Second Generation of Eurocode 8

Webinar 2: Bridges

2.3: Verifications of structural members and detailing for ductility

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6. VERIFICATION OF STRUCTURAL MEMBERS TO LIMIT STATES

Chapter 6 content:

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6.2 Material requirements
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6.3 Verification of SD limit state
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Points of interest, new features or key changes the webinar will mainly focus on…

6. VERIFICATION OF STRUCTURAL MEMBERS TO LIMIT STATES

6.1 General

- Clause **6.1(1)**

Clause 6 should be applied to the earthquake resisting system of bridges designed for DC1, DC2 or DC3

⇒ For bridges equipped with antiseismic devices ⇒ Refer to Clause 8
⇒ For cable-satyed and extradosed bridges ⇒ Refer to Clause 9
⇒ For integral abutment bridges ⇒ Refer to Clause 10

- Clause **6.1(3)**

- Clause 6 should be applied for the **design of structural members** and for the **detailing of the critical regions** of each member type.

- **Outside the critical regions, the detailing of structural members should satisfy relevant provisions in prEN 1992-1-1, prEN 1993-2 and prEN 1994-2**.

6. VERIFICATION OF STRUCTURAL MEMBERS TO LIMIT STATES

6.2 Material requirements

- Clause **6.2.1(1)**: Class of concrete **≥ C25 in primary seismic members**
- Clause **6.2.1(2)**: Reinforcing steel made of **ribbed bars in all regions of primary or secondary seismic members**
- Clauses **6.2.1(3)** and **6.2.2(1)**: Reinforcing steel of **ductility class B in primary seismic members, except in critical regions if designed for DC3 ➡ Ductility class C**
- Clauses **6.2.2(2)** and **6.2.2(4)**: In steel and steel-concrete composite bridges, material properties in the dissipative zones shall ensure that plastic deformations occur where they are intended to in the design.
  - ➡ Steel grade in dissipative zones to be specified and noted on the drawings,
  - ➡ Higher grade should not be supplied for these zones

6. VERIFICATION OF STRUCTURAL MEMBERS TO LIMIT STATES

6.3 Verification of Significant Damage (SD) limit state

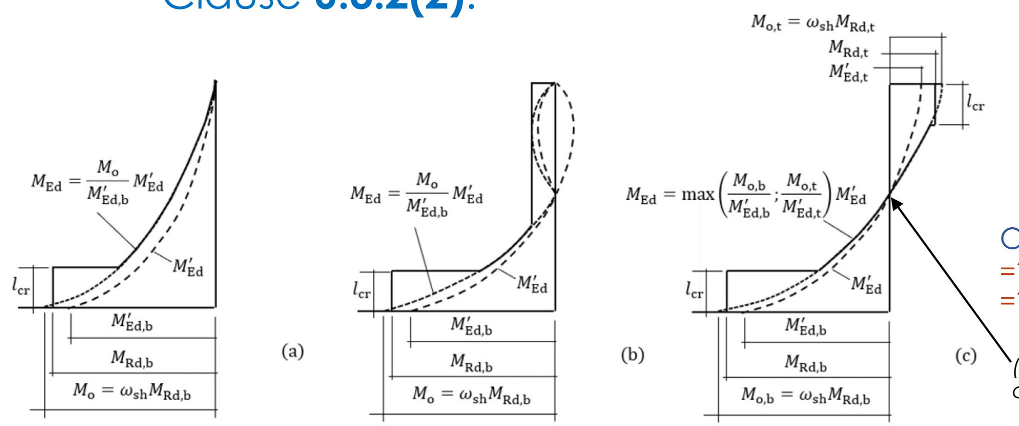
- Clause **6.3.1(1)**:
  - **Force-based approach** ➡ Verification of **local resistances**
  - **Demand on <u>non-ductile members</u> from <u>capacity design effects</u>**

6. VERIFICATION OF STRUCTURAL MEMBERS TO LIMIT STATES

6.3 Verification of Significant Damage (SD) limit state

6.3.2 Capacity design effects

- Clause **6.3.2(1)**: Brittle and other undesired failure mechanisms should be avoided by deriving design action effects from **capacity design** *(if not exceeding those obtained with q=1)*
- Clause **6.3.2(2)**:



a) Cantilever pier

b) Cantilever pier with significant higher modes effect

c) Pier that frames into the deck and is designed to form plastic hinges at both ends

$$M_o = \gamma_{Rd} \omega_{rm} \omega_{sh} M_{Rd}$$

Design flexural resistance of adjacent plastic hinge

NDP

Overstrength partial factor
=**1,1** for verification of shear mechanism
=**1,0** otherwise (recommended values)

Strain hardening factor
=**1,05** for reinforcement steel in reinforced concrete members

Material randomness factor
=**1,15** for reinforcement steel in reinforced concrete members

6. VERIFICATION OF STRUCTURAL MEMBERS TO LIMIT STATES

6.3 Verification of Significant Damage (SD) limit state

6.3.2 Capacity design effects

- Clause **6.3.2(3)**: In the case of reinforced concrete sections with special confining reinforcement in accordance with 7, and normalized axial force $\eta_k \geq 0,1$:
  ⇒ γ_{Rd} **should be multiplied by** $1+2(\eta_k - 0,1)^2$

- Clause **6.3.2(4)**:
  - ω_{rm} **should be neglected within the length of members that develop plastic hinges**
    (Assumption that the longitudinal reinforcement along the pier portion encompassing the critical zone and the zone adjacent to it are from the same steel production)
  - M_{Ed} **should not be greater than** M_{Rd} **(constant value) on the entire length of the critical region** l_{cr}

6. VERIFICATION OF STRUCTURAL MEMBERS TO LIMIT STATES

6.3 Verification of Significant Damage (SD) limit state

6.3.3 Concrete members

- Clause **6.3.3.1(1)**: $\mathbf{M_{Ed} \leq M_{Rd}}$

6.3.3.2 Structures of DC1

- Clause **6.3.3.2(1)**: M_{Ed} derived from analysis
- Clause **6.3.3.2(2)**: **For shear resistance verification** of concrete members, seismic action effect $\mathbf{A_{Ed}}$ **should be multiplied by the behavior factor q**.

6.3.3.3 Structures of DC2 and DC3

- Clause **6.3.3.3.1(1)**: M_{Ed} accounting for capacity design effects
- Clause **6.3.3.3.1(2)**: **For shear resistance verification** of concrete members, design action effect should **account for capacity design effect**.

6. VERIFICATION OF STRUCTURAL MEMBERS TO LIMIT STATES

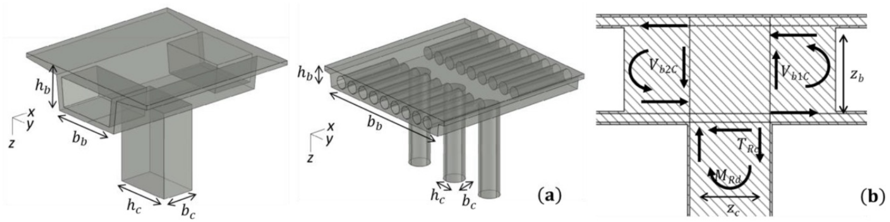
6.3 Verification of Significant Damage (SD) limit state

6.3.3 Concrete members

6.3.3.3 Structures of DC2 and DC3

6.3.3.3.2 Verification of joints adjacent to critical regions

(1) Any joint between a vertical ductile pier and the deck or a foundation member adjacent to a plastic hinge in the pier should be designed in shear to resist the capacity design effects of the plastic hinge in the relevant direction.



(7) The design value of the shear stress in the joint, assumed unreinforced, at first cracking, $v_{\mathrm{Rdj,cr}}$, may be taken as a lower limit to its design shear resistance, given by Formula (6.9).

$$v_{\mathrm{Edj}} \leq v_{\mathrm{Rdj,cr}} = f_{\mathrm{ctd}}\sqrt{\left(1+\frac{n_{\mathrm{x}}}{f_{\mathrm{ctd}}}\right)\left(1+\frac{n_{\mathrm{y}}}{f_{\mathrm{ctd}}}\right)\left(1+\frac{n_{\mathrm{z}}}{f_{\mathrm{ctd}}}\right)} \quad (6.9)$$

where $v_{\mathrm{Edj}} = v_{\mathrm{x}} = v_{\mathrm{z}} = \frac{V_{\mathrm{Edj,x}}}{b_{\mathrm{j}} z_{\mathrm{c}}} = \frac{V_{\mathrm{Edj,z}}}{b_{\mathrm{j}} z_{\mathrm{b}}}$

(8) The diagonal compression induced in the joint by the diagonal strut mechanism should not exceed the compressive strength of concrete in the presence of transverse tensile strains, taking into account also confining pressures and reinforcement.

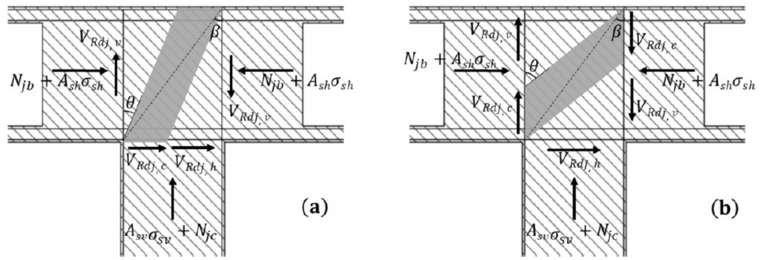


Figure 6.3 — Pier-deck joints: (a) stress conditions with $\theta < \beta$; (b) stress conditions with $\theta > \beta$

6. VERIFICATION OF STRUCTURAL MEMBERS TO LIMIT STATES

6.3 Verification of Significant Damage (SD) limit state

6.3.3 Concrete members

6.3.3.4 Deck verification

- Clauses **6.3.3.4(1)** and **(2)**: **No significant yielding should occur in the deck**
  - For bridges of DC1 ➡ Under the most adverse design action effect from analysis
  (with significant reduction of the torsional stiffness of the deck from 5.1.1(8))
  - for bridges of DC2 and DC3 ➡ Under the capacity design effects
  (with assumed torsional stiffness of the deck equal to 70% of 5.1.1(8))

NOTE Yielding of the deck for flexure within a horizontal plane is considered to be significant if the reinforcement of the top slab of the deck yields up to a distance from its edge equal to 10 % of the top slab width, or up to the junction of the top slab with a web, whichever is closer to the edge of the top slab.

6. VERIFICATION OF STRUCTURAL MEMBERS TO LIMIT STATES

6.3 Verification of Significant Damage (SD) limit state

6.3.4 Steel and steel-concrete composite members

- Clause **6.3.4(1)**: Energy dissipation shall be considered only in the piers and not in the deck
- Clause **6.3.4(3)**: Members of dissipative zones should be of cross-sectional class:
  - 1 in DC3
  - 1 or 2 in DC2.
  - may be of cross-sectional class 3 when q = 1,5.
- Other clauses: Refer mainly to:
  - Capacity design principles from 6.3.2
  - **prEN 1998-1-2**:2021, clause 11

6. VERIFICATION OF STRUCTURAL MEMBERS TO LIMIT STATES

6.3 Verification of Significant Damage (SD) limit state

6.3.5 Foundations

- Clause **6.3.5.1(1)**: Bridge foundation systems should conform to **prEN 1998-5**:2024, Clause 9

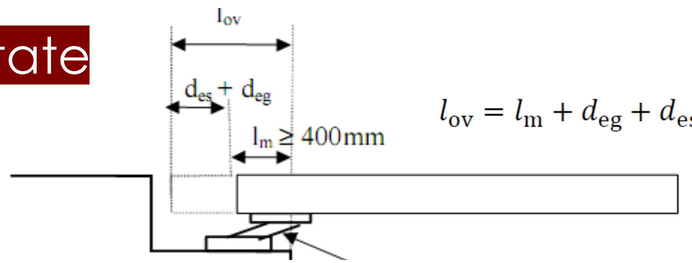
NOTE Elastic response of the structural members of the foundations is preferred for bridges, as indicated in 4.3.1(10). Non-yielding piles are preferred, designed according to FprEN 1998-5:2024, 9.5.4, unless it is shown that they can be inspected and repaired according to 4.3.3(1). Typical configurations where this is possible are those where piles are arranged in one row.

Some relevant clauses of **prEN 1998-5**:2024 applicable to bridge foundations:

- Clause 9.1 (5) Different foundation types for different vertical elements of the same structural system, e.g. piles combined with shallow foundations, may be used only if a specific study is carried out. In this case, foundation stiffness and differential displacements should be considered in the analysis model for the verification of the structure.
- **Clause 9.2** for determination of **design action effects**
- **Clause 9.4** for resistance verification of **surface and shallow embedded foundations**
- **Clause 9.5** for resistance verification of **pile foundations**

6. VERIFICATION OF STRUCTURAL MEMBERS TO LIMIT STATES

6.3 Verification of Significant Damage (SD) limit state



$$l_{ov} = l_m + d_{eg} + d_{es}$$

6.3.6 Connections

- Clause **6.3.6(1):** Minimum overlap lengths (see 8.5)
- Clauses **6.3.6(2)** and **(3):** Avoidance of all bearings uplift at the same support, unless it has no detrimental effect on the bearings

6.3.7 Concrete abutments

- Clause **6.3.7.1(1):** All main structural components of the abutments should be designed to remain elastic under the design seismic action

NOTE Abutment back-walls are structural components that can be designed as sacrificial elements.

6.3.7.2 Abutments flexibly connected to the deck ➡ Refer to **prEN 1998-5**:2024, Clause 10 ***(Earth retaining structures)***

6.3.7.3 Abutments rigidly connected to the deck ➡ Refer to Clause 10 ***(Integral abutment bridges)***

6. VERIFICATION OF STRUCTURAL MEMBERS TO LIMIT STATES

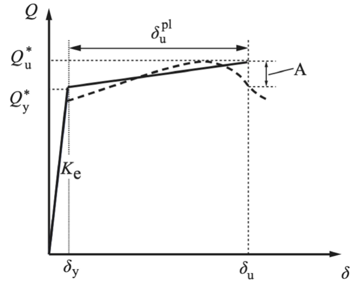
6.3 Verification of Significant Damage (SD) limit state

6.3.8 Verification for the displacement-based approach

- Clauses **6.3.8(1)** and **(2)**: Verification for **bending within critical regions** to be carried out in terms of **local deformations** *(e.g. chord rotations)*

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

where $\alpha_{SD,\theta} = 0,5$



- Clause **6.3.8(3)**: **In response-history analysis**, for verification of local deformations within critical regions, use **biaxial interaction** model from prEN 1992-1-1:2023, Formula (8.2), replacing acting and resisting bending moments by chord rotation demands and capacities and taking α_N=1,5:

$$\left(\frac{|M_{Edz}|}{M_{Rdz.N}}\right)^{a_N} + \left(\frac{|M_{Edy}|}{M_{Rdy.N}}\right)^{a_N} \leq 1,0$$

prEN 1992-1-1:2023, Formula (8.2)

- Clause **6.3.8(4)**: Verification for **bending and shear outside critical regions** to be carried out in terms of **forces**

6. VERIFICATION OF STRUCTURAL MEMBERS TO LIMIT STATES

6.4 Verification to other limit states

6.4.1 Verification of Near Collapse (NC) limit state

- Clause **6.4.1(1)**: Verifications should be carried out with the **displacement-based approach**, via **non-linear static or response-history analysis** *(since the seismic action for this LS can drive the structure into the non-linear range to an extent where results of a linear analysis are less reliable than they are at the SD limit state)*
- Clause **6.4.1(2)**: **Chord rotation capacity** to be evaluated, depending on the material, according to prEN 1998-1-1:2024, Clause 7

6.4.2 Verification of Damage Limitation (DL) limit state

6.4.3 Verification of Operational (OP) limit state

- Clauses **6.4.2(1)** and **6.4.3(1)**: Verification may be carried out with the **force-based or the displacement-based** approach
- Clauses **6.4.2(2)** and **6.4.3(2)**: If the force-based approach is used, displacements should be calculated using prEN 1998-1-1:2024, Formula (6.9): $d_{\mathrm{s}} = q_{\mathrm{disp}} d_{\mathrm{r}}$
- Clauses **6.4.2(3)** and **6.4.3(3)**: **Relevant criteria should be agreed with the relevant authority**

7. DETAILING FOR DUCTILITY

Chapter 7 content:

Points of interest, new features or key changes the webinar will mainly focus on…

7. DETAILING FOR DUCTILITY

7.1 General

- Clause **7.1(1)**: Clause 7 should be applied to **primary seismic members (piers and abutments) of bridges designed for DC2 and DC3** through plastic hinging and aims to ensure a minimum level of curvature/rotation ductility at the plastic hinges

7.2 Concrete piers

7.2.1 General

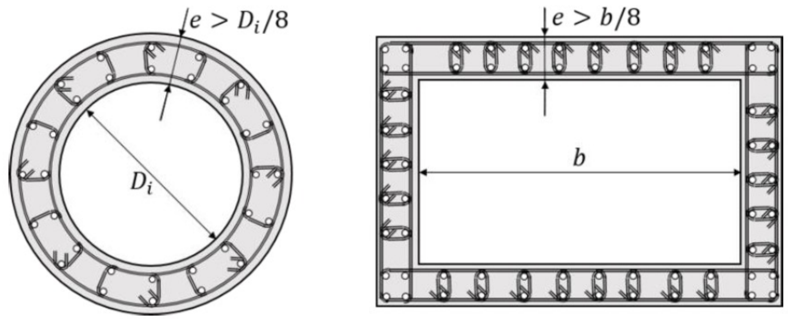
7.2.1.1 Longitudinal reinforcement

- Clause **7.2.1.1(1)**: $\rho_L \geq$ **0,5 %**
- Clause **7.2.1.1(2)**: $d_{bL} \geq 16$ mm

7.2.1.2 Hollow piers

- Clauses **7.2.1.2(1)** and **(2)**:

b/e (resp. D_i/e) < 8 *(in critical region)*



7. DETAILING FOR DUCTILITY

7.2 Concrete piers

7.2.2 Requirements for critical regions

7.2.2.1 Length of critical regions (l_{cr})

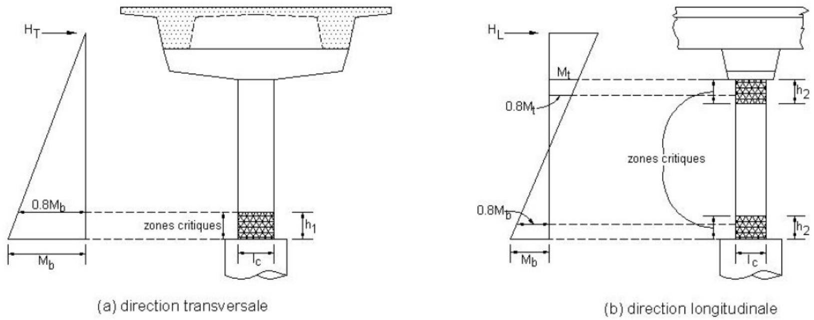
*(only for detailing the reinforcement of the plastic hinge, not for estimating the plastic hinge rotation - Clause **7.2.2.1(3)**)*

- Clause **7.2.2.1(1)**: When $\eta_k = N_{Ed}/A_c f_{ck} \leq 0,3$

l_{cr} = max
- **a) The depth of the pier section within the plane of bending *(⊥ axis of rotation)***
- **b) Distance between M_{max} and 0,8 M_{max} locations ≤ 1,5 x depth of pier section from a)**

- Clause **7.2.2.1(2)**: When $0,3 < \eta_k \leq 0,6$

l_{cr} is increased by 50 %



(a) direction transversale (b) direction longitudinale

7. DETAILING FOR DUCTILITY

7.2 Concrete piers

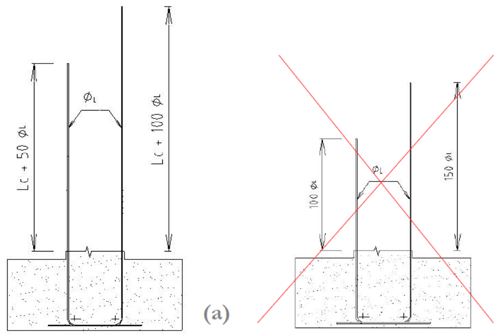
7.2.2 Requirements for critical regions

7.2.2.2 Longitudinal reinforcement

- Clauses **7.2.2.2(2)** and **(3)**:

➡ **Longitudinal reinforcement constant and fully effective over the length of the critical region l_{cr}**

➡ **No splicing by lapping or welding of longitudinal reinforcement within the critical region**



7. DETAILING FOR DUCTILITY

7.2 Concrete piers

7.2.2 Requirements for critical regions

7.2.2.3 Confinement

- Clauses **7.2.2.3.1(1)** to **7.2.2.3.3(1)**:

➡ **In critical regions of the primary seismic members**, through rectangular or circular hoops and/or cross-ties or spirals, with $d_{bT} \geq 10$ mm

NOTE If spirals are used, it is recommended to arrange them in two or more independent strands.

➡ **Quantity of confining reinforcement** defined through the mechanical reinf. ratio: $\omega_{\mathrm{wd}} = \rho_{\mathrm{w}} \frac{f_{\mathrm{yd}}}{f_{\mathrm{cd}}}$

	Transverse reinforcement volumetric ratio	$\omega_{\mathrm{wd,min}}$	
		DC2	**DC3**
Rectangular sections	$\rho_{\mathrm{w}} = \frac{A_{\mathrm{sw}}}{s_{\mathrm{L}} b}$	0,08	0,12
Circular sections	$\rho_{\mathrm{w}} = \frac{4 A_{\mathrm{sp}}}{D_{\mathrm{sp}} s_{\mathrm{L}}}$	0,12	0,18

- To be provided over the entire length l_{cr}
- Gradually reduced outside critical region
- But not less than 50 % over an additional length l_{cr}

7. DETAILING FOR DUCTILITY

7.2 Concrete piers

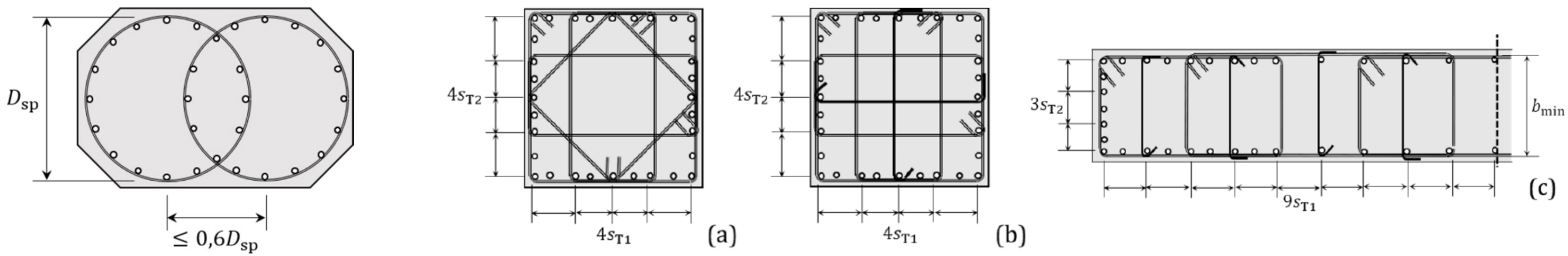
7.2.2 Requirements for critical regions

7.2.2.3 Confinement

- Clauses **7.2.2.3.1(1)** to **7.2.2.3.3(1)**:

➡ $s_L \leq 6\ d_{bL}$ or 1/5 of the smallest dimension of confined concrete core b_{min}

➡ $s_T \leq 1/3\ b_{min}$ or 200 mm for $b_{min} \leq 1{,}0$ m or 300 mm for $b_{min} > 1{,}5$ m



7. DETAILING FOR DUCTILITY

7.2 Concrete piers

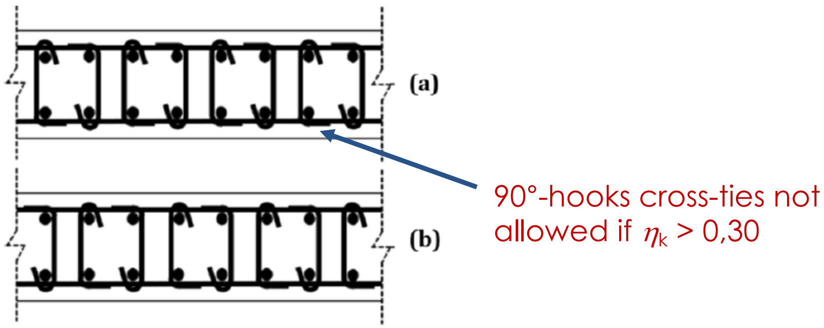
7.2.3 Buckling of longitudinal compression reinforcement

7.2.2.3 Confinement

- Clauses **7.2.3(1)** to **7.2.3(4)**:

➡ **All main longitudinal bars should be restrained against outward buckling by transverse reinforcement** spacing $s_L \leq 5\, d_{bL}$ and $s_T \leq 200$ mm

➡ $$\min\left(\frac{A_t}{s_L}\right) = \frac{\sum A_s f_{yd}}{1{,}6 f_{yt}}$$



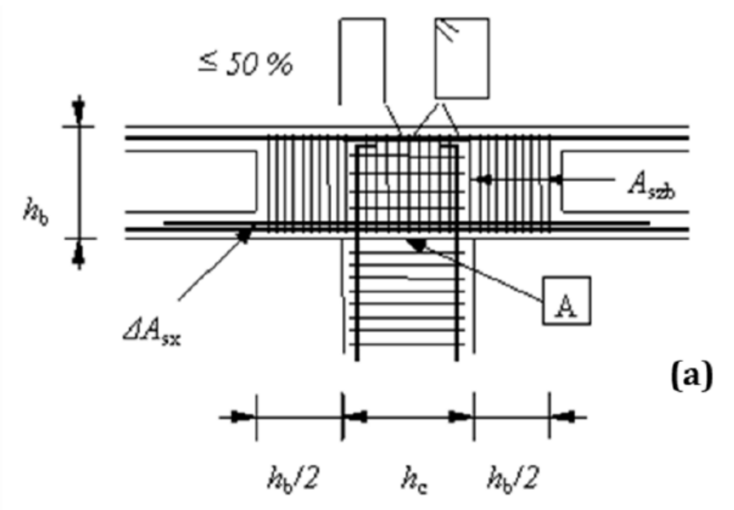
Examples of cross-ties in critical regions: (a) row *i*, (b) row *i*+1

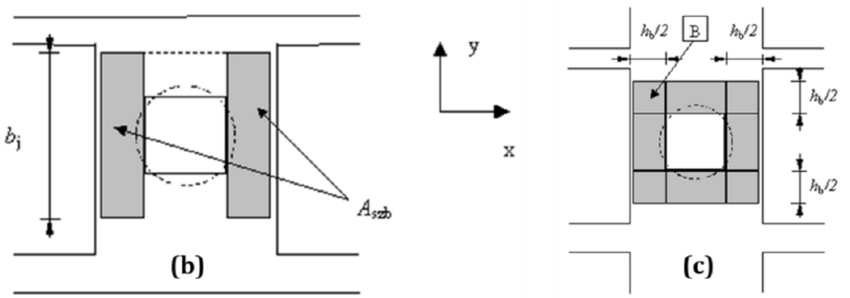
7. DETAILING FOR DUCTILITY

7.2 Concrete piers

7.2.4 Joints adjacent to critical regions

Same as before…





Key

A pier-horizontal member interface

B stirrups in common areas count in both directions

Figure 7.5 — Alternative arrangements of joint reinforcement, with: (a) vertical section within plane xz; (b) plan view for plastic hinges forming in the x-direction; (c) plan view for plastic hinges in the x- and y-directions

7. DETAILING FOR DUCTILITY

7.3 Steel piers

Refers to **prEN 1998-1-2**:2021, clause 11 and Annex E

7.4 Foundations

7.4.1 Spread foundation

Refers to **prEN 1998-5**:2024, clause 9.4

7.4.2 Pile foundations

Refers to **prEN 1998-5**:2024, clause 9.5

Thank you for your kind attention

Denis DAVI

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