TITLE 5 DESIGN

CHAPTER 8

INFORMATION CONCERNING MATERIALS TO BE USED IN THE DESIGN

Article 38. Characteristics of steel for reinforcements

38.1 General

The characteristics of the steel used for the design described in this article, are referred to the properties of the passive reinforcements placed in the structural element in accord to the article 3.2.1 in the EN 1992-1-1.

38.2 Characteristic stress-strain diagram for passive reinforcement steel

The characteristic stress-strain diagram is the diagram used as a basis for the calculations and associated in this Code with a percentage of 5% of the lowest stress-strain diagrams.

The characteristic stress-strain diagram for tensioned steel is the diagram whose stress values, corresponding to strains not exceeding 10 per 1000, have a confidence level of 95% relative to the values obtained during tensile tests conducted in accordance with UNE EN 10080. The same diagram may be adopted for compression.

In the absence of accurate experimental data, the characteristic diagram may be assumed to adopt the shape in figure 38.2, and this diagram may be taken as being characteristic, if the standardised values for the yield stress given in Article 32 are adopted. The compression arm shall always be symmetrical to the tension arm, in relation to the origin.

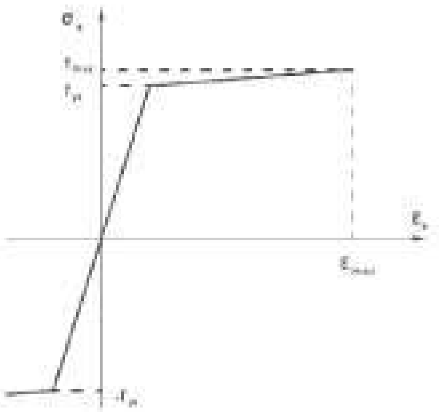

Figure 38.2. Characteristic stress-strain diagram for passive reinforcements

38.3 Design strength of steel in passive reinforcements

The following value, f_{yd} shall be considered to be the design yield strength of the steel:

$$f_{yd} = \frac{f_{yk}}{\gamma_s}$$

In which f_{yk} is the characteristic yield stress and γ_s is the partial safety coefficient defined in Article 15.

The expressions indicated are valid for tension and compression.

If steels with different yield stresses are used in one section, each shall be considered in the calculation, together with its corresponding diagram.

38.4 Design stress-strain diagram for steel in passive reinforcements

The design stress-strain diagram for steel in passive reinforcements (in tension or compression), shall be calculated from the characteristic diagram using oblique affinity, parallel to Hooke's line, in a ratio of $1/\gamma_s$.

When the diagram in figure 38.2 is used, the design diagram for figure 38.4 is obtained, in which it may be noted that, starting from f_{yd} a second leg, with a positive slope obtained using oblique affinity from the characteristic diagram, or a second horizontal leg, with the latter being generally sufficiently accurate, can be considered,.

Other simplified design diagrams may be used, provided that they produce results that are sufficiently confirmed by experience.

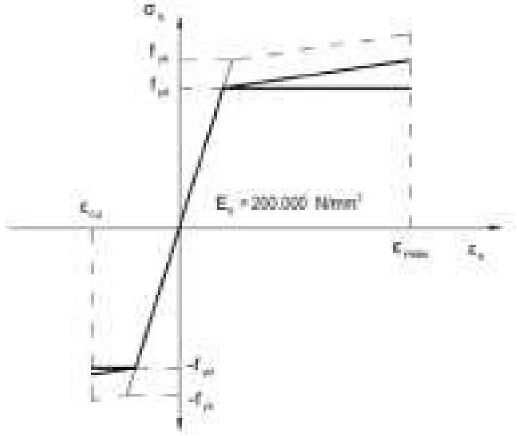

Figure 38.4. Design stress-strain diagram in passive reinforcements

A maximum strain of steel in tension of ε_{max} – *0.01*, shall be adopted in the design

38.5 Characteristic stress-strain diagram of steel in active reinforcements

The characteristic stress-strain diagram for the steel set out by its manufacturer may be used in active reinforcements (wire, bar or strand) up to a strain of at least $\varepsilon_p = 0.010$, and so that for a given strain the tensions are exceeded in 95% of cases.

If this guaranteed diagram is not available, the diagram shown in figure 38.5 may be used. This diagram comprises a first straight section with slope ε_p and a second curve section, starting from 0.7 f_{pk}, defined by the following expression:

$$\varepsilon_p = \frac{\sigma_p}{E_p} + 0{,}823\left(\frac{\sigma_p}{f_{pk}} - 0{,}7\right)^5 \qquad para \quad \sigma_p \geq 0{,}7\, f_{pk}$$

In which E_p is the modulus of longitudinal strain defined in 38.8.

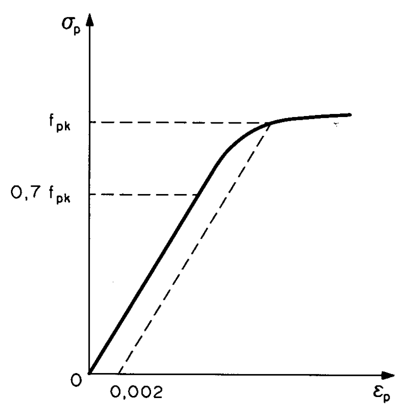

Figure 38.5. Characteristic stress-strain diagram for active reinforcements

38.6 Design strength of steel in active reinforcements

The following shall be used for the design strength of steel in active reinforcements.

$$f_{pd} = \frac{f_{pk}}{\gamma_s}$$

In which f_{pk} is the characteristic yield stress and γ_s is the partial safety coefficient of the steel indicated in Article 15.

38.7 Design stress-strain diagram for steel in active reinforcements

The design stress-strain diagram for the steel in active reinforcements shall be calculated from the corresponding characteristic diagram using oblique affinity, parallel to Hooke's straight line, in a ratio of $1/\gamma_s$ (see figure 38.7.a).

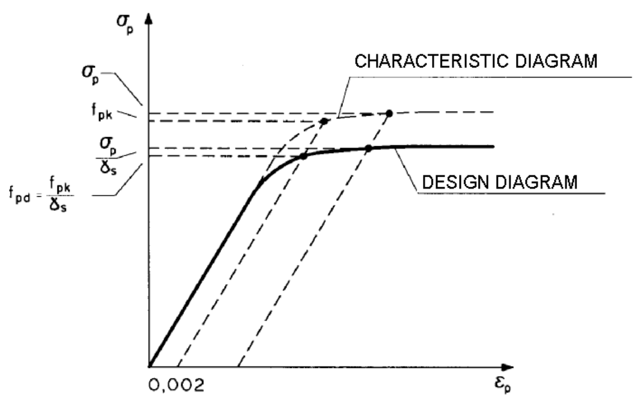

Figure 38.7.a. Design stress-strain diagram in active reinforcements

For simplification purposes, based on f_{pd}, $\sigma_p = f_{pd}$ may be used (see figure 38.7b)

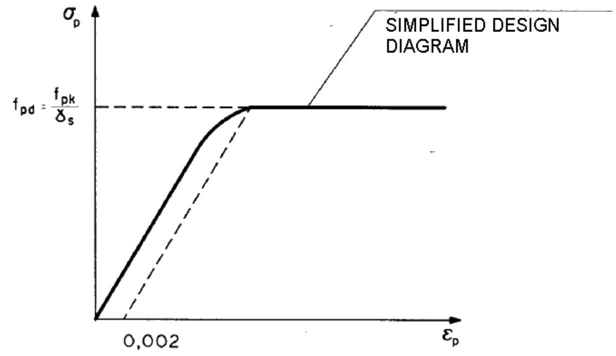

Figure 38.7.b. Design stress-strain diagram in active reinforcements

38.8 Modulus of longitudinal strain of steel in active reinforcements

The value of E_p = 200,000 N/mm^2, may be taken as the modulus of longitudinal strain in steel in reinforcements comprising wires or bars, unless experimentally otherwise confirmed.

The values set by the manufacturer or experimentally determined may be adopted in strands as the reiterative and noval values. In the characteristic diagram (see 38.5) the value of the reiterative modulus shall be taken. If no earlier experimental values are available prior to the project, the value of E_p = 190,000 N/mm^2 may be adopted.

When checking elongation during tensioning, the value of the noval modulus value determined experimentally shall be used.

38.9 Relaxation of steel in active reinforcements

The relaxation ρ of steel at constant length, for an initial tensile stress of $\sigma_{pi} = \alpha f_{max}$ with the fraction α, being between 0.5 and 0.8 for time *t,* may be estimated using the following expression:

$$\log \rho = \log \frac{\Delta \sigma_p}{\sigma_{pi}} = K_1 + K_2 \log t$$

in which:

$\Delta_{\sigma p}$ Loss of stress due to relaxation at constant length at the end of time *t,* in hours.

K_1, K_2 Coefficients which vary according to the type of steel and the initial stress (figure 38.9).

The steel manufacturer shall supply the relaxation values at 120 h and 1,000 h, for initial stresses of 0.6, 0.7 and 0.8 of f_{max} at a temperature of 20±1°C and shall guarantee the value at 1,000 h for α = 0.7. From these relaxation values, the coefficients K_1 and K_2 for α = 0.6, 0.7 and 0.8, may be obtained.

In order to obtain relaxation with another value of α, this may be linearly interpolated by allowing for α = 0.5; ρ = 0.

The value which is obtained for the estimated life of the structure, expressed in hours, or 1,000,000 hours in the absence of this information, may be taken as the final value of p_f .

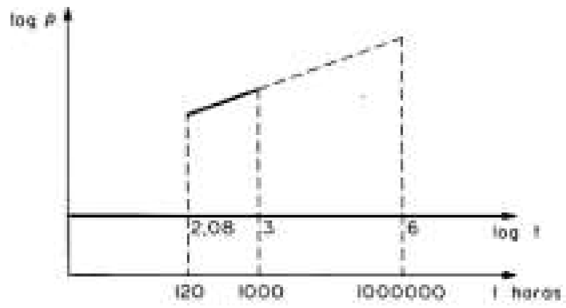

Figure 38.9

38.10 Fatigue characteristics of active and passive reinforcements

The variation in maximum stress, due to fatigue loading, shall be less than the limit fatigue values indicated in table 38.10.

Table 38.10 Fatigue limit for passive and active reinforcements

Type of reinforcement	Fatigue Limit $\Delta\sigma_D$ [N/mm^2]	
	Direct bonding	Bonding inside steel sheaths
Passive reinforcements: - Bars - Electro-welded mesh	 150 100	 -- --
Active reinforcements: - Wires - 7-wire strands - Pre-tensioned bars	 150 150 --	 100 100 100

In the absence of specific and representative results for bent bars, the fatigue limit indicated in table 38.10 shall be reduced depending on the following factor:

$$\Delta\sigma_{D,red} = \left(1 - 3\frac{d}{D}\right)\Delta\sigma_D$$

in which:

d Diameter of the bar.

D Bending diameter.

No reduction in the fatigue limit will be necessary in vertical stirrups with a diameter of 10 mm or less.

38.11 Fatigue characteristics of anchorage devices and splicing of active reinforcement

Anchorage and splicing devices shall be located, wherever possible, in sections where the minimum variations in stresses occur.

Generally, the fatigue limit for this type of element is lower than the limit for reinforcements, and shall be supplied by the manufacturer after specific and representative tests have been conducted.

Article 39. Characteristics of the concrete

39.1 Definitions

The design characteristic strength, f_{ck}, is the value adopted in the design for compression strength, as the basis for calculations. It is also called the specified characteristic strength or design strength.

The actual on-site characteristic strength value, $f_{c\ real}$, is the value corresponding to the 5% quantile in the compression strength distribution of the concrete supplied to the site.

The estimated characteristic strength value, $f_{c\ est}$, is the value that calculates or quantifies the actual characteristic strength on site based on a finite number of standardised compression strength test results on test pieces collected in situ. It can be abbreviated to characteristic strength.

The average tensile strength value, $f_{ct,m}$, may be calculated, in the absence of test results, using the following:

$$f_{ct,m} = 0{,}30\, f_{ck}^{2/3} \ \text{ if } \ f_{ck} \le 50\ N/mm^2$$

$$f_{ct,m} = 0{,}58\, f_{ck}^{1/2} \ \text{ if } \ f_{ck} > 50\ N/mm^2$$

If test results are not available, the characteristic strength may be allowed to be less than the tensile strength, $f_{ct,k}$, (corresponding to the 5% quantile) indicated, as a function of the average tensile strength, $f_{ct,m}$, using the following formula:

$$f_{ct,k} = 0.70\, f_{ct,m}$$

The average flexural strength, $f_{ct,m,fl}$, is indicated by the following expression, which is a function of the total depth of the element h in mm:

$$f_{ct,m,fl} = \max\{(1{,}6 - h/1000)\, f_{ct,m};\ f_{ct,m}\}$$

The units are N and mm in all these formulae.

In this Code, the expression characteristic tensile strength refers always, unless otherwise indicated, to the lower characteristic tensile strength, $f_{ct,k}$.

39.2 Identification of concretes

Concretes shall be identified in accordance with the following format (which shall be shown in the drawings and the structure's Project Technical Specifications):

T - R / C / TM / A

In which:

T Symbol which will be HM in the case of a mass concrete , HA in the case of a reinforced concrete, and HP in the case of a pre-stressed concrete.
R Specified characteristic strength, in N/mm^2.
C Initial letter showing the type of consistency, as defined in 31.5.
TM Maximum aggregate size in millimeters as defined in 28.3.
A Designation of the environment, in accordance with 8.2.1.

It is recommended that the following series is used for the specified characteristic strength:

20, 25, 30, 35, 40, 45, 50, 55, 60, 70, 80, 90, 100

In which the figures indicate the specified characteristic compression strength of the concrete at 28 days, expressed in N/mm^2.

The strength of 20 N/mm^2 is limited to mass concretes.

The concrete prescribed shall be such that, in addition to mechanical strength, it ensures compliance with the durability requirements (minimum cement content and maximum water/cement ratio) corresponding to the environment of the structural element and indicated in 37.3.

39.3 Characteristic stress-strain diagram of the concrete

The characteristic stress-strain diagram of the concrete depends on a large number of variables: age of the concrete, duration of loading, shape and type of cross-section, nature of the set of load factors in a cross-section, type of aggregate, moisture level etc.

Given the difficulty of providing a characteristic stress-strain diagram for concrete applicable to each specific design, the simplified characteristic diagrams such as those provided in Article 21 may be used for practical purposes,.

39.4 Design strength of the concrete

The following value shall be used as the design compression strength of the concrete:

$$f_{cd} = \alpha_{cc} \frac{f_{ck}}{\gamma_c}$$

in which:

- α_{cc} Factor which takes account of the fatigue in the concrete when it is subjected to high levels of compression stress due to long duration loads. The value of α_{cc} = 1, is used in this Code.
- f_{ck} The characteristic design strength.
- γ_c Partial safety coefficient used in the values indicated in Article 15.

The following value shall be considered as the concrete's design tensile strength.

$$f_{ctd} = \alpha_{ct} \frac{f_{ct,k}}{\gamma_c}$$

in which :

- α_{cc} Factor which takes account of the fatigue in the concrete when it is subjected to high levels of compression stress due to long duration loads. The value of α_{ct} = 1, is used in this Code.
- $f_{ct,k}$ Characteristic tensile strength.
- γ_c Partial safety coefficient used in the values indicated in Article 15.

39.5 Design stress-strain diagram for the concrete

When designing sections subjected to a normal set of load factors in cross-section, one of the following diagrams shall be used for Ultimate Limit States:

a) Rectangular parabola diagram

This comprises a parabola of degree n and a rectilinear segment (Figure 39.5.a). The vertex of the parabola is on the abscissa ε_{c0} (strain of the concrete under ultimate load in simple compression), and the end vertex of the rectangle is on the abscissa ε_{cu} ((ultimate bending strain of the concrete). The maximum ordinate in this diagram corresponds to a compression of f_{cd}.

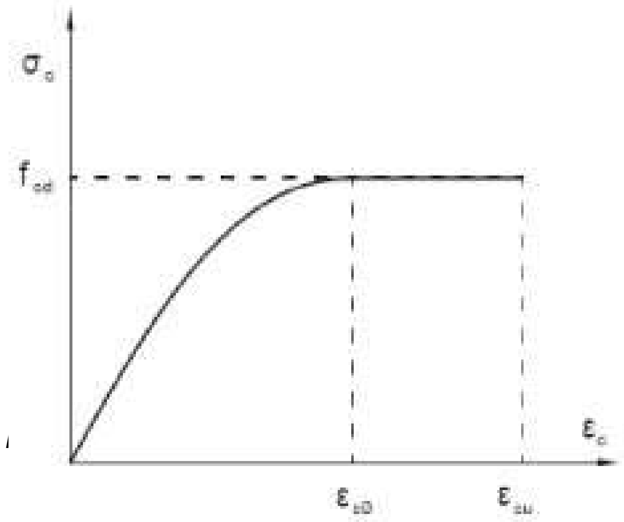

Figure 39.5.a. Parabolic-rectangular design diagram

The equation in this parabola is:

$$\sigma_c = f_{cd}\left[1-\left(1-\frac{\varepsilon_c}{\varepsilon_{c0}}\right)^n\right] \qquad \text{if } 0 \le \varepsilon_c \le \varepsilon_{c0}$$

$$\sigma_c = f_{cd} \qquad \text{if } \varepsilon_{c0} \le \varepsilon_c \le \varepsilon_{cu}$$

The values of the maximum compressive strain in the concrete under simple compression, ε_{c0}, are as follows:

$$\varepsilon_{c0} = 0{,}002 \qquad \text{if } f_{ck} \le 50 \text{ N/mm}^2$$

$$\varepsilon_{c0} = 0{,}002 + 0{,}000085(f_{ck} - 50)^{0{,}50} \qquad \text{if } f_{ck} > 50 \text{ N/mm}^2$$

The ultimate strain values, ε_{cu}, are provided by:

$$\varepsilon_{cu} = 0{,}0035 \qquad \text{if } f_{ck} \le 50 \text{ N/mm}^2$$

$$\varepsilon_{cu} = 0{,}0026 + 0{,}0144\left[\frac{(100 - f_{ck})}{100}\right]^4 \qquad \text{if } f_{ck} > 50 \text{ N/mm}^2$$

And the value n, which defines the exponent of the parabola is obtained as follows:

$$n = 2 \qquad \text{if } f_{ck} \leq 50 \text{ N/mm}^2$$

$$n = 1{,}4 + 9{,}6\left[(100 - f_{ck})/100\right]^4 \qquad \text{if } f_{ck} > 50 \text{ N/mm}^2$$

b) Rectangular diagram

This is formed from a rectangle whose depth λ(x) h, and size, η(x) f_{cd}, depend on the depth of the neutral axis, x (figure 39.5.b) and the concrete's strength. The values are:

$$\eta(x) = \eta \qquad if\ 0 < x \leq h$$
$$\eta(x) = 1 - (1-\eta)\frac{h}{x} \qquad if\ h \leq x < \infty$$

$$\lambda(x) = \lambda\frac{x}{h} \qquad if\ 0 < x \leq h$$
$$\lambda(x) = 1 - (1-\lambda)\frac{x}{h} \qquad if\ h \leq x < \infty$$

where:

η = 1,0 if $f_{ck} \leq 50$ N/mm^2
η = 1,0 - (f_{ck}-50)/200 if $f_{ck} > 50$ N/mm^2

λ = 0,8 if i $f_{ck} \leq 50$ N/mm^2
λ = 0,8 - (f_{ck}-50)/400 if $f_{ck} > 50$ N/mm^2

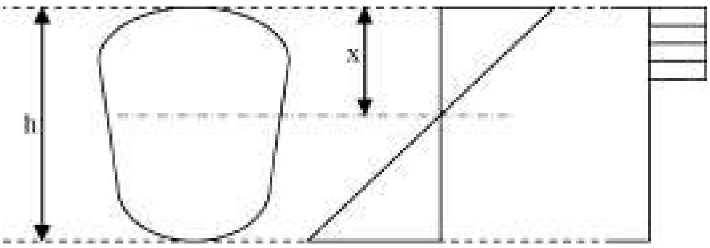

Figure 39.5.b. Rectangular calculation diagram

c) Other calculation diagrams, such as parabolic, bi-rectilinear, trapezoidal, etc. diagrams shall be accepted, provided that the results obtained from these are satisfactorily equivalent to those from the rectangle-parabola, and err on the side of safety.

39.6 Modulus of longitudinal deformation of the concrete

The following shall be adopted as the longitudinal secant modulus of deformation, E_{cm} at 28 days (slope of the secant of the actual curve σ-ε)):

$$E_{cm} = 8500\sqrt[3]{f_{cm}}$$

This expression shall be valid provided that the tensions in service conditions do not exceed the value of 0.40 f_{cm}, with f_{cm} being the average compression strength of the concrete at 28 days.

The initial modulus of longitudinal deformation of the concrete at 28 days, with regard to transient or rapidly varying loads (with the slope of the tangent at the origin), shall be taken to be approximately equal to

$$E_c = \beta_E \cdot E_{cm}$$

$$\beta_E = 1{,}30 - \frac{f_{ck}}{400} \leq 1{,}175$$

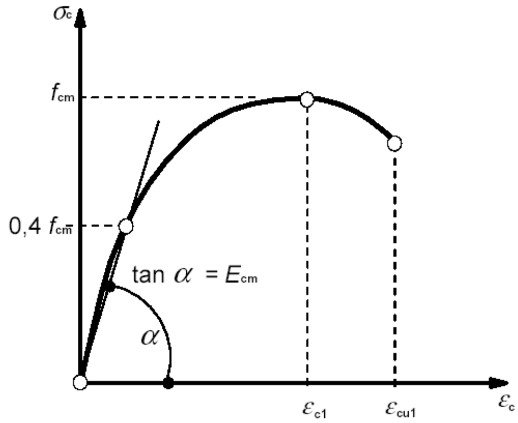

Figure 39.6. Diagrammatic representation of the stress-strain relationship in concrete

39.7 Shrinkage of concrete

When calculating the shrinkage value, the various influential variables have to be taken into consideration, in particular: ambient humidity, the thickness or smallest dimension of the element, the concrete's composition, and the time which has elapsed since it was produced, which defines how long shrinkage continues.

39.8 Creep in concrete

The stress-dependent strain at time *t,* for a constant stress, $\sigma(t_0)$*, of* less than 0.45 f_{cm}, applied at t_0, may be calculated in accordance with the following criterion:

$$\varepsilon_{c\sigma}(t, t_0) = \sigma(t_0)\left(\frac{1}{E_{c,t_0}} + \frac{\varphi(t, t_0)}{E_{c28}}\right)$$

in which t_0 and *t* are expressed in days.

The first sum in brackets represents the instantaneous strain for a unit of stress, and the second a unit of creep, in which:

E_{c28} Modulus of instantaneous longitudinal strain in the concrete, with the tangent at the origin, at 28 days as defined in 39.6.

$E_{c,t0}$ Secant value of the longitudinal strain in the concrete at time, t_0 applied to the load, as defined in 39.6.

$\varphi(t,t_0)$ Creep coefficient.

39.9 Poisson's rate

A mean value of 0.20 shall be used for Poisson's rate, relating to elastic deformations at normal tensions in use.

39.10 Thermal expansion coefficient

A figure of 10^{-5} shall be used