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

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2<sup>nd</sup> generation of Eurocode 2 on concrete structures



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



2 generation of Eurocode 2 on concrete structures / Madrid, October 17th, 2023

# 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<sub>ref</sub> higher than 28 days

(2) The value for t<sub>ref</sub>
(i) should be taken as 28 days in general; or
(ii) may be taken between 28 and 91 days when specified for a project.



**Different compressive strengths of concrete** 



Design compressive strength of concrete f<sub>cd</sub>



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

# Advantages of new f<sub>cd</sub>

# v is not dependent of f<sub>ck</sub> (shear, punching, struts&ties...)

simplification of stress distributions

modifications of parabola-rectangle diagram improve results

#### SHEAR 8.2.3

(6) A value v = 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:

$$\nu = \frac{1}{1,0 + 110 \cdot (\varepsilon_{x} + (\varepsilon_{x} + 0,001) \cdot \cot^{2}\theta)} \le 1,0$$

(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:

# Advantages of new f<sub>cd</sub>

v is not dependent of f<sub>ck</sub> (shear, punching, struts&ties...) simplification of stress distributions modifications of parabola-rectangle diagram improve results

#### SHEAR WEB-FLANGES 8.2.5

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

$$r_{\rm Ed} \le \frac{A_{\rm sf}}{s_{\rm f} \cdot h_{\rm f}} \cdot f_{\rm yd} \cdot \cot\theta_{\rm f}$$
(8.69)

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

$$\sigma_{\rm cd} = \tau_{\rm Ed} (\cot\theta_{\rm f} + \tan\theta_{\rm f}) \le \nu \cdot f_{\rm cd} \tag{8.70}$$

where the following strength reduction factor may be used:

$$\nu = 0,5 \tag{8.71}$$

. .

# Advantages of new f<sub>cd</sub>

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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:

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

where v may be determined by the formulae in Annex G. A value of v = 0.60 may be used when  $\cot \theta = 1.0$ .



# Advantages of new f<sub>cd</sub>

v is not dependent of f<sub>ck</sub> (shear, punching, struts&ties...) simplification of stress distributions modifications of parabola-rectangle diagram improve results

#### **STRUT & TIE 8.5.2**

a)	for compression f	ields and struts crossed	or deviated by a tie at an angle:
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$- 20^{\circ} \le \theta_{\rm cs} < 30^{\circ}$	$\nu = 0,4$	(8.115)
$- 30^{\circ} \le \theta_{\rm cs} < 40^{\circ}$	$\nu = 0,55$	(8.116)
$-40^{\circ} \le \theta_{\rm cs} < 60^{\circ}$	$\nu = 0,7$	(8.117)
$-60^{\circ} \le \theta_{\rm cs} < 90^{\circ}$	$\nu = 0,85$	(8.118)

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

. 1	(0.110)
$v = \frac{1}{1,11+0,22 \cdot \cot^2 \theta_{\rm cs}}$	(8.119)

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

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\nu = 1,0 (8.120)
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# Advantages of new f<sub>cd</sub>

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a) cross-section

b) assumed strain distribution

c) parabola-rectangle stress distribution

d) rectangular stress distribution



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



### Definition of hypothesis for partial factors of materials

Design situations — Limit states	γs for reinforcing and prestressing steel	$\gamma_{\rm C}$ and $\gamma_{\rm CE}$ for concrete	γv for shear and punching resistance without shear reinforcement				
Persistent and transient design situation	1,15	1,50ª	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.							
<sup>a</sup> The value for $\gamma_{CE}$ applies when the indicative value for the elastic modulus according 5.1.4(2) is used. A value							

Table 4.3 (NDP) - Partial factors for materials

<sup>a</sup> The value for  $\gamma_{CE}$  applies when the indicative value for the elastic modulus according 5.1.4(2) is used. A valu  $\gamma_{CE} = 1,3$  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"

## Definition of hypothesis for partial factors of materials

	Coefficient of variation	Bias factor <sup>a</sup>
Partial factor for reinforcement $\gamma_S$		
Yield strength $f_y$	$V_{\rm fy}=0,045$	$f_{\rm ym}/f_{\rm yk} = \exp(1,645V_{\rm fy})$
Effective depth d	$V_{\rm d}=0,050^{ m b}$	$\mu_{\rm d}=0.95^{ m b}$
Model uncertainty	$V_{ extsf{ hetas}} = 0,045^{\circ}$	$\mu_{ hetas} = 1,09^{\circ}$
Coefficient of variation and bias factor of resistance for reinforcement	$V_{\rm RS} = 0,081^{\rm i}$	$\mu_{\rm RS} = 1,115^{\rm i}$
Partial factor for concrete $\gamma_c$		
Compressive strength fc (control specimen)	$V_{\rm fc} = 0,100$	$f_{\rm cm}/f_{\rm ck} = \exp(1,645V_{\rm fc})^{\rm d}$
Insitu factor $\eta_{is} = f_{c,ais}/f_c e$	$V_{\eta is} = 0,120$	$\mu_{\eta is} = 0,95$
Concrete area A <sub>c</sub>	$V_{\rm Ac} = 0,040$	$\mu_{\rm Ac}=1,00$
Model uncertainty	$V_{ m  heta c} = 0,070^{ m f}$	$\mu_{ m  extsf{ heta} m c} = 1,02^{ m f}$
Coefficient of variation and bias factor of resistance for concrete	$V_{\rm RC} = 0,176^{\rm i}$	$\mu_{\rm RC} = 1,142^{\rm i}$
Partial factor for shear and punching $\gamma_V$ (see 8.2.1, 8.2.2, 8.4, 1.8.3.1, 1.8.5)		
Compressive strength fc (control specimen)	$V_{\rm fc} = 0,100$	$f_{\rm cm}/f_{\rm ck} = \exp(1,645V_{\rm fc})^{\rm d}$
Insitu factor $\eta_{is} = f_{cais}/f_c^{e}$	$V_{\eta is} = 0,120$	$\mu_{\eta is} = 0,95$
Effective depth d	$V_{\rm d} = 0,050^{\rm b}$	$\mu_{\rm d}=0,95^{ m b}$
Model uncertainty	$V_{ m  heta v} = 0,107$ g	$\mu_{ m Bv} = 1,10$ g
Residual uncertainties	$V_{\rm res,v} = 0,046^{\rm h}$	-
Coefficient of variation and bias factor of resistance for shear and punching (members without shear reinforcement)	$V_{\rm RV}=0,137^{\rm i}$	$\mu_{\rm RV} = 1,085^{\rm i}$
The values in this column refer to ratio between mean value and values used in the design	formulae (characteristi	ic or nominal).

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



Procedure to modify partial factors of materials

 $R_{c} = f_{c,cyl} \cdot \eta_{is} \cdot A_{c} \cdot \theta_{c} \begin{cases} f_{c,cyl} : compressive strength of the control specimen \\ \eta_{is} : f_{c,cyl} \rightarrow f_{c,ais} \\ A_{c} : area of concrete \\ \theta_{c} : model uncertainty \end{cases} f(\log R_{c})$ 

$$V_{\text{Rc}} = \frac{\sigma_{\text{Rc}}}{R_{\text{cm}}} = \sqrt{V_{\text{fc,cyl}}^2 + V_{\text{\eta is}}^2 + V_{\text{Ac}}^2 + V_{\theta c}^2}$$
$$\mu_{\text{Rc}} = \frac{R_{\text{cm}}}{R_{\text{ck}}} = \mu_{\text{fc,cyl}} \cdot \mu_{\text{\eta is}} \cdot \mu_{\text{Ac}} \cdot \mu_{\theta c} \text{ where } \mu_{\text{fc,cyl}} = \frac{f_{\text{cm}}}{f_{\text{ck}}} = e^{1.645 V_{\text{fc}}}$$

$$\gamma_{c} = \frac{R_{cd}}{R_{ck}} = \frac{e^{\alpha_{R} \cdot \beta_{tgt} \cdot V_{Rc}}}{\mu_{Rc}}$$



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

Design situations/Limit states	Sensitivity factors for resistance $\alpha_{\rm R}$	target value for the 50-year reliability index $\beta_{\rm igt}$
Persistent or transient design situation	0,8	3,8
Fatigue design situation	0,8	3,8
Accidental design situation	0,8	2,0

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

# 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

# Procedure to modify partial factors of materials Specific cases table A1

Tolerance Class 2 instead of Class 1

Condition for adjusted material factors		persistent and transient design situations		accidental design situations			
		γs	γс	γv	γs	γc	γv
		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	1,081,481,330,971,151,11in 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 4.4 for h)					ons d), e), may be tatistical in (8) for sistance ven in

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



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

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



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Design situations — Limit states	$\gamma_{\rm C}$ and $\gamma_{\rm CE}$ for concrete	γv for shear and punching resistance without shear reinforcement			
Persistent and transient design situation	1,50ª	1,40			
Fatigue design situation	1,50	1,40			
Accidental design situation	1,15	1,15			
Serviceability limit state	1,00	_			



# Use of design value of effective depth on shear

- Thin members: geometrical uncertainties govern
- Deep members: geometrical uncertainties negligible
- More rational to use d<sub>d</sub>
- 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  $V_d = 0,00$  and  $\mu_d = 1,00$  if the calculation of the design resistance is based on the design value of the effective depth  $d_d$ :  $d_d = d_{nom} - \Delta d$  (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  $d_d$  can be used unless the National Annex gives limitations.



## Use of design value of effective depth on shear

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- Deep members: geometrical uncertainties negligible
- More rational to use d<sub>d</sub>
- Reduced values of  $\gamma_v$  and  $\gamma_s$  can be obtained

	Condition for adjusted material factors	persistent and transient design situations			accidental design situations		
		γs	γc	γv	γs	γc	γv
		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)	1,03     1,50     1,29     0,94     1,15       in case also at least one of the condition f) or h) is fulfilled, the partial factors n calculated according to (3) with the sta values given in (6) and in (7) for d) or i e); with the updated values of the resi model for (f) and with the values giv					ns d), e) may be atistical in (8) fo istance ven in

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

# Thank you for your attention

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