EC8 Webinars

Second Generation of Eurocode 8

Assessment and retrofit of reinforced concrete structures

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22nd November 2023

OUTLINE OF PRESENTATION

- 8.1 Scope of Clause 8
  - Navigation trough the code
- 8.2 Identification of geometry, details and materials
- 8.3 Structural modelling
- 8.4 Resistance models for assessment
- 8.5 Verification of Limit States
- 8.6 Resistance models for retrofitting

- **Note**: The slides are based on the following codes
  - prEN 1998-3:2023-ENQ
  - FprEN 1998-1-1:2024-FV
  - prEN 1998-1-2:2023-ENQ
  - FprEN1992-1-1:2023

8.1 Scope of Clause 8

Clause 8
contains specific criteria for the assessment of reinforced concrete structures
- In their present state
- For their upgrading, if necessary

8.2
gives information on what data should be collected, and rules for knowledge levels
- Complementary to **5** for buildings. For bridges **12.4.2** should be applied

8.3 and 8.4.2.4.3
give rules for structural modelling of reinforced concrete structures
- Complementary to **6.3**

8.4.2
gives resistance models for assessment of existing members in terms of generalised deformations

8.4.3 and 8.4.4
give resistance models for assessment of existing members and joints, respectively, in terms of shear

8.5
gives rules for verification of limit states
- Complementary to **6.5**

8.6
gives resistance models for retrofitting of existing structures

- **Note**: the **numbers** above refer to clauses or sub-clauses of **EN1998-3**. When references to clauses of other codes are made then the particular code is mentioned along with the relevant clause

8.1 Scope of Clause 8 – Navigation through the code

- For the user to apply the code the following steps may be followed:

1. Start from **8.2** to collect information and establish the knowledge level
2. Proceed to **8.3** and **8.4.2.4.3** for the structural modelling
3. Obtain the resistance models for assessment of existing members in terms of deformations from **8.4.2**
4. Obtain resistance models for shear in critical zones and joints from **8.4.3** and **8.4.4**
5. Obtain the safety verification requirements from **8.5**
6. Use the resistance models in **8.6** for strengthening, if needed, of existing members

8.2 Identification of geometry, details and materials

- One important aspect of the assessment of existing structures is the identification of the
  - Geometry (**8.2.2**)
  - Details of the reinforcement (**8.2.3**)
  - Material properties (**8.2.4**)
- Sub-clause **8.2** states which data should be collected as a minimum (in addition to **5**), so as to be able to perform a proper assessment of an existing reinforced concrete structure. For bridges, **12.4.2** should be applied
- This information will be used for
  - structural modelling,
  - the resistance models, and
  - the partial factors on resistance

8.2 Identification of geometry, details and materials…

- There is a knowledge level for each of the three attributes
  - Geometry: KLG1, KLG2 and KLG3
  - Construction Details: KLD1, KLD2 and KLD3
  - Material properties: KLM1, KLM2 and KLM3

  where **1**, **2**, and **3** corresponds to **minimum**, **average** and **high knowledge**
- The definitions of these knowledge levels and how each one is attained for **geometry** and **construction details** are given in **5**
- According to **5.4.4(2)** the achieved KL on **materials**, based on the collected information, should be taken as defined in **8** to **12**. For reinforced concrete structures, the relevant sub-clause is **8.2.4**

8.2 Identification of geometry, details and materials…

- The selection of KL depends on the availability and detail of the original design documents (outline or detailed construction drawings) and on the extent of the survey, which can be Limited (L), Extended (E), or Comprehensive (C). **Tables 5.1**, **5.3** and **8.1** shown below, indicate the KLs for geometry, construction details and materials (concrete and steel), respectively.

Table 5.1: KL on Geometry as a function of collected information

Original design documents	Extent of Survey*		
	L	E	C
Not available	KLG1	KLG2	KLG3
Incomplete set	KLG2	KLG3	
Complete set	KLG3		

*L: limited; E: extended; C: comprehensive
** For meaning of 1, 2, 3 see 5.4.4

Table 5.3: KL on Construction Details as a function of collected information

Original design documents (detailed structural drawings)	Extent of Survey*		
	L	E	C
Not available	KLD1	KLD2	KLD3
Incomplete set	KLD2	KLD3	
Complete set	KLD3		

*L: limited; E: extended; C: comprehensive
** For meaning of 1, 2, 3 see 5.4.4

8.2 Identification of geometry, details and materials…

Table 8.1: KL on Materials as a function of collected information on concrete or steel reinforcement

Original design documents	Testing		
	L	E	C
Not available	KLM1(*)	KLM2	KLM3
Design specifications (**)	KLM2	KLM3	
Material test reports	KLM3		

* When original design documentation on material is not available and testing is not undertaken (as allowed for reinforcing steel), default values according to the ruling standards at the time of construction or the state of practice can be assumed.
** For instance, from design report or notes in drawings.

NOTE Default values for the material properties based on state of practice and ruling standard as a function of time of construction can be found in the National Annex.

8.2 Identification of geometry, details and materials…

- For each type of structural member, the minimum percentage of members that should be surveyed is given by **Formula (5.1)**

$$p = p_1 n^{-c} \qquad (5.1)$$

where n is the total number of members of this type in the structure determined according to **5.4.1(5)** while p_1 and c are obtained from Table 5.2

Table 5.2 — Minimum requirements for different levels of survey (vertical members)

Level of survey	Limited (L)	Extended (E)	Comprehensive (C)
P_1	200	250	300
C	0,8	0,6	0,5

(4) The values of p_1 and c from Table 5.2 should be used for vertical members; for horizontal members, irrespective of target KL, Limited survey may be undertaken

NOTE: The level of survey for horizontal members is not taken into account in determining the KL

8.3 Structural modelling

- The **member stiffness for linear analysis** (except when the q-factor method is used) and the **initial stiffness for non-linear analysis** should be based on the **secant value at yielding**, determined as given in a) and b):
  a) The initial effective stiffness (pre-yielding stiffness) of a structural member should be defined based on
    - the **yield moment M_y** (for the axial load resulting from the gravity loads concurrent with the seismic action) and
    - the corresponding **chord rotation at yielding θ_y**

  b) The stiffness of a member may be taken to be equal to the mean value of

$$\frac{M_y\, L_V}{3\theta_y}$$

    at the two ends of the member
    - θ_y should be taken as given in 8.4.2.2.1(1).
    - For preliminary analysis the stiffness of a member may be taken as specified in Annex A (25% of gross).

8.4 Resistance models for assessment

- This sub-clause defines the resistance models for
  - beams, columns and walls under flexure with or without axial force (**8.4.2**),
  - beams, columns and walls, verification of shear in critical zones (**8.4.3**), and
  - beam-column joints (**8.4.4**)

8.4.2 Beams, columns and walls under flexure with or without axial force

8.4.2.1 General

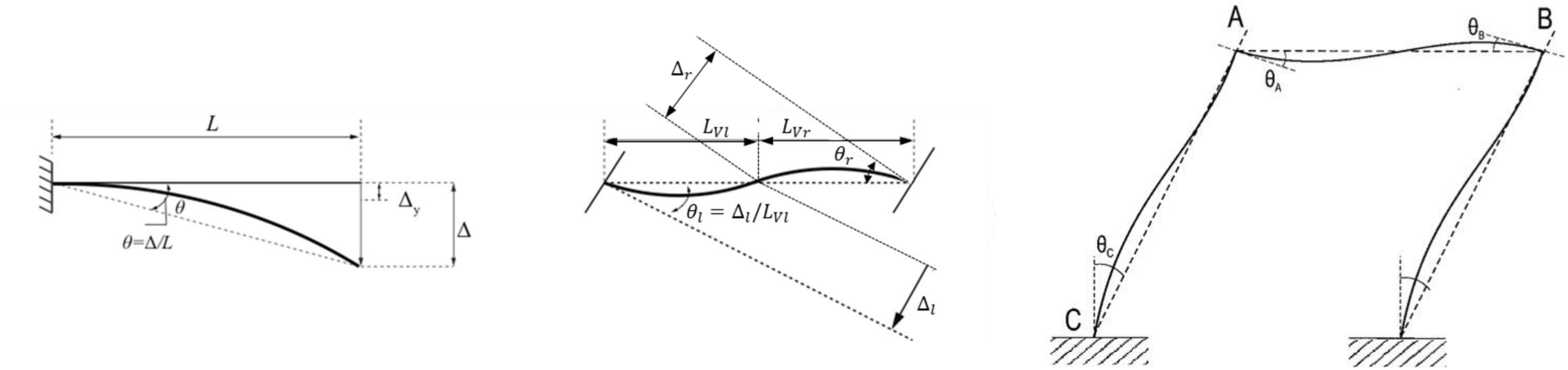
(1) Verification in bending of (beams, column, walls), which have not yielded in the seismic situation associated with the limit state considered, may be carried out using

- **prEN 1998-1-2:2023, 10**, in case of buildings or
- **prEN 1998-2:2023, 6**, in case of bridges

(2) The deformation capacity in rotation of members that have yielded should be defined in terms of the chord rotation *θ*, as defined in **FprEN 1998-1-1:2024-FV, 7.1**

8.4 Resistance models for assessment…

8.4.2.1 General …



(a) (b)

Figure 7.1 – Definition of chord rotation (θ)

8.4 Resistance models for assessment…

8.4.2.1 General …

(3) The ultimate chord rotation of an existing member is given by Formula (8.1)

$$\theta_{\mathrm{u}} = \theta_{\mathrm{y}} + a_{\mathrm{bars}}\theta_{\mathrm{u}}^{\mathrm{pl}} \qquad (8.1)$$

θ_y	is the chord rotation of the shear span, L_V, at yielding of the end section;
θ_u^{pl}	is the plastic part of the ultimate chord rotation;
α_{bars}	≤ 1 is a reduction factor accounting for the type of bars (ribbed vs smooth) and lap-splices, if any

(4) Rules for the deformation capacity of members should be taken as given in a) to c), as appropriate

a) 8.4.2.2 for members with continuous ribbed bars

b) 8.4.2.3 for members with ribbed bars, lap-spliced at floor levels

c) 8.4.2.4 for columns with smooth (plain) bars, lap-spliced at floor levels

- Existing walls conforming to the definition of "large walls" of **FprEN 1998-1-1:2024-FV**, may be verified in accordance with **prEN 1998-1-2:2023**, **10.9**.

8.4 Resistance models for assessment…

8.4.2.2 Members with continuous ribbed bars

(1) The chord rotation at yield, θ_y, may be evaluated using **FprEN 1998-1-1:2024-FV, 7.2.2.1.1**, according to which:

a) For rectangular columns, Formula (7.1)

$$\theta_{\mathrm{y}} = \phi_{\mathrm{y}} \frac{L_{\mathrm{V}}+a_1}{3} + \frac{\phi_{\mathrm{y}} d_{\mathrm{bL}} f_{\mathrm{y}}}{8\sqrt{f_{\mathrm{c}}}} + 0{,}0019\left(1 + \frac{h}{1{,}6\, L_{\mathrm{V}}}\right) \quad (7.1)$$

b) For walls of any cross-sectional shape and members with hollow rectangular section, Formula (7.2)

$$\theta_{\mathrm{y}} = \phi_{\mathrm{y}} \frac{L_{\mathrm{V}}+a_1}{3} + \frac{\phi_{\mathrm{y}} d_{\mathrm{bL}} f_{\mathrm{y}}}{8\sqrt{f_{\mathrm{c}}}} + 0{,}0011\left(1 + \frac{h}{3\, L_{\mathrm{V}}}\right) \quad (7.2)$$

c) For circular columns, Formula (7.3)

$$\theta_{\mathrm{y}} = \phi_{\mathrm{y}} \frac{L_{\mathrm{V}}+a_1}{3} + \frac{\phi_{\mathrm{y}} d_{\mathrm{bL}} f_{\mathrm{y}}}{8\sqrt{f_{\mathrm{c}}}} + 0{,}0025\left(1 - min\left(1; \frac{L_{\mathrm{V}}}{8\, D}\right)\right) \quad (7.3)$$

NOTE: The first term in Formulas (7.1) to (7.3) accounts for the flexural contribution. The second term represents the anchorage slippage of bars and the third the contribution of shear deformation.

8.4 Resistance models for assessment…

8.4.2.2 Members with continuous ribbed bars …

(2) Factor a_{bars} (in Formula 8.1) is taken equal to 1,0

(3) The plastic part of the ultimate chord rotation, θ_u^{pl}, may be calculated using **FprEN 1998-1-1:2024-FV**, **7.2.2.1.2(2)**, **Formula (7.5)**, according to which if the compression zone is rectangular and at right angles to the web of the member:

$$\theta_{\mathrm{u}}^{\mathrm{pl}} = \kappa_{\mathrm{conform}}\, \kappa_{\mathrm{axial}}\, \kappa_{\mathrm{reinf}}\, \kappa_{\mathrm{concrete}}\, \kappa_{\mathrm{shearspan}}\, \kappa_{\mathrm{confinement}}\, \theta_{\mathrm{u0}}^{\mathrm{pl}} \qquad (7.5)$$

$\theta_{\mathrm{u0}}^{\mathrm{pl}}$ Is the basic value of plastic chord rotation capacity of a member, assuming a) the member is detailed for ductility according to DC3, b) zero axial force, c) symmetric reinforcement concentrated at opposite ends of the section, d) a concrete strength equal to 25 MPa, e) L_V / h = 2,5 (shear span-to-depth ratio) at the section of maximum moment. With these assumptions, $\theta_{\mathrm{u0}}^{\mathrm{pl}}$ should be taken equal to

= 0,039 rad, if the member is a beam or a column with a section consisting of rectangular parts

= 0,023 rad, if the member is a rectangular wall

= 0,027 rad, if the member is a wall with perpendicular primers, T, I, H, or C shape or box section

8.4 Resistance models for assessment…

8.4.2.2 Members with continuous ribbed bars …

$$\theta_{u}^{pl} = \kappa_{conform}\,\kappa_{axial}\,\kappa_{reinf}\,\kappa_{concrete}\,\kappa_{shearspan}\,\kappa_{confinement}\,\theta_{u0}^{pl} \qquad (7.5)$$

$\kappa_{conform}$ = 1 for a structure conforming to DC3
= 0,9 for a structure conforming to DC2
= 0,8 for a structure in DC1

κ_{axial} = $0{,}2^{\nu}$ is the correction factor for an axial force different than zero

κ_{reinf} = $\left[\frac{\max(0{,}01;\omega')}{\max(0{,}01;\omega_{tot}-\omega')}\right]^{0{,}25}$ is the correction factor for asymmetrical reinforcement

$\kappa_{concrete}$ = $\left[min\left(2;\frac{f_c\,(MPa)}{25}\right)\right]^{0{,}1}$ is the correction factor for concrete strength different than 25 MPa

$\kappa_{shearspan}$ = $\left[\frac{1}{2{,}5}min\left(9;\frac{L_V}{h}\right)\right]^{0{,}35}$ is the correction factor for a shear span-depth ratio different than 2,5

$\kappa_{confinement}$ = $24^{\left(\frac{\alpha\rho_{sw}f_{yw}}{f_c\,(MPa)}\right)}$ is the correction factor taking into account the confinement of concrete due to transverse bars

8.4 Resistance models for assessment…

8.4.2.2 Members with continuous ribbed bars …

FprEN 1998-1-1:2024-FV, 7.2.2.1.2 (3) For members of any cross-sectional shape (including circular) not covered by (2) , θ_u^{pl}, may be calculated by **Formulae (7.6)** and **(7.7)**

$$\theta_u^{pl} = (\phi_u - \phi_y)L_{pl}\left(1 - \frac{0{,}5\,L_{pl}}{L_V}\right) + \Delta\theta_{u,slip} \qquad (7.6)$$

$$\Delta\theta_{\mathrm{u,slip}} = 9{,}5\, d_{\mathrm{bL}} \frac{\phi_{\mathrm{u}}+\phi_{\mathrm{y}}}{2} \qquad (7.7)$$

f_y	is the yield curvature at the end-section calculated from a section analysis using linear elastic material laws until the first component of the section yields;
f_u	is the ultimate curvature at the end-section calculated from a section analysis according to (4) and using non-linear material laws;
L_{pl}	is the plastic hinge length, given in (6);
$\Delta\theta_{\mathrm{u,slip}}$	is the post-yield fixed-end rotation due to yield penetration in the anchorage zone beyond the yielding end of the member, taken as given by Formula (7.7).
d_{bL}	is the longitudinal bar diameter

8.4 Resistance models for assessment…

8.4.2.2 Members with continuous ribbed bars …

FprEN 1998-1-1:2024-FV, 7.2.2.1.2 (4) and **(5)** gives strains by which the ultimate curvature, ϕ_u, in **Formula (7.6)**, may be calculated for confined and unconfined concrete, respectively.

FprEN 1998-1-1:2024-FV, 7.2.2.1.2 (6) gives **Formulae (7.13) and (7.14)** for calculating the plastic hinge length, L_{pl}, to be used in **Formula (7.6)**

a) For beams or columns with section consisting of rectangular parts, walls of all types, and hollow piers, **Formula (7.13)** should be used

$$L_{\mathrm{pl}} = \lambda_{\mathrm{section}}\, \lambda_{\mathrm{shearspan}}\, \lambda_{\mathrm{axial}}\, (0{,}3h) \quad (7.13)$$

where

$$\lambda_{\mathrm{section}} = 1 - \frac{1}{3}\sqrt{\min\left(2{,}5; \max\left(0{,}05; \frac{b_{\mathrm{w}}}{h}\right)\right)}$$

$$\lambda_{\mathrm{shearspan}} = 1 + 0{,}4 \min\left(9; \frac{L_{\mathrm{V}}}{h}\right)$$

$$\lambda_{\mathrm{axial}} = 1 - 0{,}45 \min(0{,}7; \nu)$$

8.4 Resistance models for assessment…

8.4.2.2 Members with continuous ribbed bars …

FprEN 1998-1-1:2024-FV, 7.2.2.1.2 (6)…

b) For columns with circular cross-section of diameter, *D*, **Formula (7.14)** should be used

$$L_{\mathrm{pl}} = \lambda_{\mathrm{shearspan}}\, \lambda_{\mathrm{axial}}\, (0{,}7D) \qquad (7.14)$$

where

$$\lambda_{\mathrm{shearspan}} = 1 + \frac{1}{7}\min\left(9; \frac{L_{\mathrm{V}}}{h}\right)$$

$$\lambda_{\mathrm{axial}} = 1 - \min(0{,}7; \nu)$$

From prEN 1998-3:2023-ENQ

(4) If detailing of the member does not conform to codes for seismic design for ductility, the plastic hinge length may be taken equal to 1,3 times the value obtained from **prEN 1998-1-1:2022, 7.2.2.1.2, Formula (7.13) or (7.14)**, as appropriate.

8.4 Resistance models for assessment…

8.4.2.3 Members with ribbed bars, lap-spliced starting at the end section

(1) Unless lappings are short according to (2), 8.4.2.2 and **FprEN 1998-1-1:2024-FV, 7.2.2.1.2(2)** should be applied

(2) Lappings should be considered short when the lap length is shorter than $l_{ou,min}$, given by **Formula (8.2)**

$$l_{ou,min} = \frac{d_{bL} f_y}{\left(1 + a_c a_n a_s \sqrt{\frac{d_{bL}}{2R_c}} min\left(3; \frac{p_c}{f_{ct}}\right)\left(1 - \frac{1}{6} min\left(3; \frac{p_c}{f_{ct}}\right)\right)\right) f_{ct}} \qquad (8.2)$$

(3) If lappings are short, the yield moment and curvature and the chord rotation of a member should be reduced

(4), (5), (6), (7) and (8) give Formulae for satisfying (3) by modifying the provisions presented in 8.4.2.2 for members with continuous ribbed bars

8.4 Resistance models for assessment…

8.4.2.4 Columns with smooth bars lap-spliced at floor levels

8.4.2.4.1 General

(1) The maximum stress that a vertical bar of diameter d_{bL} can develop ahead of a standard 180° hook or bend, f_o, may be taken from Formula (8.7)

$$f_o = 60\sqrt{\frac{f_c}{25}}\left(\frac{20}{d_{bL}}\right)^{0,2}\{\min[2;k_{corr}]\} \quad (8.7)$$

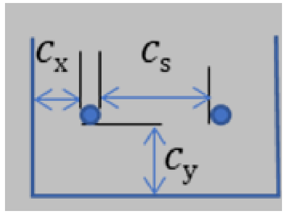


Figure 8.1

where

$$k_{corr} = \left(min\left(3,5;\frac{c_{min}}{d_{bL}}\right)\right)^{0,25} \times \left(\min\left(5;\frac{c_{max}}{c_{min}}\right)\right)^{0,1} + 12k_{conf}\min\left(0,05;\frac{a_{sw}}{d_{bL}n_b}\right) \quad (8.8)$$

(2) 8.4.2.4 should be applied to building columns with smooth bars lap-spliced at floor levels as in Figure 8.3

8.4 Resistance models for assessment…

8.4.2.4 Columns with smooth bars lap-spliced at floor levels…

- **8.4.2.4.2** prescribes how to calculate the **yield moment for smooth bars** with
  - standard 180° hook at its end
  - straight ends without hooks
- **8.4.2.4.3** gives formulae for calculating the **chord rotation at yielding** (8.11) (with f_o from Fromula (8.7)) and the **effective stiffness** of a column (8.16)

$$\theta_y = \frac{M_y}{EI_c}\frac{L_V}{3} + 0{,}0019\left(1 + \frac{h}{1{,}6L_V}\right) + \theta_{y,slip} \qquad (8.11)$$

$$EI_{eff} = \left(\frac{M_{y,top,i}}{\theta_{y,top,i}} + \frac{M_{y,bot,i}}{\theta_{y,bot,i}}\right)\frac{H_i - h_{b,i}}{12} \qquad (8.16)$$

- **8.4.2.4.4** specifies how to obtain the **ultimate chord rotation** at the end of a column consisting of rectangular parts, without or with lap-splices by **specifying a_{bars}** to be used in Formula 8.1, while $\boldsymbol{\theta_u^{pl}}$ may be calculated according to **FprEN 1998-1-1:2024-FV, 7.2.2.1.2**

8.4 Resistance models for assessment…

8.4.3 Beams, columns and walls: verification of shear in critical zones

(1) As specified in 5.5, mean values of material properties should be used in the verifications

(2) The shear resistance of beams, columns and walls should be calculated in accordance with **FprEN 1998-1-1:2024-FV**, **7.2.3** which specifies modifications in (2) to (7) to be used with **FprEN 1992-1-1:2023**, **8.2**

8.4.4 Beam-column joints

(1) The shear resistance of beam/column joints should be calculated in accordance with **FprEN 1998-1-1:2024**, **7.2.3(8)**, which directs to **FprEN1992-1-1:2023**, **8.2.3(12)**

8.5 Verification of limit states

8.5.1 Beams, columns and walls under flexure with and without axial force

8.5.1.1 Limit state of Near Collapse (NC)

(1) The chord rotation capacity corresponding to NC should be given by the ultimate value, θ_u, given in 8.4.2, and 8.6, as relating to each retrofitting method, divided by the corresponding partial factor on resistance (deformation) γ_{Rd}, using Formula (8.20)

$$\theta_{\mathrm{NC}} = \theta_{\mathrm{u}}/\gamma_{\mathrm{Rd}} \qquad (8.20)$$

(2) γ_{Rd} accounts for uncertainty in the ultimate deformation, by considering the uncertainty of all parameters involved in the corresponding Formulas in 8.4.2, and those rules in 8.6 relating to each retrofitting method.

Values for primary members are given in (3) to (5), while for secondary members γ_{Rd}=1.0

8.5 Verification of limit states …

8.5.1 Beams, columns and walls under flexure with and without axial force…

8.5.1.1 Limit state of Near Collapse (NC)…

(3) In case of ribbed bars, continuous or with lappings longer than $l_{ou,min}$ in the plastic hinge region

- **prEN 1998-1-2:2023, Table 10.2** provides the values of the total logarithmic standard deviation σ_{lnR} of the resistance model required to evaluate the partial factor (see note 2 of **FprEN 1998-1-1:2024-FV**, **6.7.2(1)**)

Table 10.2 – Total logarithmic standard deviation , σ_{lnR} (prEN 1998-1-2:2023)

Section shape	Chord rotation θ_u	Shear
Rectangular, Hollow	0,22	0,35
Circular	0,17	0,30

8.5 Verification of limit states …

8.5.1 Beams, columns and walls under flexure with and without axial force…

8.5.1.1 Limit state of Near Collapse (NC)…

(3) In case of ribbed bars, continuous or with lappings longer than $l_{ou,min}$ in the plastic hinge region …

- According to note 2 of **FprEN 1998-1-1:2024-FV**, 6.7.2(1), γ_{Rd}, is obtained using the equation below, with the resistance sensitivity factor, $\alpha_R^* = 0{,}85$, σ_{lnR} from Table 10.2 and $\beta_{t,LS,CC}$ from table F.1 of Annex F of **FprEN 1998-1-1:2024-FV**

$$\gamma_{Rd} = e^{\alpha_R^* \cdot \beta_{t,LS,CC} \cdot \sigma_{lnR}}$$

Table F.1 (NDP) — Target reliability index $\beta_{t,LS,CC}$ in a 50-year ref. per.

Limit state	Consequence class			
	CC1	CC2	CC3-a	CC3-b
NC	1,75	2,33	2,56	2,91
SD	1,20	1,60	1,76	2,00
DL	0,38	0,50	0,55	0,63

Table 10.3 – Partial factors at SD and NC (prEN 1998-1-2:2023)

Section shape	Chord rotation θ_u		Shear	
	SD	NC	SD	NC
Rectangular, hollow	1,35	1,55	1,6	2,0
Circular	1,26	1,40	1,5	1,8

(3) also gives the logarithmic standard deviations, σ_{lnR}, for ribbed bars with short lappings, and (4) and (5) for smooth bars with hooks and straight ends, respectively, as a function of the Knowledge level

8.5 Verification of limit states …

8.5.1 Beams, columns and walls under flexure with and without axial force…

8.5.1.2 Limit state of Significant Damage (SD)

(1) The chord rotation capacity corresponding to significant damage, θ_{SD}, to be used for verification should be assumed to be a fraction of the ultimate chord rotation θ_{u} given in 8.4.2, and those rules in 8.6 relating to each retrofitting method. This fraction should be as defined in **prEN 1998-1-2:2023, 6.7.2 Formulas (6.32) and (6.34)**, and the same value of $\alpha_{\mathrm{SD},\theta} = 0{,}50$ or $\alpha_{\mathrm{SD},d} = 0{,}35$ may be used. The value should be divided by the corresponding partial factor on resistance, γ_{Rd}

$$\delta_{SD} = \frac{1}{\gamma_{Rd}}\left(\delta_y + \alpha_{SD,\theta}\delta_u^{pl}\right) \quad (6.32)$$

Verification in terms of local deformations

$$d_{SD}^* = \frac{1}{\gamma_{Rd}}\left(d_y^* + \alpha_{SD,d}\left(d_u^* - d_y^*\right)\right) \quad (6.34)$$

Verification in terms of displacements of the equivalent SDOF model

8.5 Verification of limit states …

8.5.1 Beams, columns and walls under flexure with and without axial force…

8.5.1.2 Limit state of Significant Damage (SD) …

(2) The partial factor γ_{Rd} accounting for uncertainty in the deformation at Significant Damage should be evaluated by considering the total logarithmic standard deviations, σ_{lnR}, in 8.5.1.1 and the target reliability index for SD and the appropriate CC, according to **note 2 of prEN 1998-1-1:2024, 6.7.2(1)**

- **Table 10.3 of prEN 1998-1-2:2023** shows the partial factors for continuous ribbed bars or with adequate lappings for $\beta_{t,LS,CC} = \beta_{50,\mathrm{SD},CC2} = 1.60$

Table 10.3 – Partial factors at SD and NC (prEN 1998-1-2:2023), for continuous ribbed bars or with adequate lappings

Section shape	Chord rotation θ_u		Shear	
	SD	NC	SD	NC
Rectangular, hollow	1,35	1,55	1,6	2,0
Circular	1,26	1,40	1,5	1,8

8.5 Verification of limit states …

8.5.1 Beams, columns and walls under flexure with and without axial force…

8.5.1.3 Limit state of Damage Limitation (DL)

(1) At the DL limit state, so that deformations remain in the elastic domain, the bending moment should be limited to the yield moment, M_y, under the design value of the axial load.

8.5 Verification of limit states …

8.5.2 Beams, columns and walls: Shear

8.5.2.1 Limit state of Near Collapse (NC)

(1) The action effects on these members should be verified against the resistances given in 8.4.3 for existing members and in 8.6 (relating to each retrofitting method) for strengthened members, divided by the corresponding partial factor on resistance γ_{Rd}, using Formula (8.21)

$$V_{\mathrm{NC}} = V_{\mathrm{R}}/\gamma_{\mathrm{Rd}} \qquad (8.21)$$

(3) Values of γ_{Rd} may be taken as given in a) and b):

(a) Values of the total logarithmic standard deviation, σ_{lnR}, for calculating the partial factor for NC are given in Table 8.5

(b) For secondary members and in all formulas γ_{Rd}=1,0

8.5.2.2 Limit state of Significant Damage (SD) and Damage Limitation (DL)

(1) Verification against the exceedance of these two LS is not required, unless one of these two LS is the only one to be verified. In that case 8.5.2.1 should be applied

8.5 Verification of limit states ...

8.5.3 Beam-column joints

8.5.3.1 Limit state of Near Collapse (NC)

(1) The design horizontal shear force, $V_{Ed,j}$, is evaluated as given in (2) to (6), using the mean properties for materials

(2) If $\sum M_{yb} < \sum M_{yc}$

$$\sum M_{yb} < \sum M_{yc}$$

$$V_{Ed,j} = V_{jh} \quad (8.22)$$

$$V_{jh} = (A_{Sb1} + A_{Sb2})f_y - V_c \quad (8.23)$$

for interior joint

$$V_{jh} = A_{Sb1}f_y - V_c \quad (8.24)$$

for exterior joint

8.5 Verification of limit states ...

8.5.3 Beam-column joints…

8.5.3.1 Limit state of Near Collapse (NC)…

(3) If $\sum M_{yb} > \sum M_{yc}$

$\sum M_{yb} > \sum M_{yc}$

$$V_{Ed,j} = h_c \frac{V_{jv}}{h_b} \quad (8.25)$$

$$V_{jv} \approx \sum M_c \left(\frac{1}{Z_c} - \frac{1}{L_b} \frac{H_{st}}{H_{st,n}} \right) + \frac{|\Delta V_b|}{2} \quad (8.26)$$

(6) The horizontal shear force from Formulas (8.22) to (8.25), whichever controls according to (2) or (3), should be verified against the design shear resistance of the joint, which should be estimated according to **FprEN 1998-1-1:2024, 7.2.3(8)**, which directs to **FprEN1992-1-1:2023, 8.2.3(12)**

8.5.3.2 Limit state of Significant Damage (SD) and Damage Limitation (DL)

(1) Verification against the exceedance of these two LS is not required, unless one of these two LS is the only one to be verified. In that case, 8.5.3.1 applies

8.6 Resistance models for retrofitting

8.6.1 General

(1) The partial factors on resistance should be applied on the resistance and deformation capacity of the retrofitted member, as determined in accordance with 8.6 using the ultimate capacities in 8.4.2 and 8.4.3

8.6.2 Concrete jacketing

8.6.2.1 General

- The purposes of concrete jackets are described in 8.6.2.1

8.6.2.2 Enhancement of strength, stiffness and deformation capacity

(1) The simplifying assumptions for the purpose of evaluating strength and deformation capacities of jacketed columns or walls are given in 8.6.2.2

8.6 Resistance models for retrofitting …

8.6.2 Concrete jacketing …

8.6.2.2 Enhancement of strength, stiffness and deformation capacity …

(2) Formulas (8.27) to (8.30) may be used to relate the values of V_R, M_y, θ_y, and θ_u, calculated under the assumptions in (1) to the values V_R^*, M_y^*, θ_y^* , and θ_u^* to be adopted in the resistance verifications.

$$V_R^* = 0{,}9V_R \tag{8.27}$$

$$M_y^* = (0{,}95 - 0{,}28\nu)M_y \tag{8.28}$$

$$\theta_y^* = \begin{cases} 1{,}05\,\theta_y & \text{when special measures to prevent interface slip are applied} \\ (1{,}26 + 0{,}28\nu)\,\theta_y & \text{for all other cases} \end{cases} \tag{8.29}$$

$$\theta_u^* = \theta_u \tag{8.30}$$

where $\nu = \dfrac{N}{\left[b_c h_c f_{c,c} + \left(b_j h_j - b_c h_c\right) f_{c,j}\right]}$

8.6 Resistance models for retrofitting …

8.6.3 Steel jacketing

8.6.3.1 Introduction

(1) Steel jackets may be applied to columns for the purpose of increasing shear strength and/or improving the strength of deficient lap-splices. They may also be considered to increase ductility through confinement.

8.6.3.2 Shear Strength

(2) Provided that the jacket remains in the elastic range, then the contribution of the jacket to shear strength may be assumed as additive to the existing strength. In this case the steel stress of the jacket should be limited to 50% of the steel yield strength, in which case the additional shear V_j carried by the jacket should be calculated from Formula (8.31)

$$V_{\mathrm{j}} = 0{,}5 \frac{2t_{\mathrm{j}}}{s} bhf_{\mathrm{yj},d}(\cot\theta + \cot\beta)\sin\beta \qquad (8.31)$$

8.6 Resistance models for retrofitting …

8.6.3 Steel jacketing …

8.6.3.3 Clamping of lap-splices

(1) To improve cyclic deformation capacity, a) to c) should all be applied:

a) the length of the jacket should exceed by at least 50% the length of the splice region;

b) the jacket should be pressured against the faces of the column by at least two rows of bolts on each side normal to the direction of loading;

c) when splicing occurs at the base of the column, the rows of bolts should be located one at the top of the splice region and another at 1/3 of that region, starting from the base.

8.6 Resistance models for retrofitting …

8.6.4 FRP plating and wrapping

8.6.4.1 General

(1) Externally bonded FRP may be used for the purpose of one or several from a) to d):

- (a) **Enhancement of the flexural resistance** of beams, columns and walls with and without axial force;
- (b) **Enhancement of the shear resistance** of columns and walls, by applying externally bonded FRP sheets or strips with the fibres in the hoop direction;
- (c) **Enhancement of the available ductility** at member ends, through added confinement in the form of FRP jackets, with the fibres oriented along the perimeter;
- (d) **Prevention of lap splice failure**, through increased lap confinement again with the fibres along the perimeter

8.6 Resistance models for retrofitting …

8.6.4 FRP plating and wrapping …

8.6.4.2 Beam, columns and walls under flexure with and without axial force

8.6.4.2.1 Concrete members with continuous ribbed bars

8.6.4.2.1.1 Chord rotation at yielding of the end of a concrete member

(1) θ_y is calculated according to **FprEN 1998-1-1:2024, 7.2.2.1.1**

(2) For members having rectangular compression zone at right angles to the web, and wrapped in FRP, θ_u is calculated from Formula (8.1), applied with $\alpha_{bar} = 1$, and θ_u^{pl} according to **FprEN 1998-1-1:2024, Formula (7.5)**, applied with $\kappa_{conform} = 1$, and $\kappa_{confinement}$ given by Formula (8.32)

$$\kappa_{\text{confinement}} = 24^{\max\left(\left(\frac{\alpha\rho_{sw}f_{yw}}{f_c}\right);\left(\frac{\alpha\rho f_u}{f_c}\right)_f\right)} \tag{8.32}$$

8.6 Resistance models for retrofitting …

8.6.4 FRP plating and wrapping …

8.6.4.2 Beam, columns and walls under flexure with and without axial force …

8.6.4.2.1 Concrete members with continuous ribbed bars …

8.6.4.2.1.1 Chord rotation at yielding of the end of a concrete member …

(3) For members of any cross-sectional shape (including circular), wrapped in FRP, θ_u^{pl} in Formula (8.1), may be estimated using **FprEN 1998-1-1:2024, Formula (7.6)**

(4) The strains to be used for calculating the ultimate curvature, ϕ_u, to be used in **FprEN 1998-1-1:2024, Formula (7.6)** above are given in this sub-clause

(5) The plastic hinge length, L_{pl}, to be used **in FprEN 1998-1-1:2024, Formula (7.6)** may be calculated using **FprEN 1998-1-1:2024, Formulas (7.13) and (7.14)**

8.6 Resistance models for retrofitting …

8.6.4 FRP plating and wrapping …

8.6.4.2 Beam, columns and walls under flexure with and without axial force …

8.6.4.2.2 Concrete members with ribbed longitudinal bars, lap-spliced starting at the end section

8.6.4.2.2.1 General rule

(1) 8.4.2.3 Members with ribbed bars, lap-spliced starting at the end section should be applied

8.6.4.2.2.2 Moment, curvature and chord rotation at yielding of the end of a concrete member with a lap-splice

(1) To account for short lappings on the yield moment and curvature of a member wrapped with FRP, Formula (8.3) should be applied with $l_{oy,min}$ given by

$$l_{\mathrm{oy,min}} = \frac{0{,}25 d_{\mathrm{bL}} f_{\mathrm{y}}}{\max\left(\frac{c_{\mathrm{min}}}{d_{\mathrm{bL}}}; 0{,}7\right)\left(1 + 4\frac{t_{\mathrm{f}}}{R}\frac{E_{\mathrm{f}}}{E_{\mathrm{c}}}\right)^{2} f_{\mathrm{ct}}} \qquad (8.38)$$

8.6 Resistance models for retrofitting …

8.6.4 FRP plating and wrapping …

8.6.4.2 Beam, columns and walls under flexure with and without axial force …

8.6.4.2.2 Concrete members with ribbed longitudinal bars, lap-spliced starting at the end section …

8.6.4.2.2.3 Ultimate chord rotation at the end of a concrete member with lap-splice

(1) The lap length, $l_{ou,min}$, beyond which the ultimate chord rotation is not reduced, may be calculated using Formula (8.2) using the values of the parameters shown in this sub-clause

(2) Formula (8.1) may be used for calculating, θ_u, while θ_u^{pl} may be calculated using **FprEN 1998-1-1:2024, Formula (7.5)** with $\kappa_{confinement}$ specified according to the bars around the perimeter of the member

(3) For members with FRP wrapping of the lap-splice region 8.4.2.3(2) and **FprEN 1998-1-1:2024, Formula (7.13), (7.14)**, should be used with ε_{su} from Formula (8.36)

8.6 Resistance models for retrofitting …

8.6.4 FRP plating and wrapping …

8.6.4.2 Beam, columns and walls under flexure with and without axial force …

8.6.4.2.3 Concrete columns with smooth bars lap-spliced at floor levels

(1) 8.4.2.4 should be applied to members wrapped with a FRP in the lap-splice region, with the complement given in (2), except for 8.4.2.4.4, which is modified as given in (3) and (4)

(2) The maximum stress that a vertical bar of diameter d_{bL} can develop ahead of a standard 180° hook or bend, f_o, may be taken from Formulas (8.7) and (8.8), where

$$a_{\mathrm{sw}} = \frac{A_{\mathrm{sw}}}{s} + \frac{t_{\mathrm{f}} E_{\mathrm{f}}}{E_{\mathrm{s}}} \qquad (8.39)$$

8.6 Resistance models for retrofitting …

8.6.4 FRP plating and wrapping …

8.6.4.2 Beam, columns and walls under flexure with and without axial force …

8.6.4.2.3 Concrete columns with smooth bars lap-spliced at floor levels …

(3) The **ultimate chord rotation** at the end of a column wrapped with a FRP where **longitudinal bars are continuous** may be estimated using Formula (8.40)

$$\theta_{\mathrm{u,cont.bars,FRP}} = \theta_{y,\mathrm{cont.bars}} + 0{,}85\,\theta_{\mathrm{u}}^{\mathrm{pl}} \qquad (8.40)$$

(4) The **ultimate chord rotation** at the end of a column wrapped in FRP where **longitudinal bars are lap-spliced** may be estimated using Formula (8.41)

$$\theta_{\mathrm{u,lap\ hook,FRP}} = \theta_{\mathrm{y,lap}} + 0{,}75\,\alpha_{\mathrm{lap\ hook,FRP}}^{\mathrm{pl}}\,\theta_{\mathrm{u}}^{\mathrm{pl}} \qquad (8.41)$$

$$\alpha_{\mathrm{lap\ hook}}^{\mathrm{pl}} = \min\left(1; \frac{l_o}{50 d_{\mathrm{bL}}}\left(1 + 400\lambda''(0{,}1 - \lambda'')\right)\right), \qquad \text{with } \lambda'' = \min\left(0{,}05; \rho_{\mathrm{f}}\frac{E_{\mathrm{f}}}{E_{\mathrm{c}}}\right) \qquad (8.42)$$

8.6 Resistance models for retrofitting …

8.6.4 FRP plating and wrapping …

8.6.4.3 Shear resistance

(1) To enhance shear resistance of brittle components in beams, columns or walls, FRP strips or sheets may be applied, either by fully wrapping the member, or in the case of beams, by bonding them to the sides and the soffit of the beam (U-shaped strip or sheet), as shown in Figure 8.5

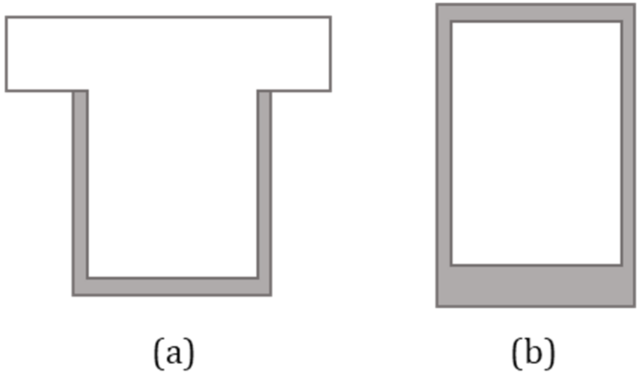


Figure 8.5 — FRP retrofitting configurations: (a) open (U-wrapped); (b) fully wrapped

8.6 Resistance models for retrofitting …

8.6.4 FRP plating and wrapping …

8.6.4.3 Shear resistance …

(2) The **shear resistance** which is controlled by the stirrups and the FRP should be evaluated as the **sum of one contribution from the existing reinforced concrete** member, evaluated in accordance with **prEN 1998-1-1:2022, 7.2.3**, and **another contribution, $V_{\mathrm{R,f}}$, from the FRP**, according to (4)

(3) The shear resistance which is controlled by diagonal compression along the inclined compression field should be evaluated without any direct contribution from the FRP

(4) In members with their plastic hinge region fully wrapped in a FRP jacket the contribution of the FRP jacket to shear resistance, $V_{\mathrm{R,f}}$ may be calculated from Formula (8.43)

$$V_{\mathrm{R,f}} = 0{,}5 \min\left(1; \frac{R}{R_{\mathrm{o}}}\right)\left(2 - \min\left(1; \frac{R}{R_{\mathrm{o}}}\right)\right) \rho_{\mathrm{f}}\, b_{\mathrm{w}}\, f_{\mathrm{u,fd}} \min(z \cot\theta; l_{\mathrm{f}}) \qquad (8.43)$$

Thank you for your attention