'objet des chapitres 3 et 4.2 de l'EC 2 qui concernent le béton, l'armature ainsi que les aciers et accessoires de précontrainte. Pour la technologie des matériaux, les exigences générales, les essais et le contrôle de qualité, l'EC 2 se réfère aux normes européennes, en particulier à l'ENV 206 et aux projets des normes prEN 10 080 et prEN 10 138. Les dipsositions les plus importants de l'EC 2 et des normes précitées font l'objet du présent article.

ZUSAMMENFASSUNG

Baustoffkennwerte für die Bemessung sind Gegenstand der Abschnitte 3 und 4.2 von EC 2, wobei zwischen solchen für Beton, Betonstahl, Spannstahl und Spannverfahren unterschieden wird. Hinsichtlich der Baustofftechnologie, entsprechenden allgemeinen Anforderungen, Prüfverfahren und Güteprüfungen nimmt EC 2 Bezug auf Europäische Normen, insbesondere auf ENV 206 sowie auf die Entwürfe von prEN 10 080 und prEN 10 138. Die wichtigsten Festlegungen in EC 2 und den vorgenannten Normen sind im vorliegenden Beitrag zusammengefasst.

1 GENERAL-REFERENCE DOCUMENTS

Material properties are the subject of Chapter 3 of Part 1 of Eurocode 2, subdivided into Sub-Chapters

3.1 Concrete
3.2 Reinforcing steel
3.3 Prestressing steel
3.4 Prestressing devices.

Chapter 3 is relatively concise, summarizing only the data for design of concrete structures and referring for production methods, general requirements, testing and quality control to other Standards such as:

- ENV 206 Concrete-Performance, production, placing and compliance criteria (issued 1990);

- prEN 10 080 Steel for the reinforcement of concrete. Weldable ribbed reinforcing steel B 500. Technical delivery conditions for bars, coils and welded fabric (draft 1991);

- prEN 10 138 Prestressing steel

Part 1:	General requirements	(draft 1992)
Part 2:	Stress relieved cold drawn wire	(draft 1992)
Part 3:	Strand	(draft 1992)
Part 4:	Hot rolled and processed bars	(draft 1992)
Part 5:	Quenched and tempered wire	(draft 1992)

Design data of materials are given in Chapter 4.2 of EC2. Lightweight aggregate concrete is considered in ENV 206 but not in Part 1 of Eurocode 2. It is subject of an additional Part 1C which is actually under preparation.

2 CONCRETE
2.1 Technology (ENV 206)

The main topics of ENV 206 are the basic requirements for concrete composition and constituents, the requirements for durability, the properties of fresh and hardened conrete, the specifications for mixes and the requirements for the operations of production (mixing), transport, placing and curing of fresh concrete and finally the quality control procedures to ensure that the specified requirements are satisfied.

The following paragraphs give a survey of those topics which are of direct importance for the designer using Eurocode 2.

Concrete is classified in classes according to its compressive *strength*, based on characteristic strength determined on cylinders or cubes (see section 2.2 "Strength" below).

Durability requirements are related to environmental conditions classified in Table 1: Exposure classes related to environmental conditions (identical with Table 2 of ENV 206 and 4.1 of Eurocode 2).

Table 1: Exposure classes related to environmental conditions

Exposure class		Examples of environmental conditions
1 dry environment		interior of dwellings or offices[1]
2 humid environment	a without frost	- interior of buildings where humidity is high (e.g. laundries) - exterior components - components in non-aggressive soil and/or water
	b with frost	- exterior components exposed to frost - components in non-aggressive soil and /or water and exposed to frost - interior components where the humidity is high and exposed to frost
3 humid environment with frost and de-icing agents		- interior and exterior components exposed to frost and de-icing agents
4 seawater environment	a without frost	- components completely or partially submerged in seawater, or in the splash zone - components in saturated salt air (coastal air)
	b with frost	- components partially submerged in seawater or in the splash zone and exposed to frost - componenets in sturated salt air and exposed to frost
The following classes may occur alone or in combination with the above classes:		
5 aggressive chemical environment[2]	a	- slightly aggressive chemical environment (gas, liquid or solid) - aggressive industrial atmosphere
	b	moderately aggressive chemical environment (gas, liquid or solid)
	c	highly aggressive chemical environment (gas, liquid or solid)

1) This exposure class is valid only as long as during construction the structure or some of its components is not exposed to more severe conditions over a prolonged period of time

2) Chemically aggressive environments are classified in ISO 9690. The following equivalent exposure conditions may be used:
Exposure class 5a: ISO classification A1G, A1L, A1S
Exposure class 5b: ISO classification A2G, A2L, A2S
Exposure class 5c: ISO classification A3G, A3L, A3S

Durability requirements for concrete are given in Table 3 of ENV 206, related to the above exposure classes. They concern mainly the maximum water/cement ratio, the minimum cement content and, in case of exposure to frost, also the minimum air content of fresh concrete.

As an example, for the normal conditions in residential buildings, i.e. exposure class 2a, the maximum w/c ratio admissible for reinforced and prestressed concrete is 0.60, the minimum cement content has to be 280 kg/m^3 for reinforced and 300 kg/m^3 for prestressed concrete.

Minimum requirements for *cover* to reinforcement in view of durability are given in Eurocode 2. The minimum values for exposure class 2a are 20 mm for reinforcing steel and 30 mm for prestressing steel.

The important effect of *curing* and of the *quality* of the concrete cover has been recognised during the last years, and got full attention in ENV 206 (Para 10.6). Conditions and methods of curing are given there. Depending on the strength development of the concrete (rapid, medium or slow), on the temperature of concrete during curing and the ambient conditions, Table 12 in ENV 206 gives mimimum curing periods. They vary between 1 day under best conditions up to 10 days under the worst.

Quality control is dealt with in Chapter 11 in ENV 206. It consists of two distinct, but interconnected parts, namely *production control* and *compliance control.*

Production control to be carried out by the contractor, comprises material control, equipment control, control of production procedure and concrete properties. The inspections and tests to be carried out are laid down in corresponding tables (Tables 14 to 17).

Conformity control is done by using one of the following systems:

Case 1 - Verification by a certification body
Case 2 - Verification by the client.

Sampling plans and conformity criteria are laid down in Chapter 11 of ENV 206 for the different possible cases. Conformity criteria for compressive strength may be one of the following:

<u>Criterion 1</u> (for 6 or more consecutive samples):

$$\left.\begin{array}{l} \bar{x}_n \geq f_{ck} + \lambda * s_n \\ x_{min} \geq f_{ck} - k \end{array}\right\} \qquad (1)$$

Values for λ and k may be taken from Table 19 in ENV 206 according to the number of samples n.

<u>Criterion 2</u> (for 3 samples):

$$\left.\begin{array}{l} \bar{x}_3 \geq f_{ck} + 5 \\ x_{min} \geq f_{ck} - 1 \end{array}\right\} \qquad (2)$$

2.2 Strength

Eurocode 2 is based on the characteristic 28 days compressive strength f_{ck} measured on *c y l i n d e r s* and defined as that value of strength below which 5 % of all possible strength test results for the specified concrete may be expected to fall.

Design is based on a strength class of concrete in accordance with ENV 206. These classes are related to the cylinder strength f_{ck} and the cube strength $f_{ck,cube}$, the latter only mentioned as an alternative method to prove compliance.

The tensile strength may be derived from the compressive strength by the equation

$$f_{ctm} = 0{,}30 * f_{ck}^{2/3}, \tag{3}$$

f_{ctm} being the mean tensile strength in uniaxial tension.

For design purposes, also 5% and 95% fractiles of the characteristic tensile strength:

$$\begin{aligned} f_{ctk,0,05} &= 0{,}7 * f_{ctm} \\ f_{ctk,0,95} &= 1{,}3 * f_{ctm} \end{aligned} \tag{4}$$

have to be considered, depending on the problem under consideration.

The values of strength are given in Table 2 (identical with Table 3.1 of EC2). Design values are derived from the characteristic values by applying the appropriate partial safety factor γ_c for concrete, such as:

a) design value of concrete cylinder compressive strength:

$$f_{cd} = \frac{f_{ck}}{\gamma_c} \tag{5}$$

b) the basic design shear strength of members without shear reinforcement (Table 4.8):

$$\tau_{Rd} = \frac{0{,}25*f_{ctk,0,05}}{\gamma_c} \tag{6}$$

c) the design values for the ultimate bond stress for good bond conditions:

$$f_{bd} = \frac{0{,}36\sqrt{f_{ck}}}{\gamma_c} \quad \text{for plain bars} \tag{7}$$

$$f_{bd} = \frac{2{,}25*f_{ctk,0,05}}{\gamma_c} \quad \text{for high bond bars.} \tag{8}$$

Table 2: Concrete strength classes, characteristic compressive strengths f_{ck} (cylinder) mean tensile strength f_{ctm}, and characteristic tensile strengths f_{ctk} of the concrete (in N/mm²). (The classification of concrete eg, C20/25 refers to cylinder/cube strength as defined in Section 7.3.1.1 of ENV 206).

Strength Class of Concrete	C12/15	C16/20	C20/25	C25/30	C30/37	C35/45	C40/50	C45/55	C50/60
f_{ck}	12	16	20	25	30	35	40	45	50
f_{ctm}	1.6	1.9	2.2	2.6	2.9	3.2	3.5	3.8	4.1
$f_{ctk,0.05}$	1.1	1.3	1.5	1.8	2.0	2.2	2.5	2.7	2.9
$f_{ctk,0.95}$	2.0	2.5	2.9	3.3	3.8	4.2	4.6	4.9	5.3

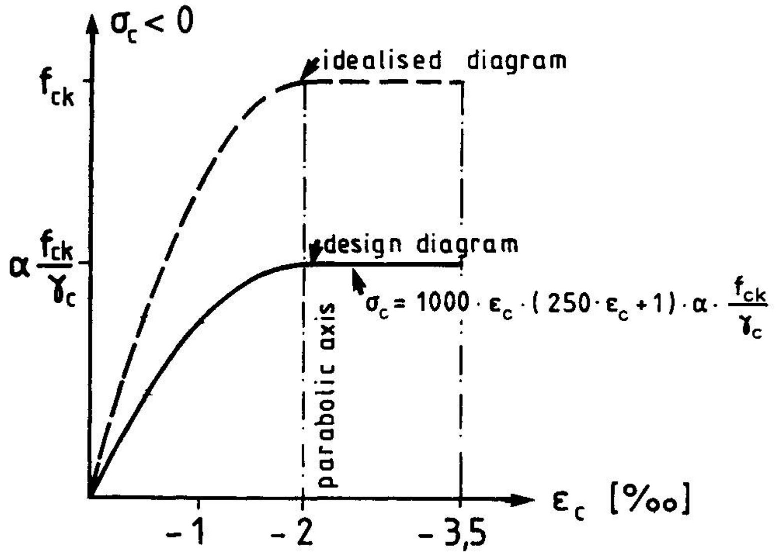

Figure 1: Parabolic-rectangular stress-strain diagram for concrete in compression

2.3 Deformation Properties

The values of the deformation properties depend not only upon the concrete strength class but also upon other parameters such as the properties of the aggregates, the mix design, the environment and the conditions of use in general.

Where an accurate calculation is considered necessary, they should be established from known data appropriate to the particular conditions. Nevertheless, for many calculations an appropriate estimate will usually be sufficient and data for *instantaneous* and *time dependent* deformations of concrete for those cases are given in Para 3.1.2.5 and 4.2.1.3 in EC2.

The general form of the *stress-strain* diagram for uniaxial compression is shown schematically in Figure 3.1 of EC2. Idealized stress-strain diagrams for design calculations are given in 4.2.1.3.3: for structural analysis the idealization is given by a mathematical model expressed by the function (4.2), for cross-section design the preferred idealization is the parabolic rectangular diagram which is shown in Figure 1 of this paper (identical to Figure 4.2 of EC2).

Values of the secant modulus of elasticity E_{cm} are given in Table 3.2 of EC2.

Poisson's ratio for elastic strain may be taken equal to 0,2, if cracking is permitted for concrete in tension it may be assumed to zero.

Where thermal expansion is not of great influence, the *coefficient of thermal expansion* may be taken equal to $10 \cdot 10^{-6}/°C$.

For *time dependent* deformations the data are given in EC2-

Table 3.3 - Final creep coefficient $\phi(\infty, t_0)$
Table 3.4 - Final shrinkage strains $\varepsilon_{cs\infty}$.

2.4 Lightweight aggregate concrete

The properties and the technology of lightweight aggregate concrete are given in ENV 206 in addition to those of normal weight concrete.

Lightweight aggregate concrete, denoted by the symbol LC, is classified according to its density in Table 9 of ENV 206, which distinguishes density classes from 1,0 (density 901 to 1000 kg/m^3), 1,2 (density 1001 to 1200 kg/m^3), ... up to class 2,0 (density 1801 to 2000 kg/m^3). All data different from those in Eurocode 2 Part 1 for normal weight concrete are given in Part 1C which is complementary to Part 1 for the use of lightweight aggregate concrete and drafted according to same table of contents.

3 REINFORCING STEEL

Section 3.2 - Reinforcing steel - of Eurocode 2 applies to bars, coiled rods and welded fabrics.

The products are classified according to grade (denoting f_{yk}), class (indicating the ductility characteristics), size, surface characteristics and weldability.

Two shapes of *surface characteristics* are defined:

- ribbed bars, indicated by the value of the projected rib factor f_{Rk}, resulting in high bond action when the characteristic value f_{Rk} is not less than that specified in EN 10 080;
- Plain smooth bars, resulting in low bond action (ribbed bars not satisfying the requirements for f_{Rk} should be treated as plain bars with respect to bond).

Two *classes of ductility* are defined:

- High (H): $\varepsilon_{uk} > 5{,}0$ %; value of $(f_t/f_y)_k > 1{,}08$ (9)
- Normal (N): $\varepsilon_{uk} > 2{,}5$ %; value of $(f_t/f_y)_k > 1{,}05$

It is likely that, during the ENV period, a higher ductility steel (class S) will be introduced for use in seismic regions.

For *structural analysis* in ultimate limit states, the plastic approach may be used only for very ductile structural elements where high ductility steel is used (Para 2.5.3.2.2). Using linear analysis with redistribution, the condition related to the steel, allowing the omitance of an explicit check on the rotation capacity of critical zones is

$\delta \geq 0{,}7$ for class H and $\delta \geq 0{,}85$ for class N, (10)

δ being the ratio of the redistributed moment to the moment before redistribution (para 2.5.3.4.2).

For overall analysis, an idealized bi-linear *stress-strain diagram* may generally be used. It is given as Figure 2 of this paper (identical to Figure 4.5 of EC2). It may be modified, e.g. with a flatter or horizontal top branch, for local verifications and section design.

prENV 10 080 gives the methods of production, the specified characteristics, the methods of testing and the methods of attestation of conformity for reinforcing steel.

It considers weldable steel, specifies f_{Rk} in function of the diameter (Table 5 of prEN 10 080), considers one grade $f_{yk} \geq 500$ N/mm², and two ductility classes H and N, denominated B 500 H and B 500 N in Table 3 of this paper (identical to Table 1 of prEN 10 080).

Table 3: Properties of reinforcing steel grades B 500 H and B 500 N of various product forms

1	Product form	Bars		Coils		Welded Fabric		p 1)
2	Steel grade	B 500 H	B 500 N 2)	B 500 H	B 500 N	B 500 H	B 500 N	
3	Nominal size 3) (mm)	6 to 40	6 to 16	6 to 16	4 to 16	6 to 16	4 to 16	-
4	Yield strength R_e (N/mm²)	500	500	500	500	500	500	0,95
5	Ratio R_m/R_e *)	1,08	1,03*) or 1,05	1,08	1,03*) or 1,05	1,08	1,03*) or 1,05	0,95*)
6	Total elongation *) at max. force A_{gt} (%)	5,0	2,0 *) or 2,5	5,0	2,0*) or 2,5	5,0	2,0 *) or 2,5	0,95*)
7	Suitability for bending (Rebend test)	Table 3	Table 3	Table 3	Table 3	Table 3	Table 3	
8	Fatigue strength (N/mm²) (stress range $2\sigma_A$)	200 4)	200	200	200	100	100	*) 5)
9	Strength of welded joints (N)	-	-	-	-	$0{,}3.R_e$xA 6)	$0{,}3.R_e$xA 6)	0,95
10	Permissible deviation from nominal mass (%)	-4,5	-4,5	-4,5	-4,5	-4,5	-4,5	0,95
11	Projected rib area f_R	Table 5	Table 5	Table 5	Table 5	Table 5	Table 5	7)
12	Chemical composition and carbon equivalent	Table 2	Table 2	Table 2	Table 2	Table 2	Table 2	8)

1) See 3.6 (1-α=0,90 in all cases).
2) Cut from coil and straightened.
3) Details see Table 4.
4) 150 N/mm² for nominal sizes > 20 mm.
5) Type test, see note to 5.5.4.
6) A: Nominal cross sectional area of the thicker wire.
7) Minimum values.
8) Maximum values.
*) Values and/or their means of evaluation under discussion.

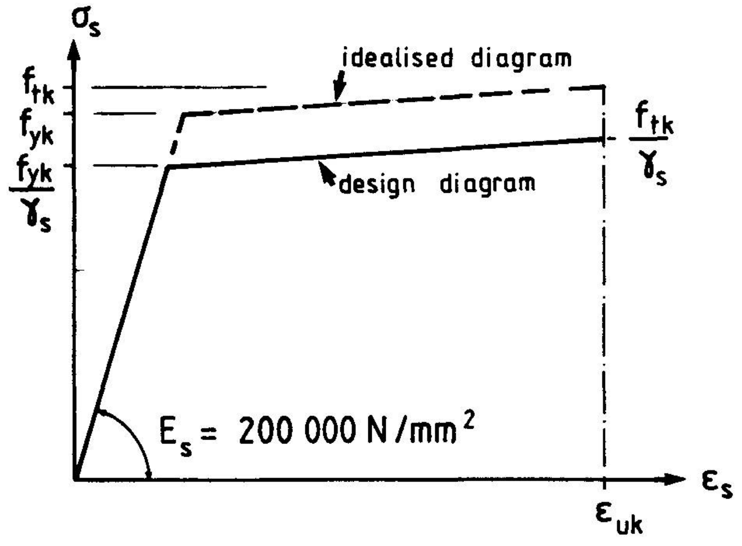

Figure 2: Design stress-strain diagram for reinforcing steel

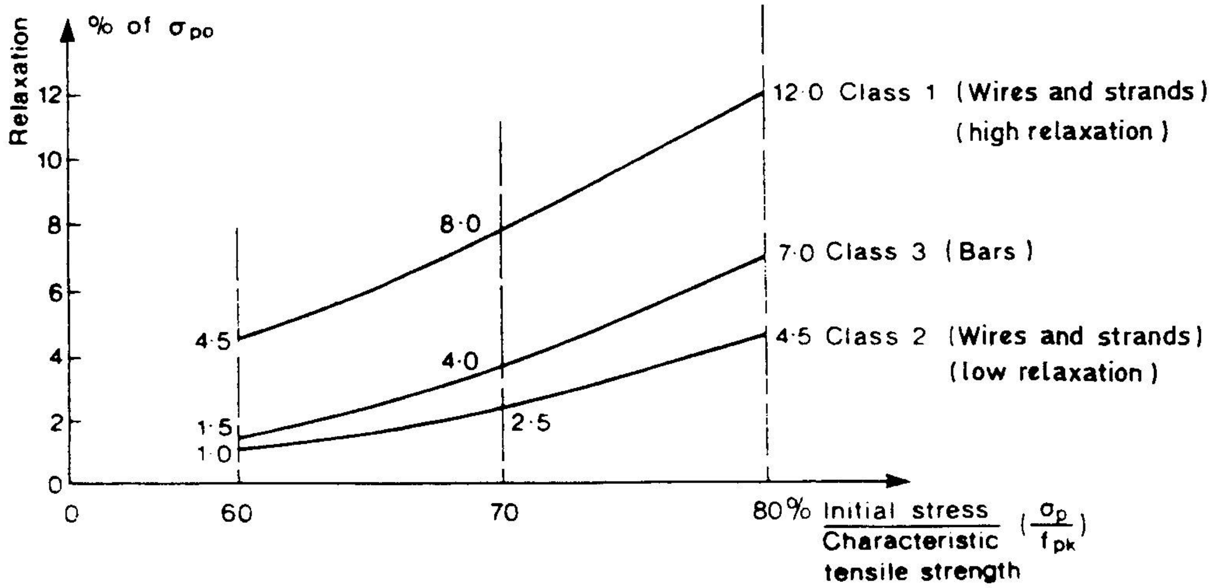

Figure 3: Relaxation losses after 1000 h at 20° C for relaxation classes

1: Wires, strands with high relaxation
2: Wires, strands with low relaxation
3: Prestressing Bars

4 PRESTRESSING STEEL

Section 3.3 "Prestressing Steel" of Eurocode 2 applies to wires, bars and strands used as prestressing tendons.

The products are classified according to grade ($f_{p0,1k}$ and f_{pk}), class (indicating the relaxation behaviour), size and surface characteristics.

Three *classes of relaxation* are defined (Figure 3):

Class 1: for wires and strands, high relaxation
Class 2: for wires and strands, low relaxation
Class 3: for bars.

According prEN 10 138-1, curves for relaxation of load shall be established, at a nominal temperature of 20° C, for a period of 1.000 h from an initial load of 70 % of the actual breaking load.

According 4.2.3.4.1 of Eurocode 2 the long term values of the relaxation losses may be assumed to be three times the relaxation losses after 1000 h; Fig. 3 gives relaxation losses for other values of the initial stress, needed for design purposes.

prEN 10 138-2 and 3 specify low relaxation, 2,5 %, respectively for all stress relieved cold drawn wire and strand.

Strength is specified by the characteristic breaking load, the characteristic 0,1% proof load and the maximum load (which is 1,15 * characteristic breaking load for wire and strand according prEN 10 138-2 and 3).

The products shall have adequate *ductility* in elongation and bending (para 3.3.4.3). Adequate ductility is assumed by specified minimum elongation at maximum load (3,5 % for wire and strand according prEN 10 138-2 and 3) and by requirements for bendability in reverse bends testing for wire and constriction at break for wire and strand.

Stress-strain diagrams for the products shall be prepared and made available by the producer as an annex to the certificate accompanying the consignment. Such as for reinforcement steel, an idealized bi-linear diagram (Figure 4.6 of EC2) may generally be used for design purposes.

The products shall have adequate *fatigue strength*. According prEN 10 138-1 the material shall withstand without failure two million cycles of stress fluctuation down from a maximum stress of 70 % of the actual strength. The fluctuating stress range is 200 N/mm² for smooth wires, 180 N/mm² for indented wires, 190 N/mm² for smooth wire strands and 170 N/mm² of indented wire strands.

Dimensions and properties of stress relieved cold drawn wires are given in Table 4 (identical to Table 2 of prEN 10 138-2) and those of strands in Table 1 of prEN 10 138-3.

Table 4: Dimensions and properties of stress relieved cold drawn wire

Nominal (1)				Specified									
Diameter d	Tensile strength (2)	Cross sectional area	Mass (3)	Tolerance on cross sectional area	Characteristic breaking load F_m	Characteristic 0.1% proof load (4) $F_{p0.1}$	Maximum breaking load (5)	Minimum elongation at max load $L_0 \geq 200$ min Agt	Constriction at break	Minimum number of reverse bends	Bend radius for reverse bends	Max relaxation at 1000 h (6)	Fatigue stress range
mm	N/mm²	mm²	g/m	+/-mm²	kN	kN	kN	%			mm	%	N/mm²
4.0	1770	12.6	98.9	0.25	22.3	19.2	25.6	) for	) for	) 4 for	10	) for	) 200
4.0	1860	12.6	98.9	0.25	23.4	20.1	26.9	) all	) all	) smooth	10	) all	) for
5.0	1670	19.6	154	0.39	32.7	28.1	37.6	) wires	) wires	) wires	15	) wires	) smooth
5.0	1770	19.6	154	0.39	34.7	29.8	39.9	) 3.5 %	) a ductile	)	15	) 2.5 %	) wires
6.0	1670	28.3	222	0.47	47.3	40.7	54.4	)	) break	)	15	)	)
6.0	1770	28.3	222	0.47	50.1	43.1	57.6	)	) visible	) 3 for	15	)	) 180
7.0	1670	38.5	302	0.58	64.3	55.3	73.9	)	) to the	) indented	20	)	) for
7.5	1670	44.2	347	0.66	73.8	63.5	84.9	)	) unaided	) wires	20	)	) indented
8.0	1670	50.3	395	0.75	84.0	72.2	96.6	)	) eye	)	20	)	) wires
9.4	1570	69.4	545	1.00	109.0	90.5	125.4	)	)	)	25	)	)
10.0	1570	78.5	616	1.10	123.0	102.0	141.5	)	)	)	25	)	)

Note (1) The nominal modulus of elasticity may be taken as 205 kN/mm².

Note (2) The nominal tensile strength is calculated from the nominal cross-section and the specified characteristic breaking load.

Note (3) The mass is calculated from the nominal cross-section area and a density value of 7.85 kg/dm^3.

Note (4) For wires larger than 8 mm the specified characteristic proof load is approximately 83 % of the specified characteristic breaking load.

For wires of 8 mm and smaller the corresponding figure is 86 %.

Note (5) The maximum breaking load is 1.15 * specified characteristic breaking load.

Note (6) For nominal diameters 9.4 mm and 7.5 mm the relaxation requirement may be varied by agreement between supplier and purchaser.

The procedure of attestation of conformity by *certification* is published as Annex A of prEN 10 138-1 for detailed comments and will be covered by a separate document.

5 PRESTRESSING DEVICES

Chapter 3.4 of EC2 summarizes only the basic requirements for anchorages and couplers, ducts and sheath and for the design of anchorage zones. For the quantification of these requirements, reference is made to relevant (future) Standards and approval documents.

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