# Adjustment of partial factors for material and new approach for concrete strength

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EUROCODES

EN 1992

Design of concrete structures

## 2nd generation of Eurocode 2 on concrete structures

Madrid, October 17th, 2023

proes.

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2. Unification of the design compressive strength of concrete $f_{cd}$
3. Adjustment of partial factors for materials


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# 1. Green concretes

## Green concretes

- Composition: Replace cement > another binder (fly ashes…)
- Objective: Reduce carbon footprint
- Consequence: Slower strength development

## Open door to use green concretes

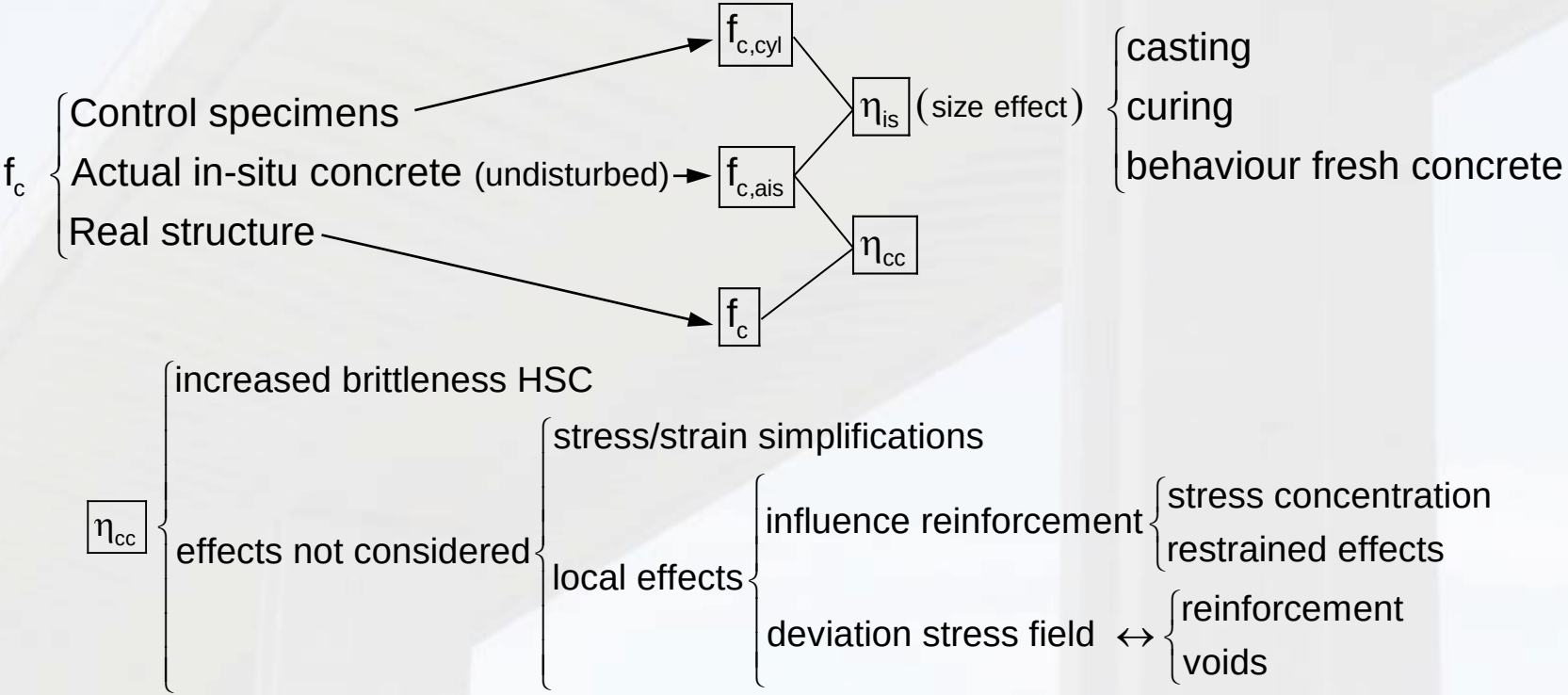
- 5.1.3 (2) allows ages $t_{ref}$ higher than 28 days

(2) The value for $t_{ref}$
(i) should be taken as 28 days in general; or
(ii) may be taken between 28 and 91 days when specified for a project.


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# 2. Unification of the design compressive strength of concrete

## Different compressive strengths of concrete




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# 2. Unification of the design compressive strength of concrete

## Design compressive strength of concrete $f_{cd}$

$$f_{cd} = \eta_{cc} \cdot k_{tc} \frac{f_{ck}}{\gamma_C}$$

$$\eta_{cc} = \left( \frac{f_{ck,ref}}{f_{ck}} \right)^{\frac{1}{3}} \leq 1{,}0 \quad \text{where} \quad f_{ck,ref} = 40 \text{ MPa}$$

$k_{tc}$ effects: high sustained loads; loading time

$$k_{tc} = \begin{cases} 1{,}0 \text{ if } t_{ref} \leq \begin{cases} 28 \text{ days (CR,CN)} \\ 56 \text{ days (CS)} \end{cases} \text{ t,load} \geq 3 \text{ months} \\ 0{,}85 \text{ other cases} \end{cases}$$

$$\gamma_C = \gamma_c \cdot \gamma_R \cdot \eta_{is}$$

$\gamma_C$ → Control specimen → Undisturbed structure

$\gamma_c$ → Material and geometrical uncertainties

$\gamma_R$ → Model uncertainties

$\eta_{cc}$ calibrated with columns in laboratory


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# 2. Unification of the design compressive strength of concrete

## Advantages of new $f_{cd}$

- $\nu$ is not dependent of $f_{ck}$ (shear, punching, struts&ties...)
- simplification of stress distributions
- modifications of parabola-rectangle diagram improve results

SHEAR 8.2.3

(6) A value $\nu = 0{,}5$ may be adopted when using the angles of the compression field given in (4).

(7) Angles of the compression field inclination to the member axis lower than $\theta_{min}$ given in (4) or values of factor $\nu$ higher than according to (6) may be adopted provided that the ductility class of the reinforcement is B or C and that the value of factor $\nu$ is calculated on the basis of the state of strains of the member according to:

$$\nu = \frac{1}{1{,}0 + 110 \cdot (\varepsilon_x + (\varepsilon_x + 0{,}001) \cdot \cot^2\theta)} \leq 1{,}0 \qquad (8.45)$$

where $\varepsilon_x$ is the average strain of the bottom and top chords calculated at a cross-section not closer than $0{,}5 \cdot z \cdot \cot\theta$ from the face of the support or a concentrated load:


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SHEAR WEB-FLANGES 8.2.5

(4) The transverse reinforcement in the flange $A_{sf}$ may be determined as follows:

$$\tau_{Ed} \leq \frac{A_{sf}}{s_f \cdot h_f} \cdot f_{yd} \cdot \cot\theta_f \qquad (8.69)$$

To prevent crushing of the compression field in the flange, the following condition should be satisfied:

$$\sigma_{cd} = \tau_{Ed}(\cot\theta_f + \tan\theta_f) \leq \nu \cdot f_{cd} \qquad (8.70)$$

where the following strength reduction factor may be used:

$$\nu = 0{,}5 \qquad (8.71)$$

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# 2. Unification of the design compressive strength of concrete

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TORSION 8.3.3

(3) The torsional strength, when governed by crushing of the compression field in concrete, may be calculated from:

$$\tau_{t,Rd,max} = \frac{\nu \cdot f_{cd}}{\cot\theta + \tan\theta} \qquad (8.84)$$

where $\nu$ may be determined by the formulae in Annex G. A value of $\nu = 0{,}60$ may be used when $\cot\theta = 1{,}0$.


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STRUT & TIE 8.5.2

a) for compression fields and struts crossed or deviated by a tie at an angle:

| | | |
|---|---|---|
| — $20° \leq \theta_{cs} < 30°$ | $\nu = 0{,}4$ | (8.115) |
| — $30° \leq \theta_{cs} < 40°$ | $\nu = 0{,}55$ | (8.116) |
| — $40° \leq \theta_{cs} < 60°$ | $\nu = 0{,}7$ | (8.117) |
| — $60° \leq \theta_{cs} < 90°$ | $\nu = 0{,}85$ | (8.118) |

Alternatively, the value of factor $\nu$ may be determined as:

$$\nu = \frac{1}{1{,}11 + 0{,}22 \cdot \cot^2\theta_{cs}} \qquad (8.119)$$

b) for compression fields and struts in a region without transverse cracking (e.g. when transverse compressive stresses are present)

$$\nu = 1{,}0 \qquad (8.120)$$


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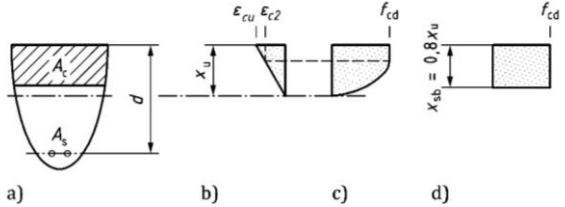
# 2. Unification of the design compressive strength of concrete

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$\varepsilon_{c2} = 0{,}002;$

$\varepsilon_{cu} = 0{,}0035.$




a) cross-section

b) assumed strain distribution

c) parabola-rectangle stress distribution

d) rectangular stress distribution

**Figure 8.2 — Stress distributions within the compression zone**




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# 3. Adjustment of partial factors for materials

- Definition of hypothesis for partial factors of materials
- Procedure to modify partial factors of materials
- New partial factor for concrete on shear $\gamma_V$
- Use of design value of effective depth on shear


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# 3. Adjustment of partial factors for materials

## Definition of hypothesis for partial factors of materials

**Table 4.3 (NDP) — Partial factors for materials**

| Design situations — Limit states | $\gamma_S$ for reinforcing and prestressing steel | $\gamma_C$ and $\gamma_{CE}$ for concrete | $\gamma_V$ for shear and punching resistance without shear reinforcement |
|---|---|---|---|
| Persistent and transient design situation | 1,15 | 1,50[a] | 1,40 |
| Fatigue design situation | 1,15 | 1,50 | 1,40 |
| Accidental design situation | 1,00 | 1,15 | 1,15 |
| Serviceability limit state | 1,00 | 1,00 | — |

NOTE The partial factors for materials correspond to geometrical deviations of Tolerance Class 1 and Execution Class 2 in EN 13670.

[a] The value for $\gamma_{CE}$ applies when the indicative value for the elastic modulus according 5.1.4(2) is used. A value $\gamma_{CE} = 1,3$ applies when the elastic modulus is determined according to 5.1.4(1).

Tolerance Class 1
Execution Class 2
} EN 13670 "Execution of concrete structures"


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# 3. Adjustment of partial factors for materials

## Definition of hypothesis for partial factors of materials

**Table A.3 — Statistical data assumed for the calculation of partial factor defined in Table 4.3 (NDP)**

| | Coefficient of variation | Bias factor[a] |
|---|---|---|
| **Partial factor for reinforcement $\gamma_S$** | | |
| Yield strength $f_y$ | $V_{fy} = 0{,}045$ | $f_{ym}/f_{yk} = \exp(1{,}645V_{fy})$ |
| Effective depth $d$ | $V_d = 0{,}050$[b] | $\mu_d = 0{,}95$[b] |
| Model uncertainty | $V_{\theta s} = 0{,}045$[c] | $\mu_{\theta s} = 1{,}09$[c] |
| Coefficient of variation and bias factor of resistance for reinforcement | $V_{RS} = 0{,}081$[i] | $\mu_{RS} = 1{,}115$[i] |
| **Partial factor for concrete $\gamma_C$** | | |
| Compressive strength $f_c$ (control specimen) | $V_{fc} = 0{,}100$ | $f_{cm}/f_{ck} = \exp(1{,}645V_{fc})$[d] |
| Insitu factor $\eta_{is} = f_{c,ais}/f_c$ [e] | $V_{\eta is} = 0{,}120$ | $\mu_{\eta is} = 0{,}95$ |
| Concrete area $A_c$ | $V_{Ac} = 0{,}040$ | $\mu_{Ac} = 1{,}00$ |
| Model uncertainty | $V_{\theta c} = 0{,}070$[f] | $\mu_{\theta c} = 1{,}02$[f] |
| Coefficient of variation and bias factor of resistance for concrete | $V_{RC} = 0{,}176$[j] | $\mu_{RC} = 1{,}142$[j] |
| **Partial factor for shear and punching $\gamma_V$ (see 8.2.1, 8.2.2, 8.4, I.8.3.1, I.8.5)** | | |
| Compressive strength $f_c$ (control specimen) | $V_{fc} = 0{,}100$ | $f_{cm}/f_{ck} = \exp(1{,}645V_{fc})$[d] |
| Insitu factor $\eta_{is} = f_{c,ais}/f_c$ [e] | $V_{\eta is} = 0{,}120$ | $\mu_{\eta is} = 0{,}95$ |
| Effective depth $d$ | $V_d = 0{,}050$[b] | $\mu_d = 0{,}95$[b] |
| Model uncertainty | $V_{\theta v} = 0{,}107$[g] | $\mu_{\theta v} = 1{,}10$[g] |
| Residual uncertainties | $V_{res,v} = 0{,}046$[h] | – |
| Coefficient of variation and bias factor of resistance for shear and punching (members without shear reinforcement) | $V_{RV} = 0{,}137$[j] | $\mu_{RV} = 1{,}085$[j] |

[a] The values in this column refer to ratio between mean value and values used in the design formulae (characteristic or nominal).

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# 3. Adjustment of partial factors for materials

## Procedure to modify partial factors of materials

$$R_c = f_{c,cyl} \cdot \eta_{is} \cdot A_c \cdot \theta_c \begin{cases} f_{c,cyl} : \text{compressive strength of the control specimen} \\ \eta_{is} : f_{c,cyl} \rightarrow f_{c,ais} \\ A_c : \text{area of concrete} \\ \theta_c : \text{model uncertainty} \end{cases}$$

$$V_{Rc} = \frac{\sigma_{Rc}}{R_{cm}} = \sqrt{V_{fc,cyl}^2 + V_{\eta is}^2 + V_{Ac}^2 + V_{\theta c}^2}$$

$$\mu_{Rc} = \frac{R_{cm}}{R_{ck}} = \mu_{fc,cyl} \cdot \mu_{\eta is} \cdot \mu_{Ac} \cdot \mu_{\theta c} \quad \text{where } \mu_{fc,cyl} = \frac{f_{cm}}{f_{ck}} = e^{1{,}645\, V_{fc}}$$

$$\gamma_C = \frac{R_{cd}}{R_{ck}} = \frac{e^{\alpha_R \cdot \beta_{tgt} \cdot V_{Rc}}}{\mu_{Rc}}$$

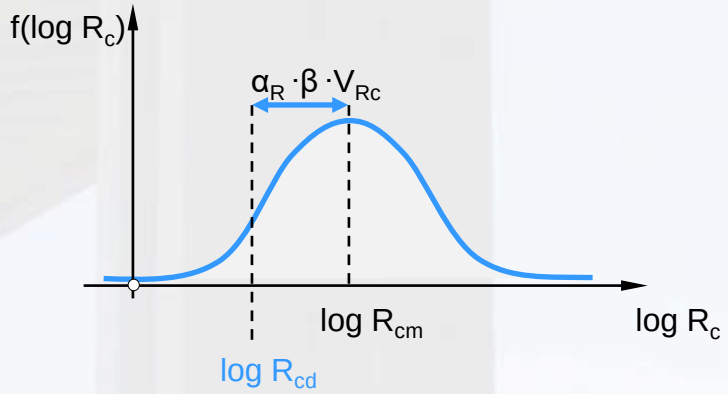



**Table A.4 (NDP) — Sensitivity factors for resistance $\alpha_R$ and target values for the 50-year reliability index $\beta_{tgt}$**

| Design situations/Limit states | Sensitivity factors for resistance $\alpha_R$ | target value for the 50-year reliability index $\beta_{tgt}$ |
|---|---|---|
| Persistent or transient design situation | 0,8 | 3,8 |
| Fatigue design situation | 0,8 | 3,8 |
| Accidental design situation | 0,8 | 2,0 |
| NOTE 1 These values refer to CC2. For others Consequence Classes, refer to EN 1990. | | |


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# 3. Adjustment of partial factors for materials

## Procedure to modify partial factors of materials

## Specific cases table A1

- Tolerance **Class 2** instead of **Class 1**
- Geometrical data measured with lower CoV
- Concrete strength assessed by core tests
- Reinforcement yield strength assessed by tests
- Use of refined methods to verify the structure
- Use of non-linear analysis with separate consideration of model uncertainty
- Different target value for the reliability index
- Use of design value of effective depth on shear

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# 3. Adjustment of partial factors for materials

## Procedure to modify partial factors of materials

## Specific cases table A1

- Tolerance **Class 2** instead of **Class 1**

**Table A.1 (NDP) — Values of adjusted material factors - General**

| Condition for adjusted material factors | persistent and transient design situations | | | accidental design situations | | |
|---|---|---|---|---|---|---|
| | $\gamma_S$ | $\gamma_C$ | $\gamma_V$ | $\gamma_S$ | $\gamma_C$ | $\gamma_V$ |
| | 1,08 | 1,48 | 1,33 | 0,97 | 1,15 | 1,11 |
| a) if the execution ensures that geometrical deviations of Tolerance Class 2 according to EN 13670 are fulfilled | in case also at least one of the conditions d), e), f) or h) is fulfilled, the partial factors may be calculated according to (3) with the statistical values given in (4) and in (7) for d) or in (8) for e); with the updated values of the resistance model for (f) and with the values given in Table A.4 for h) | | | | | |

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# 3. Adjustment of partial factors for materials

## New partial factor for concrete on shear $\gamma_V$

- Model uncertainties become dominant
- Influence of variability of $\mathbf{f_c}$ is reduced → exponent 1/3
- Better fitting of the formulation with data bases

(2) The design value of the shear stress resistance should be taken as:

$$\tau_{Rd,c} = \frac{0{,}66}{\gamma_V} \cdot \left(100\rho_l \cdot f_{ck} \cdot \frac{d_{dg}}{d}\right)^{\frac{1}{3}} \geq \tau_{Rdc,min} \qquad (8.27)$$

where

$$\rho_l = \frac{A_{sl}}{b_w d}$$

$A_{sl}$ is the effective area of tensile
(see Figure 8.7);

(1) The design punching shear stress resistance should be calculated as follows:

$$\tau_{Rd,c} = \frac{0{,}6}{\gamma_V} \cdot k_{pb} \left(100\,\rho_l \cdot f_{ck} \cdot \frac{d_{dg}}{d_v}\right)^{\frac{1}{3}} \leq \frac{0{,}5}{\gamma_V} \cdot \sqrt{f_{ck}} \qquad (8.94)$$

where

$$\rho_l = \sqrt{\rho_{l,x} \cdot \rho_{l,y}} \qquad (8.95)$$


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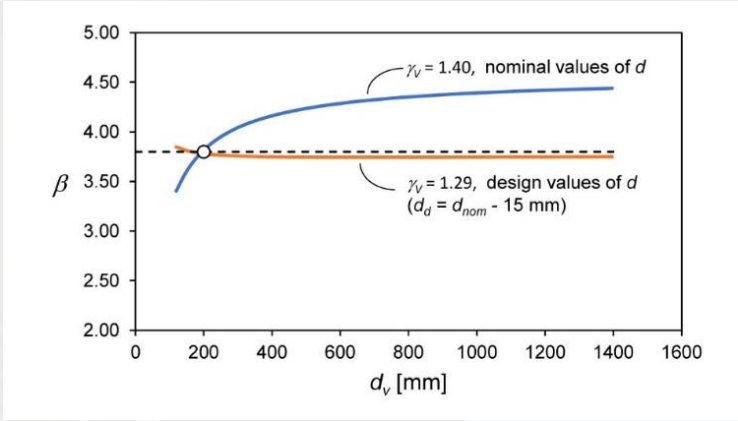
| Design situations — Limit states | $\gamma_C$ and $\gamma_{CE}$ for concrete | $\gamma_V$ for shear and punching resistance without shear reinforcement |
|---|---|---|
| Persistent and transient design situation | 1,50[a] | 1,40 |
| Fatigue design situation | 1,50 | 1,40 |
| Accidental design situation | 1,15 | 1,15 |
| Serviceability limit state | 1,00 | — |


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# 3. Adjustment of partial factors for materials

## Use of design value of effective depth on shear

- Thin members: geometrical uncertainties govern
- Deep members: geometrical uncertainties negligible
- More rational to use $\mathbf{d_d}$
- Reduced values of $\gamma_V$ and $\gamma_s$ can be obtained




(6) The statistical data of the effective depth in Table A.3 may be replaced by $V_{\mathrm{d}} = 0{,}00$ and $\mu_{\mathrm{d}} = 1{,}00$ if the calculation of the design resistance is based on the design value of the effective depth $d_{\mathrm{d}}$:

$$d_{\mathrm{d}} = d_{\mathrm{nom}} - \Delta d \qquad \text{(A.8)}$$

where

$\Delta d$ is the deviation value of the effective depth:

$\Delta d = 15$ mm for reinforcing and post-tensioning steel;

$\Delta d = 5$ mm for pre-tensioning steel.

NOTE 1 The design value of the effective depth $d_{\mathrm{d}}$ can be used unless the National Annex gives limitations.



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**Table A.1 (NDP) — Values of adjusted material factors - General**

| Condition for adjusted material factors | persistent and transient design situations | | | accidental design situations | | |
|---|---|---|---|---|---|---|
| | $\gamma_S$ | $\gamma_C$ | $\gamma_V$ | $\gamma_S$ | $\gamma_C$ | $\gamma_V$ |
| | 1,03 | 1,50 | 1,29 | 0,94 | 1,15 | 1,07 |
| c) if the calculation of design resistance is based on the design value of the effective depth according to (6) | in case also at least one of the conditions d), e), f) or h) is fulfilled, the partial factors may be calculated according to (3) with the statistical values given in (6) and in (7) for d) or in (8) for e); with the updated values of the resistance model for (f) and with the values given in Table A.4 for h) | | | | | |


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# Thank you for your attention

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