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

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Design of concrete structures

2nd generation of Eurocode 2 on concrete structures

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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.

2. Unification of the design compressive strength of concrete

Different compressive strengths of concrete

f_c
- Control specimens → $\boxed{f_{c,cyl}}$
- Actual in-situ concrete (undisturbed) → $\boxed{f_{c,ais}}$
- Real structure → $\boxed{f_c}$

$\boxed{f_{c,cyl}}$ — $\boxed{\eta_{is}}$ — $\boxed{f_{c,ais}}$ (size effect)
- casting
- curing
- behaviour fresh concrete

$\boxed{f_{c,ais}}$ — $\boxed{\eta_{cc}}$ — $\boxed{f_c}$

$\boxed{\eta_{cc}}$
- increased brittleness HSC
- effects not considered
  - stress/strain simplifications
  - local effects
    - influence reinforcement
      - stress concentration
      - restrained effects
    - deviation stress field ↔
      - reinforcement
      - voids

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

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

$$\gamma_C = \gamma_c \cdot \gamma_R \cdot \eta_{is} \longrightarrow \boxed{\text{Control specimen} \rightarrow \text{Undisturbed structure}}$$

Material and geometrical uncertainties

Model uncertainties

η_{cc} calibrated with columns in laboratory

2. Unification of the design compressive strength of concrete

Advantages of new f_{cd}

- ν 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 $\boxed{\nu = 0{,}5}$ 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 θ_{min} given in (4) or values of factor ν 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 ν is calculated on the basis of the state of strains of the member according to:

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

where ε_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:

2. Unification of the design compressive strength of concrete

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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:

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

2. Unification of the design compressive strength of concrete

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- ν is not dependent of f_{ck} (shear, punching, struts&ties...)
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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 ν may be determined by the formulae in Annex G. A value of $\boxed{\nu = 0,60}$ may be used when $\cot\theta = 1,0$.

2. Unification of the design compressive strength of concrete

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STRUT & TIE 8.5.2

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

— $20° \leq \theta_{cs} < 30°$ $\quad \boxed{\nu = 0{,}4}$ (8.115)

— $30° \leq \theta_{cs} < 40°$ $\quad \boxed{\nu = 0{,}55}$ (8.116)

— $40° \leq \theta_{cs} < 60°$ $\quad \boxed{\nu = 0{,}7}$ (8.117)

— $60° \leq \theta_{cs} < 90°$ $\quad \boxed{\nu = 0{,}85}$ (8.118)

Alternatively, the value of factor ν may be determined as:

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

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

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

2. Unification of the design compressive strength of concrete

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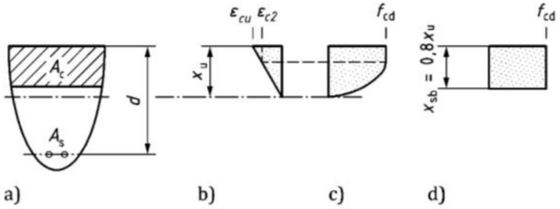
$\varepsilon_{c2} = 0{,}002;$

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



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

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 γ_V

Use of design value of effective depth on shear

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	γ_S for reinforcing and prestressing steel	γ_C and γ_{CE} for concrete	γ_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 γ_{CE} applies when the indicative value for the elastic modulus according 5.1.4(2) is used. A value γ_{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"

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 γ_S		
Yield strength f_y	$V_{fy} = 0{,}045$	$f_{ym}/f_{yk} = \exp(1{,}645 V_{fy})$
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 γ_C		
Compressive strength f_c (control specimen)	$V_{fc} = 0{,}100$	$f_{cm}/f_{ck} = \exp(1{,}645 V_{fc})$[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	$V_{RC} = 0{,}176$[i]	$\mu_{RC} = 1{,}142$[i]
Partial factor for shear and punching γ_V (see 8.2.1, 8.2.2, 8.4, I.8.3.1, I.8.5)		
Compressive strength f_c (control specimen)	$V_{fc} = 0{,}100$	$f_{cm}/f_{ck} = \exp(1{,}645 V_{fc})$[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)	$V_{RV} = 0{,}137$[i]	$\mu_{RV} = 1{,}085$[i]

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

3. Adjustment of partial factors for materials

Procedure to modify partial factors of materials

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

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

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

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

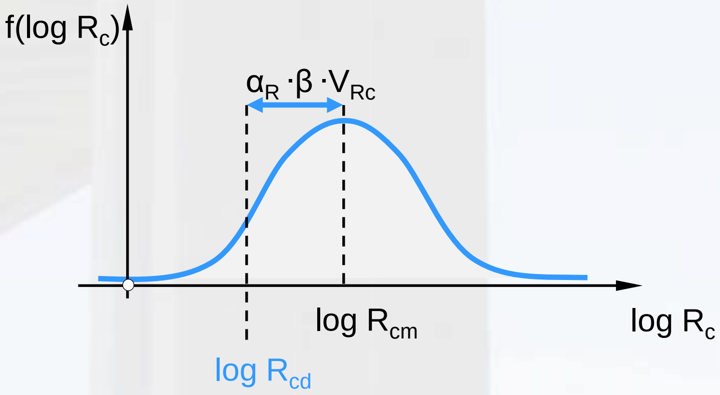


Table A.4 (NDP) — Sensitivity factors for resistance α_R and target values for the 50-year reliability index β_{tgt}

Design situations/Limit states	Sensitivity factors for resistance α_R	target value for the 50-year reliability index β_{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.		

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

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		
	γ_S	γ_C	γ_V	γ_S	γ_C	γ_V
a) if the execution ensures that geometrical deviations of Tolerance Class 2 according to EN 13670 are fulfilled	1,08	1,48	1,33	0,97	1,15	1,11
	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)					

3. Adjustment of partial factors for materials

New partial factor for concrete on shear γ_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:

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

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:

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

where

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

3. Adjustment of partial factors for materials

New partial factor for concrete on shear γ_V

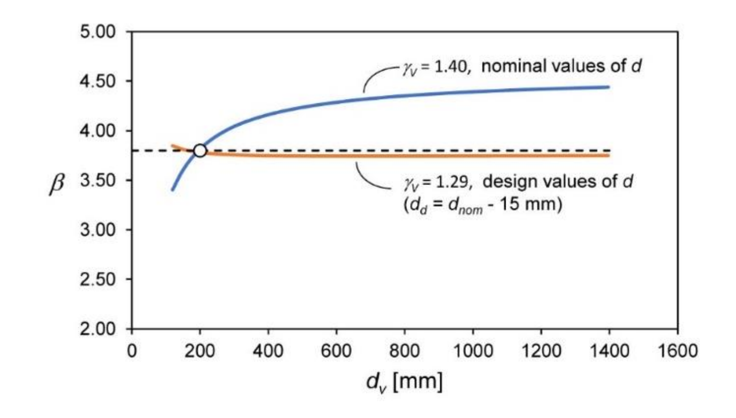
- Model uncertainties become dominant
- Influence of variability of $\mathbf{f_c}$ is reduced $\rightarrow$ exponent 1/3
- Better fitting of the formulation with data bases

Design situations — Limit states	γ_C and γ_{CE} for concrete	γ_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	—

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 γ_V and γ_s can be obtained



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

$$d_d = d_{nom} - \Delta d \tag{A.8}$$

where

Δd 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_d can be used unless the National Annex gives limitations.

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 γ_V and γ_s can be obtained

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

Condition for adjusted material factors	persistent and transient design situations			accidental design situations		
	γ_S	γ_C	γ_V	γ_S	γ_C	γ_V
c) if the calculation of design resistance is based on the design value of the effective depth according to (6)	1,03	1,50	1,29	0,94	1,15	1,07
	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)					

Thank you for your attention

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