| | |
|---|---|
| Subject | Stress-strain relationships of reinforcing steel |
| Clause N°/ Subclause N° / Annex | 3.2.3 in EN 1992-1-2 and EN 1994-1-2 |

## Reason for change

Some discrepancies exist between EN1992-1-2 and EN1994-1-2 with respect to stress-strain relationships of reinforcing steel and more data is needed for ductility of reinforcing steel.

## Original content

In EN 1992-1-2

3.2.3 Reinforcing steel

(1)P The strength and deformation properties of reinforcing steel at elevated temperatures shall be obtained from the stress-strain relationships specified in Figure 3.3 and Table 3.2 (a or b). Table 3.2b may only be used if strength at elevated temperatures is tested.

(2) The stress-strain relationships given in Figure 3.3 are defined by three parameters:

- the slope of the linear elastic range $E_{s,\theta}$

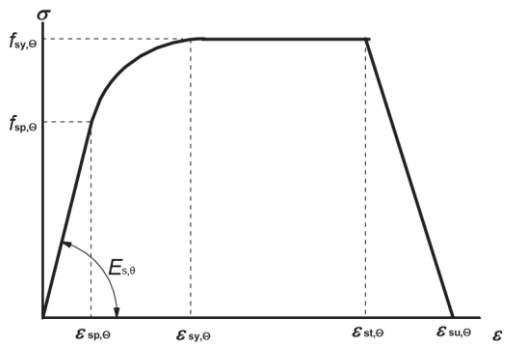
- the proportional limit $f_{sp,\theta}$

- the maximum stress level $f_{sy,\theta}$

(3) Values for the parameters in (2) for hot rolled and cold worked reinforcing steel at elevated temperatures are given in Table 3.2. For intermediate values of the temperature, linear interpolation may be used.

(4) The formulation of stress-strain relationships may also be applied for reinforcing steel in compression.

(5) In case of thermal actions according to EN 1991-1-2, Section 3 (natural fire simulation), particularly when considering the descending temperature branch, the values specified in Table 3.2 for the stress-strain relationships of reinforcing steel may be used as a sufficient approximation.



| Range | Stress $\sigma(\theta)$ | Tangent modulus |
|---|---|---|
| $\varepsilon_{sp,\theta}$ | $\varepsilon E_{s,\theta}$ | $E_{s,\theta}$ |
| $\varepsilon_{sp,\theta} \le \varepsilon \le \varepsilon_{sy,\theta}$ | $f_{sp,\theta} - c + (b/a)[a^2 - (\varepsilon_{sy,\theta} - \varepsilon)^2]^{0,5}$ | $\dfrac{b(\varepsilon_{sy,\theta} - \varepsilon)}{a\left[a^2 - (\varepsilon - \varepsilon_{sy,\theta})^2\right]^{0,5}}$ |
| $\varepsilon_{sy,\theta} \le \varepsilon \le \varepsilon_{st,\theta}$ | $f_{sy,\theta}$ | 0 |
| $\varepsilon_{st,\theta} \le \varepsilon \le \varepsilon_{su,\theta}$ | $f_{sy,\theta}[1-(\varepsilon - \varepsilon_{st,\theta})/(\varepsilon_{su,\theta} - \varepsilon_{st,\theta})]$ | - |
| $\varepsilon = \varepsilon_{su,\theta}$ | 0,00 | - |
| Parameter *) | $\varepsilon_{sp,\theta} = f_{sp,\theta} / E_{s,\theta}$ $\varepsilon_{sy,\theta} = 0,02$ $\varepsilon_{st,\theta} = 0,15$ $\varepsilon_{su,\theta} = 0,20$<br>Class A reinforcement: $\varepsilon_{st,\theta} = 0,05$ $\varepsilon_{su,\theta} = 0,10$ | |
| Functions | $a^2 = (\varepsilon_{sy,\theta} - \varepsilon_{sp,\theta})(\varepsilon_{sy,\theta} - \varepsilon_{sp,\theta} + c/E_{s,\theta})$<br>$b^2 = c\,(\varepsilon_{sy,\theta} - \varepsilon_{sp,\theta})\,E_{s,\theta} + c^2$<br>$c = \dfrac{(f_{sy,\theta} - f_{sp,\theta})^2}{(\varepsilon_{sy,\theta} - \varepsilon_{sp,\theta})E_{s,\theta} - 2(f_{sy,\theta} - f_{sp,\theta})}$ | |

*) Values for the parameters $\varepsilon_{pt,\theta}$ and $\varepsilon_{pu,\theta}$ for prestressing steel may be taken from Table 3.3. Class A reinforcement is defined in Annex C of EN 1992-1-1.

**Figure 3.3: Mathematical model for stress-strain relationships of reinforcing and prestressing steel at elevated temperatures (notations for prestressing steel "p" instead of "s")**

**Table 3.2a: Class N values for the parameters of the stress-strain relationship of hot rolled and cold worked reinforcing steel at elevated temperatures**

| Steel Temperature $\theta$[°C] | $f_{sy,\theta} / f_{yk}$ | | $f_{sp,\theta} / f_{yk}$ | | $E_{s,\theta} / E_s$ | |
|---|---|---|---|---|---|---|
| | hot rolled | cold worked | hot rolled | cold worked | hot rolled | cold worked |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 20 | 1,00 | 1,00 | 1,00 | 1,00 | 1,00 | 1,00 |
| 100 | 1,00 | 1,00 | 1,00 | 0,96 | 1,00 | 1,00 |
| 200 | 1,00 | 1,00 | 0,81 | 0,92 | 0,90 | 0,87 |
| 300 | 1,00 | 1,00 | 0,61 | 0,81 | 0,80 | 0,72 |
| 400 | 1,00 | 0,94 | 0,42 | 0,63 | 0,70 | 0,56 |
| 500 | 0,78 | 0,67 | 0,36 | 0,44 | 0,60 | 0,40 |
| 600 | 0,47 | 0,40 | 0,18 | 0,26 | 0,31 | 0,24 |
| 700 | 0,23 | 0,12 | 0,07 | 0,08 | 0,13 | 0,08 |
| 800 | 0,11 | 0,11 | 0,05 | 0,06 | 0,09 | 0,06 |
| 900 | 0,06 | 0,08 | 0,04 | 0,05 | 0,07 | 0,05 |
| 1000 | 0,04 | 0,05 | 0,02 | 0,03 | 0,04 | 0,03 |
| 1100 | 0,02 | 0,03 | 0,01 | 0,02 | 0,02 | 0,02 |
| 1200 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 |

**Table 3.2b: Class X values for the parameters of the stress-strain relationship of hot rolled and cold worked reinforcing steel at elevated temperatures**

| Steel Temperature $\theta$ [°C] | $f_{sy,\theta} / f_{yk}$ hot rolled and cold worked | $f_{sp,\theta} / f_{yk}$ hot rolled and cold worked | $E_{s,\theta} / E_s$ hot rolled and cold worked |
|---|---|---|---|
| 20 | 1,00 | 1,00 | 1,00 |
| 100 | 1,00 | 1,00 | 1,00 |
| 200 | 1,00 | 0,87 | 0,95 |
| 300 | 1,00 | 0,74 | 0,90 |
| 400 | 0,90 | 0,70 | 0,75 |
| 500 | 0,70 | 0,51 | 0,60 |
| 600 | 0,47 | 0,18 | 0,31 |
| 700 | 0,23 | 0,07 | 0,13 |
| 800 | 0,11 | 0,05 | 0,09 |
| 900 | 0,06 | 0,04 | 0,07 |
| 1000 | 0,04 | 0,02 | 0,04 |
| 1100 | 0,02 | 0,01 | 0,02 |

**Note:** The choice of Class N (Table 3.2a) or X (Table 3.2b) to be used in a Country may be found in its National Annex. Class N is generally recommended. Class X is recommended only when there is experimental evidence for these values.

<u>In EN 1994-1-2</u>

3.2.3 Reinforcing steels

(1) The strength and deformation properties of reinforcing steels at elevated temperatures may be obtained by the same mathematical model as that presented in 3.2.1 for structural steel.

(2) For hot rolled reinforcing steel the three main parameters given in Table 3.2 may be used, except that the value of u,θ k should not be greater than 1,1.

(3) The three main parameters for cold worked reinforcing steel are given in Table 3.4 (see also Table 3.2a of EN 1992-1-2).

NOTE: Prestressing steels will normally not be used in composite structures.

(4) In case of thermal actions according to 3.3 of EN 1991-1-2 (natural fire models), particularly when considering the decreasing temperature branch, the values specified in Table 3.2 for the stress-strain relationships of structural steel, may be used as a sufficiently precise approximation for hot rolled reinforcing steel.

**Table 3.4: Reduction factors $k_\theta$ for stress-strain relationships of cold worked reinforcing steel**

| Steel Temperature $\theta_s$ [°C] | $k_{E,\theta} = \frac{E_{s,\theta}}{E_s}$ | $k_{p,\theta} = \frac{f_{sp,\theta}}{f_{sy}}$ | $k_{y,\theta} = \frac{f_{sy,\theta}}{f_{sy}}$ |
|---|---|---|---|
| 20 | 1,00 | 1,00 | 1,00 |
| 100 | 1,00 | 0,96 | 1,00 |
| 200 | 0,87 | 0,92 | 1,00 |
| 300 | 0,72 | 0,81 | 1,00 |
| 400 | 0,56 | 0,63 | 0,94 |
| 500 | 0,40 | 0,44 | 0,67 |
| 600 | 0,24 | 0,26 | 0,40 |
| 700 | 0,08 | 0,08 | 0,12 |
| 800 | 0,06 | 0,06 | 0,11 |
| 900 | 0,05 | 0,05 | 0,08 |
| 1000 | 0,03 | 0,03 | 0,05 |
| 1100 | 0,02 | 0,02 | 0,03 |
| 1200 | 0 | 0 | 0 |

**Table 3.2: Reduction factors $k_\theta$ for stress-strain relationships of structural steel at elevated temperatures.**

| Steel Temperature $\theta_a$[°C] | $k_{E,\theta} = \frac{E_{a,\theta}}{E_a}$ | $k_{p,\theta} = \frac{f_{ap,\theta}}{f_{ay}}$ | $k_{y,\theta} = \frac{f_{ay,\theta}}{f_{ay}}$ | $k_{u,\theta} = \frac{f_{au,\theta}}{f_{ay}}$ |
|---|---|---|---|---|
| 20 | 1,00 | 1,00 | 1,00 | 1,25 |
| 100 | 1,00 | 1,00 | 1,00 | 1,25 |
| 200 | 0,90 | 0,807 | 1,00 | 1,25 |
| 300 | 0,80 | 0,613 | 1,00 | 1,25 |
| 400 | 0,70 | 0,420 | 1,00 | |
| 500 | 0,60 | 0,360 | 0,78 | |
| 600 | 0,31 | 0,180 | 0,47 | |
| 700 | 0,13 | 0,075 | 0,23 | |
| 800 | 0,09 | 0,050 | 0,11 | |
| 900 | 0,0675 | 0,0375 | 0,06 | |
| 1000 | 0,0450 | 0,0250 | 0,04 | |
| 1100 | 0,0225 | 0,0125 | 0,02 | |
| 1200 | 0 | 0 | 0 | |

In Clause (5) of Section 3.2.1 of EN 1994-1-2, it is written:

NOTE: Values for $\varepsilon_{au,\theta}$ and $\varepsilon_{ae,\theta}$ defining the range of the maximum stress branches and decreasing branches according to Figure 3.1, may be taken from informative Annex A.

In Clause (4) of Annex A of EN 1994-1-2, it is written:

- for strains between 4 % and 15 % (range IIIb) an horizontal plateau is considered with $\varepsilon_{au,\theta}$ = 15%;
- for strains between 15 % and 20 % a decreasing branch (range IV) is considered with $\varepsilon_{ae,\theta}$ = 20 %.

## Change

Section 3.2.3 of EN 1992-1-2 in unchanged.

Section 3.2.3 of EN 1994-1-2 becomes:

3.2.3 Reinforcing steels

(1) The strength and deformation properties of reinforcing steels at elevated temperatures may be obtained by the same mathematical model as that presented in 3.2.1 for structural steel.

(2) The three main parameters for reinforcing steel are given in Table 3.4.

NOTE: Prestressing steels will normally not be used in composite structures.

Table 3.4 Reduction factors $k_\theta$ for stress-strain relationship of reinforcing steel

| Steel Temperature $\theta_s$ [°C] | $k_{E,\theta} = \frac{E_{s,\theta}}{E_s}$ | | $k_{p,\theta} = \frac{f_{sp,\theta}}{f_{sy}}$ | | $k_{y,\theta} = \frac{f_{sy,\theta}}{f_{sy}}$ | |
|---|---|---|---|---|---|---|
| $\theta$ [°C] | hot rolled | cold worked | hot rolled | cold worked | hot rolled | cold worked |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 20 | 1,00 | 1,00 | 1,00 | 1,00 | 1,00 | 1,00 |
| 100 | 1,00 | 1,00 | 1,00 | 0,96 | 1,00 | 1,00 |
| 200 | 1,00 | 1,00 | 0,81 | 0,92 | 0,90 | 0,87 |
| 300 | 1,00 | 1,00 | 0,61 | 0,81 | 0,80 | 0,72 |
| 400 | 1,00 | 0,94 | 0,42 | 0,63 | 0,70 | 0,56 |
| 500 | 0,78 | 0,67 | 0,36 | 0,44 | 0,60 | 0,40 |
| 600 | 0,47 | 0,40 | 0,18 | 0,26 | 0,31 | 0,24 |
| 700 | 0,23 | 0,12 | 0,07 | 0,08 | 0,13 | 0,08 |
| 800 | 0,11 | 0,11 | 0,05 | 0,06 | 0,09 | 0,06 |
| 900 | 0,06 | 0,08 | 0,04 | 0,05 | 0,07 | 0,05 |
| 1000 | 0,04 | 0,05 | 0,02 | 0,03 | 0,04 | 0,03 |
| 1100 | 0,02 | 0,03 | 0,01 | 0,02 | 0,02 | 0,02 |
| 1200 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 |

(3) For the limits of the decreasing branch,

- $\varepsilon_{au,\theta}$ = 0,05 and $\varepsilon_{ae,\theta}$ = 0,10 for Class A reinforcement;
- $\varepsilon_{au,\theta}$ = 0,15 and $\varepsilon_{ae,\theta}$ = 0,20 for Class B and Class C reinforcement;

(4) In case of thermal actions according to 3.3 of EN 1991-1-2 (physically based fire models), particularly when considering the decreasing temperature branch, the values specified in Table 3.4 may be used as a sufficiently precise approximation.

## Background information

1) The term “natural fire model” in Clause 4 has been replaced by “physically based fire model” to ensure consistency with the new terminology of EN 1991-1-2.
2) All values in the new Table 3.4 are now fully consistent with the values of Table 2.1a of EN 1992-1-2. Compared to the values that are present in Table 3.2 of EN 1994-1-2, there are only slight differences due to rounding of certain values to 1% definition (for example: 0,807 is now 0,81, or 0,0375 is now 0;04).
3) The Project team of EN 1994-1-2 will decide whether Class X steel, which is mentioned in EN 1992-1-2) must be also mentioned in EN 1994-1-2, depending whether it is used or not in composite steel-concrete structures.
4) The inconsistency that was present for $\varepsilon_{au,\theta}$ and $\varepsilon_{ae,\theta}$ (with smaller values mentioned for Class A reinforcement in EN 1992-1-2 and not in EN 1994-2-1) has been eliminated. It seems quite clear that the code writers of EN 1994-1-2 had no clear intention to allow the values of 0,15 and 0,20 to be used for Class A reinforcement. Indeed:
   a. Table 3.2a of EN 1992-1-2 is explicitly mentioned in EN 1994-1-2. In EN 1992-1-2, Table 3.2a is explicitly linked to Figure 3.3 in which the values are limited.
   b. It is only through a cascade of two successive references in EN 1994-1-2 that one may conclude that the values should not be limited for class A reinforcing steel.
      i. the reference made in Clause 1 of 3.2.3 to “the same mathematical model as that presented in 3.2.1 for structural steel”,
      ii. the reference made in a note of Clause (5) of 3.2.1 to Annex A,

   The values are not limited in Annexe A because this annex was written specifically for structural steel and not for reinforcing steel. It very likely that the code writers of EN 1994-1-2 have not

been aware of the fact that the consequence of this cascade of reference would be that Class A reinforcing steel might be considered with the high values of strains.

## Ease of use justification

All information needed to use the mathematical model of 3.2.1 to reinforcing steel is now present in 3.2.3 (clauses (2) and (3)). This is a significant improvement of the ease of use.