IPHA INTERNATIONAL PRESTRESSED HOLLOWCORE ASSOCIATION

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Design of precast concrete elements and structures according to Eurocode 2

Bo Westerberg

The Eurocode system

Overview

EN	Name
1990	Basis of structural design
1991	Eurocode 1: Actions on structures
-1	General actions
-1-1	Densities, self-weight, imposed loads for buildings
-1-2	Actions on structures exposed to fire
-1-3	Snow loads
-1-4	Wind loads
-1-5	Thermal actions
-1-6	Actions during execution
-1-7	Accidental actions due to impact and explosions
-2	Traffic loads on bridges
-3	Actions induced by cranes and machinery
-4	Actions in silos and tanks

Σ 11 parts

EN	Name
1992	Eurocode 2: Design of concrete structures
-1-1	General – Common rules for building and civil engineering structures
-1-2	General – Structural fire design
-2	Bridges
-3	Liquid retaining and containment structures

EN	Name

1993 Eurocode 3: Design of steel structures

-1-1	General rules
-1-2	Structural fire design
-1-3	Coldformed thin gauge membe
-1-4	Structures in stainless steel
-1-5	Strength and stability of planar p
-1-6	Strength and stability of shell s
-1-7	Strength of planar plated struct
-1-8	Design of joints
-1-9	Fatigue strength
-1-10	Fracture toughness assessment
-1-11	Use of high strength cables
-1-12	Additional rules for high strength steel

-2	Bridges
-3-1	Towers and masts
-3-2	Chimneys
-4-1	Silos
-4-2	Tanks
-4-3	Pipe lines
-5	Piling
-6	Crane supporting structures

Σ 20 parts

EN	Name
1994	**Eurocode 4: Design of composite steel and concrete structures**
-1-1	General – Common rules and rules for buildings
-1-2	General – Structural fire design
-2	Bridges
1995	**Eurocode 5: Design of timber structures**
-1-1	General – Common rules and rules for buildings
-1-2	General – Structural fire design
-2	Bridges
1996	**Eurocode 6: Design of masonry structures**
-1-1	General – Rules for reinforced and unreinforced masonry
-1-2	General – Structural fire design
-2	Selection and execution of masonry
-3	Simplified calculation methods and simple rules for masonry structures

EN	Name
1997	**Eurocode 7: Geotechnical design**
-1-1	General rules
-2	Design assisted by testing
1998	**Eurocode 8: Design of structures for earthquake resistance**
-1	General rules seismic actions and rules for buildings
-2	Bridges
-3	Strengthening and repair of buildings
-4	Silos, tanks and pipelines
-5	Foundations, retaining structures and geotechnical aspects
-6	Towers, masts and chimneys

EN	Name
1999	Eurocode 9: Design of aluminium structures
-1	General - Common rules
-1-2	Structural fire design
-1-3	Structures susceptible to fatigue
-1-4	Coldformed thin gauge members and sheeting
-1-5	Shell structures

Totally 59 individual standards

Ca 6-7000 pages

”Packages” for the design of concrete structures

▼ Type of structure / Eurocode ▶	Basis of design	Loads									Concrete str.				Geotechnical
		Selfweight, imposed	Fire	Snow	Wind	Temperature	Execution	Accidental	Traffic load bridges	Silos…	Common rukes	Fire design	Bridges	Silos…	
	EN 1990	EN 1991-1-1	EN 1991-1-2	EN 1991-1-3	EN 1991-1-4	EN 1991-1-5	EN 1991-1-6	EN 1991-1-7	EN 1991-2	EN 1991-4	EN 1992-1-1	EN 1992-1-2	EN 1992-2	EN 1992-3	EN 1997-1
Building	■	■	■	■	■	■	■	■			■	■			■
Bridge	■	■		■	■	■	■	■	■		■		■		■
Silo etc	■	■		■	■	■				■	■			■	■

Contents of EN 1992-1-1

1. General
2.7 Fastenings esign
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5.9 Lateral instability of slender beams
6.2.2 Shear capacity w.r.t. diagonal tension
7. Serviceability
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9. Detailing of r
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B. Creep and shrin

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steel relaxation losses

E. Indicative strength classes for durability

F. Reinforcement expressions for in-plane stress conditions

H. Global second order effects in structures

I. Analysis of flat slabs and shear walls

J. Examples of regions with discontinuity in geometry or action

10. Additional rules for precast concrete elements and structures

Headings are numbered 10 followed by the number of the corresponding main section

10.2 Basis of design, fundamental requirements

The following should be considered specifically:

- transient situations
  - demoulding
  - transport to the storage yard
  - storage (supports and load conditions)
  - transport to site
  - erection
  - construction (assembly)
- bearings; temporary and permanent
- connections and joints between elements

10.3 Materials

Concrete strength

Tensile strength in serviceability limit state may, under certain conditions (quality control etc), be based on tests

Intermediate strength classes may be used

Effect of heat curing on

- Strength: $$f_{\mathrm{cm}}(t) = f_{\mathrm{cmp}} + \left(f_{\mathrm{cm}} - f_{\mathrm{cmp}}\right)\frac{\log\left(t - t_{\mathrm{p}} + 1\right)}{\log\left(28 - t_{\mathrm{p}} + 1\right)}$$

- Creep: $$t_{\mathrm{T}} = \sum_{i=1}^{n} \Delta t_i \cdot e^{-\left[4000/\left(273 + T\left(\Delta t_i\right)\right) - 13,65\right]}$$

- Relaxation: $$t_{\mathrm{eq}} = \frac{1{,}14^{T_{\max} - 20}}{T_{\max} - 20} \cdot \sum_{i=1}^{n}\left(T_{(\Delta t_i)} - 20\right) \cdot \Delta t_i$$

10.5 Structural analysis

10.5.1 (1)P The analysis shall account for

- the behaviour at all stages, w.r.t. geometry and properties and the interaction with in-situ concrete and other precast units
- the effect of connections between elements w.r.t. strength and deform. prop.
- uncertainties concerning restraints and force transmission w.r.t. deviations

(2) Beneficial effects of friction due to the weight of supported elements should not be utilised

- in seismic zones
- as the only means for taking horizontal forces for overall stability
- if accumulation of irreversible sliding can occur in bearings (e.g. due to temp.)
- if significant impact loading can occur

(3) The effect of horizontal movements should be considered w.r.t. resistance of the structure and the integrity of connections

10.5.2 Prestress loss, heat curing: $\Delta P_{\mathrm{e}} = 0{,}5 A_{\mathrm{p}} E_{\mathrm{p}} \alpha_{\mathrm{c}} \left(T_{\max} - T_0\right)$

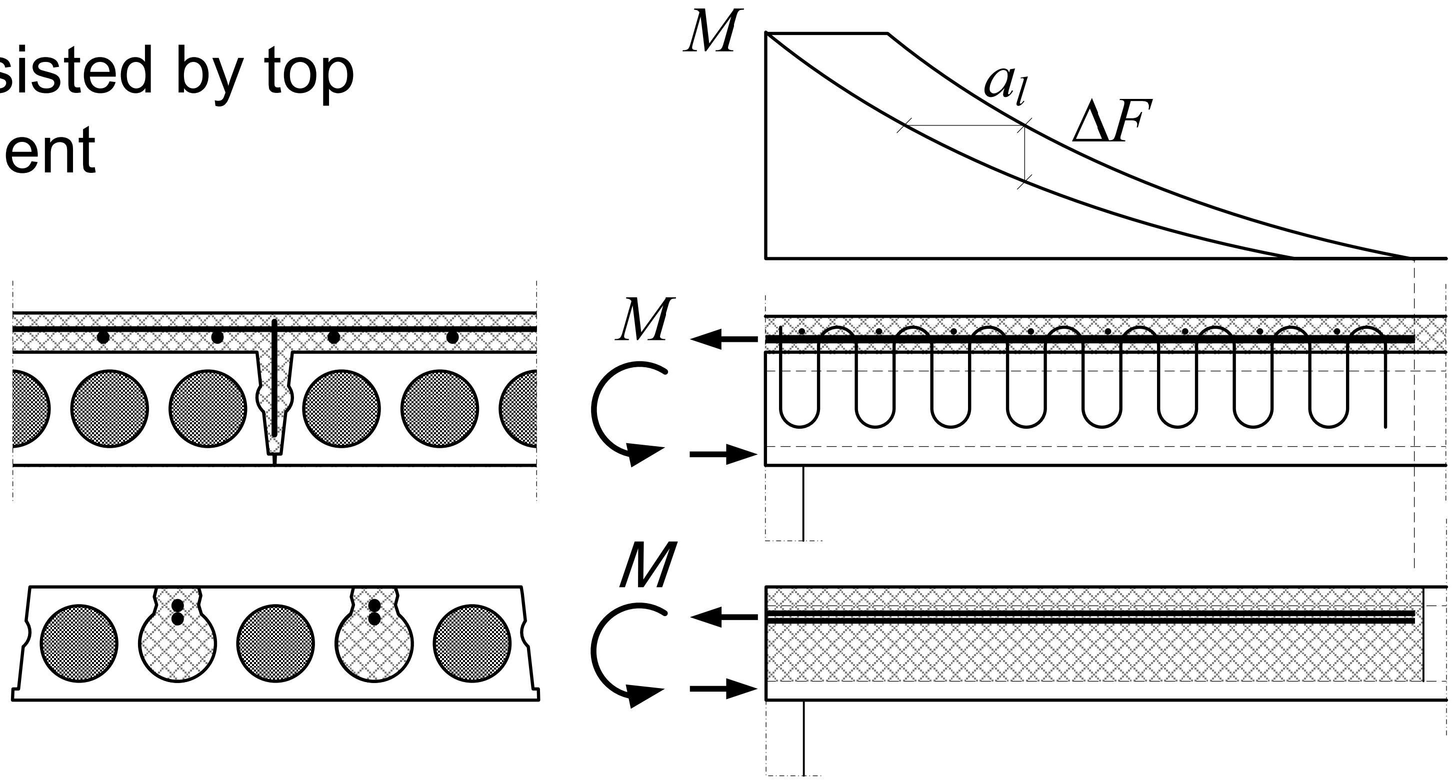
10.9 Particular rules for design and detailing

10.9.1 Restraining moments in slabs

Can be resisted by top reinforcement

a) In topping

b) In cores



Length of top reinforcement according to 9.2.1.3

Force transfer top reinforcement – topping – h.c. slab acc. to 6.2.5

May require reinforcement for shear transfer, example in figure

10.9 Particular rules for design and detailing

10.9.2 Wall to floor connections

$V/hf_{cd} \leq 0{,}5:$

No particular rein-
forcement required

$0{,}5 < V/hf_{cd} \leq 0{,}6:$

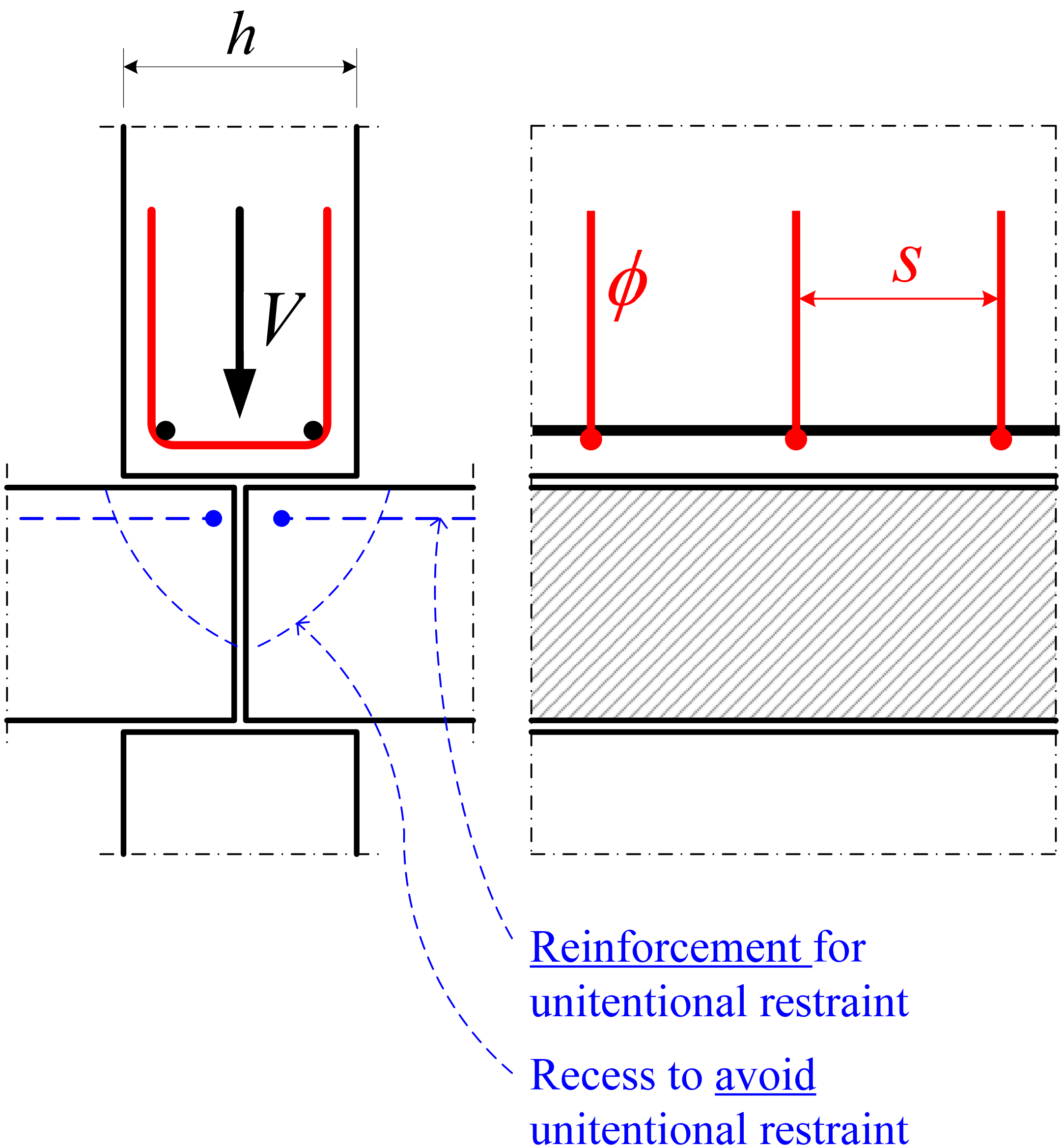
Reinforcement acc. to fig.

$\phi \geq 6\,\text{mm}$

$s \leq \min\{h, 200\,\text{mm}\}$

$V/hf_{cd} > 0{,}6:$

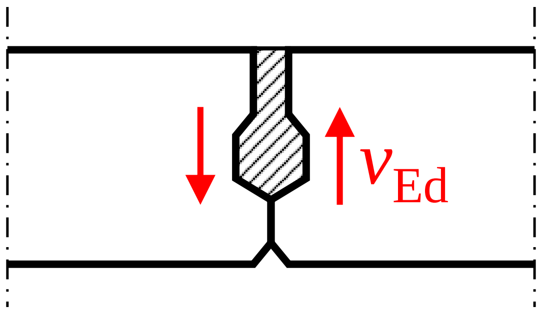
Reinforcement designed with regard to eccentricities and load concentrations



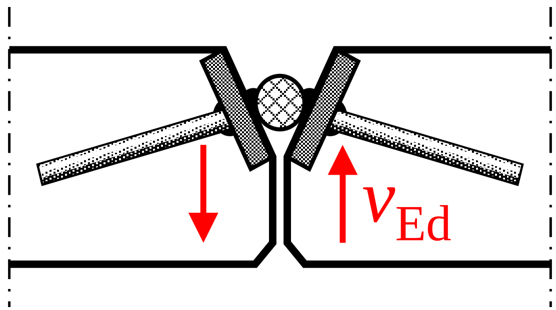
10.9 Particular rules for design and detailing

10.9.3 Floor systems

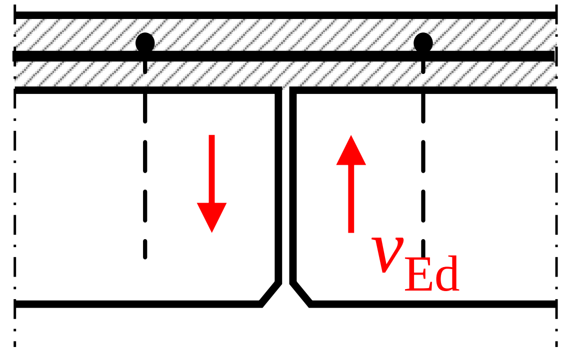
Ex. of connections for the transfer of vertical shear between floor elements



Concreted or grou-
ted connection



Mechanical con-
nection (Here: weld)



Reinforced topping

Vertical connectors
if necessary

Vertical shear force per unit length, v_{Ed}:

For uniformly distributed load, in the absence of a more accurate analysis:

$$v_{\mathrm{Ed}} \approx q_{\mathrm{Ed}} b_{\mathrm{e}} / 3$$

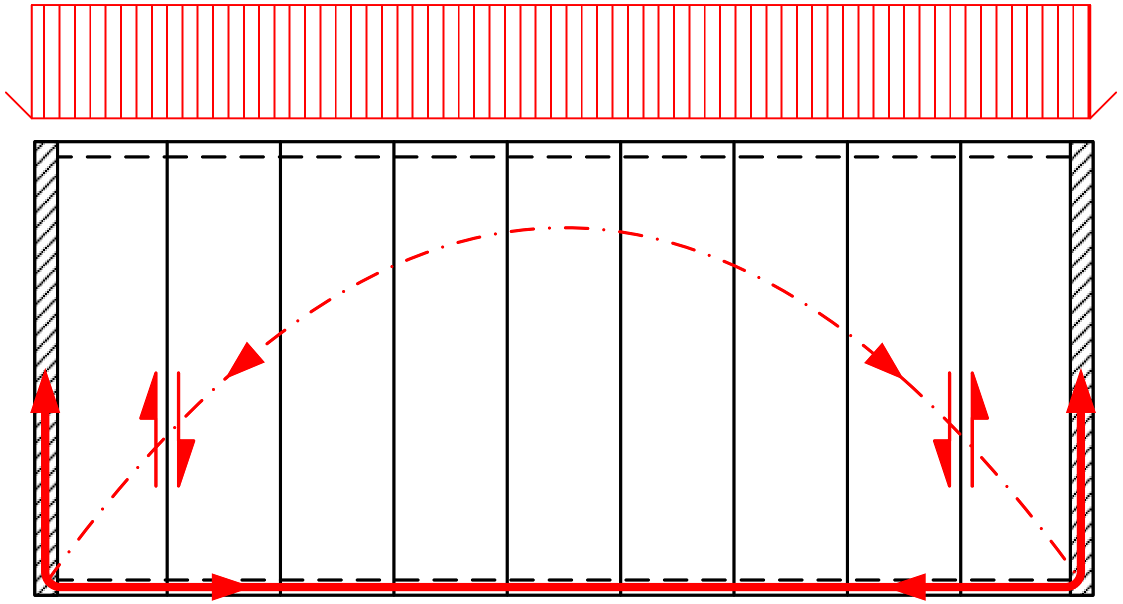
where q_{Ed} = variable load, b_{e} = element width

10.9 Particular rules for design and detailing

10.9.3 Floor systems

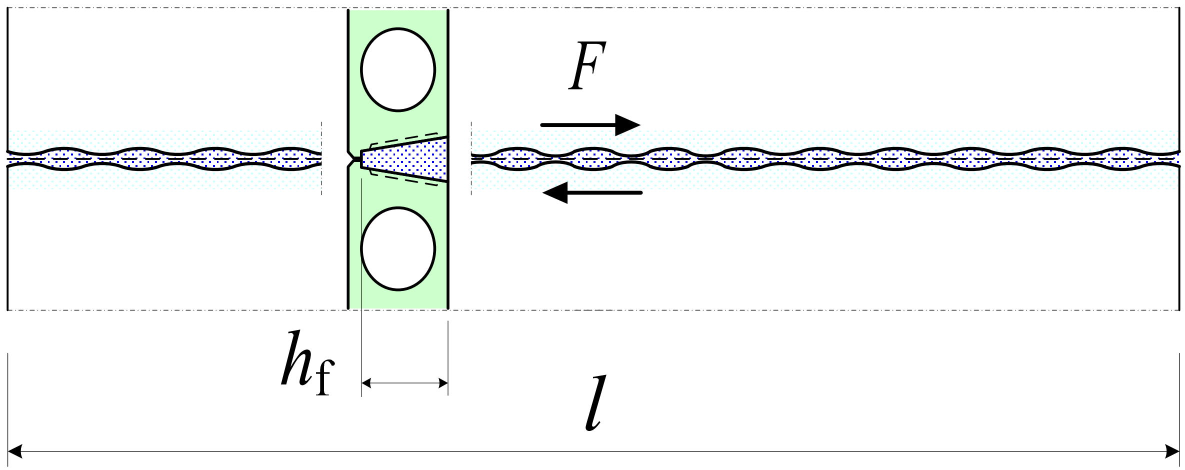
Diaphragm action for the transfer of horizontal loads:

- realistic structural model, deformation compatibility with bracing units
- take into account horizontal deformations for all parts of structure involved in transfer of horizontal loads
- reinforcement for tensile forces
- stress concentrations at openings and connections
- reinforcement for transfer of shear in connections may be concentrated along supports
- may be placed in topping, if existing



10.9 Particular rules for design and detailing

10.9.3 Floor systems



Average longitudinal shear in diaphragm action between slab units with concreted or grouted connections (e.g. hollow core slabs):

$$\tau = \frac{F}{h_f l} \leq \begin{cases} 0{,}10 \text{ MPa for very smooth surfaces} \\ 0{,}15 \text{ MPa for smooth and rough} \end{cases}$$ «

10.9 Particular rules for design and detailing

10.9.4 Connections and supports for precast elements

Materials used for connections shall be:

- stable and durable for the design working life of the structure
- chemically and physically compatible
- protected against adverse chemical and physical influences
- fire resistant to match the fire resistance of the structure

Supporting pads shall have strength and deformation properties according to design assumptions

Metal fastenings for cladding shall be of corrosion resistant material or coated (unless in X0 or XC1 or protected)

Before welding, annealing or cold forming: suitability of material shall be verified

10.9 Particular rules for design and detailing

10.9.4 Connections and supports for precast elements

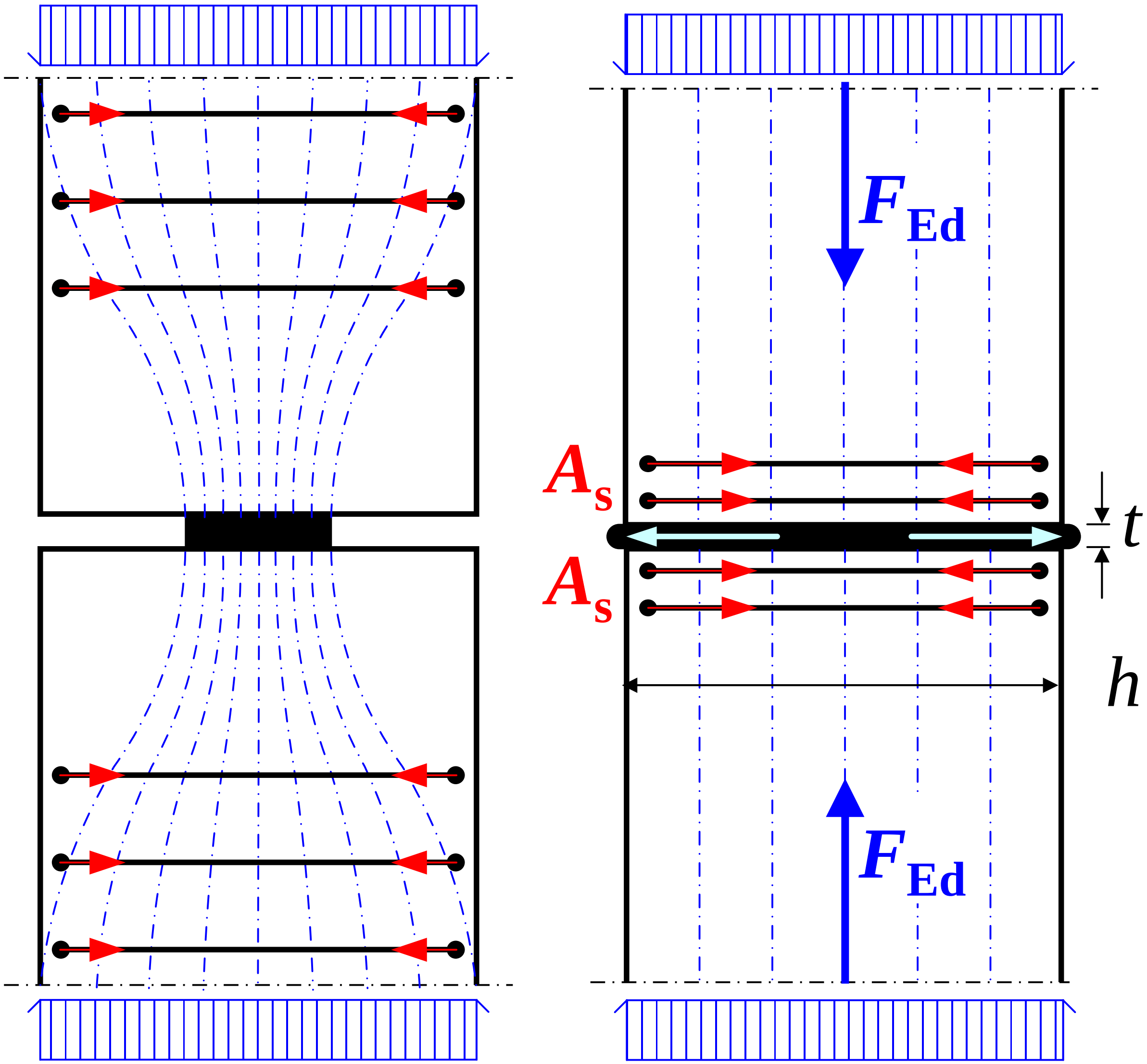
Connections transmitting compressive force

a) Partially loaded areas, 6.5 and 6.7

b) Soft padding

In the absence of more accurate models:

$$A_s = 0{,}25 \frac{t}{h} \frac{F_{Ed}}{f_{yd}}$$

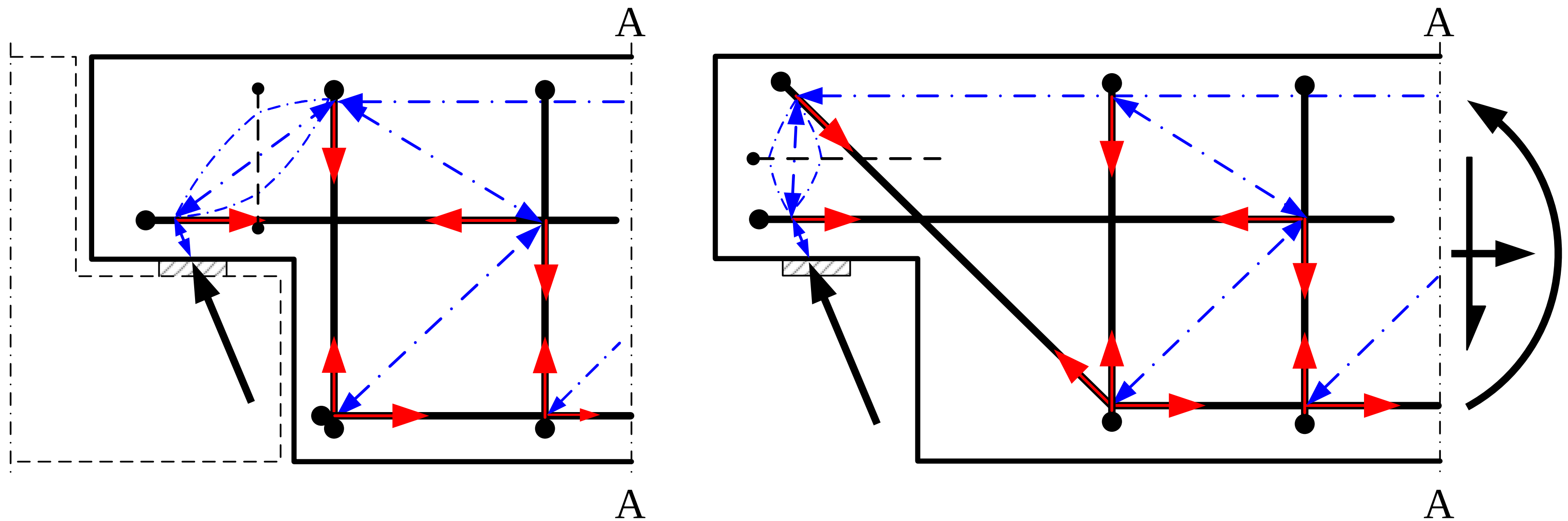


10.9 Particular rules for design and detailing

10.9.4 Connections and supports for precast elements

Half joints

Alternative strut-and-tie models:



Figures show only the main features of strut-and-tie models.
The two models may be combined.

Anchorage of reinforcement at supports

a_1 = required length wrt strength

Horizontal loop or otherwise end anchored bars:

$$d_i = c_i + \Delta a_i$$

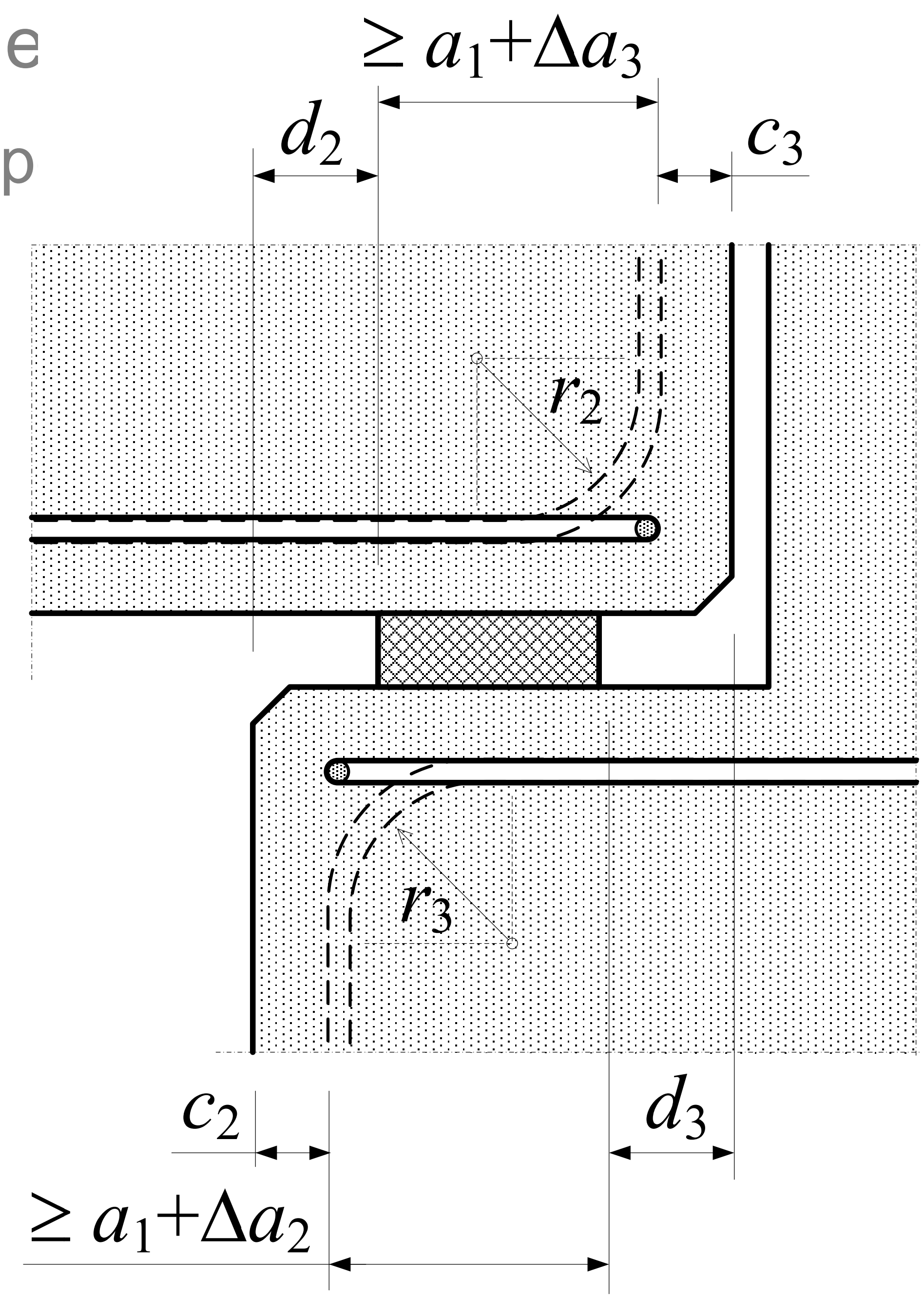
c_i = concrete cover

Δa_i = allowance for deviation

Vertically bent bars:

$$d_i = c_i + \Delta a_i + r_i$$

r_i = bend radius



10.9 Particular rules for d

10.9.5 Bearings

Available nominal bearing length:

$$a = a_1 + a_2 + a_3 + \sqrt{\Delta a_2{}^2 + \Delta a_3{}^2}$$

Required bearing length:

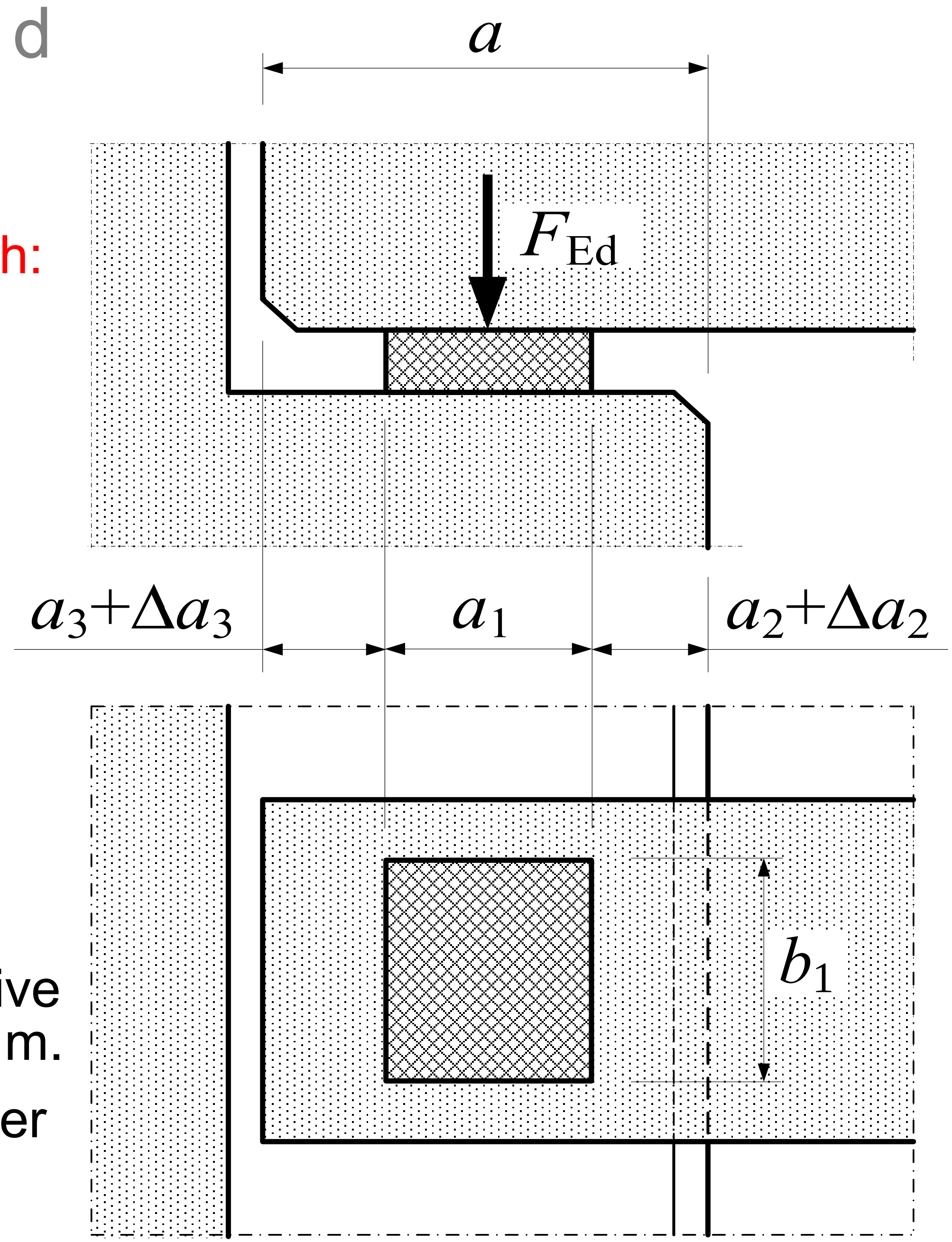
$$a_1 = F_{Ed} / (b_1 f_{Rd})$$

f_{Rd} = design value of bearing strength

a_2 = distance assumed ineffective at outer end of supporting m.

a_3 = same for supported member

Δa_i = allowance for deviation

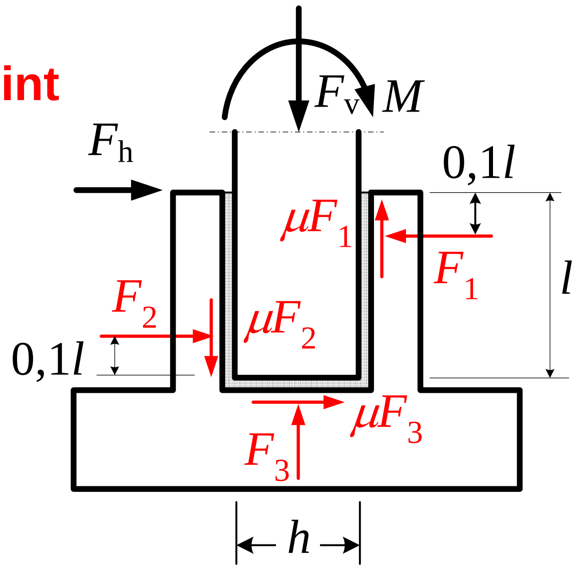


10.9.6 Pocket foundations

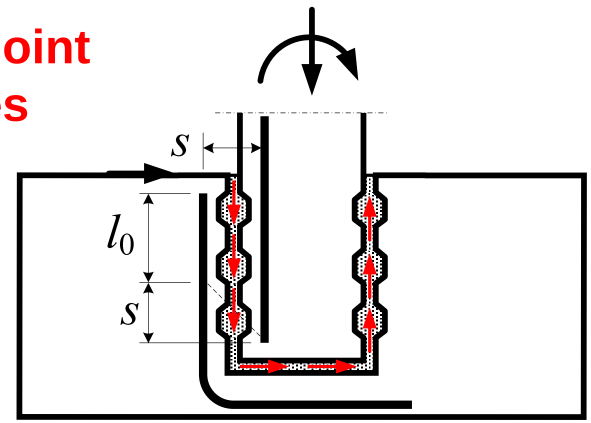
Smooth joint surfaces

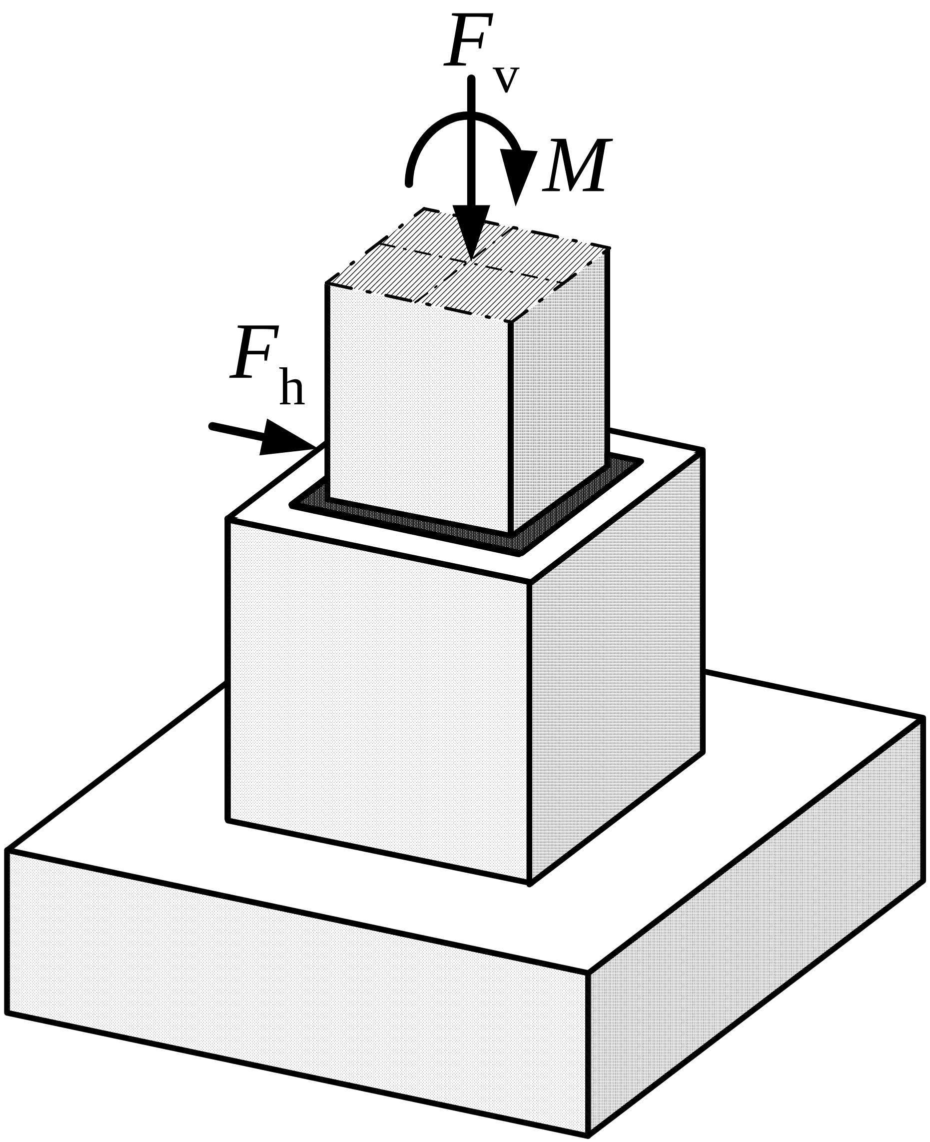
$\mu \leq 0{,}3$

$l \geq 1{,}2h$



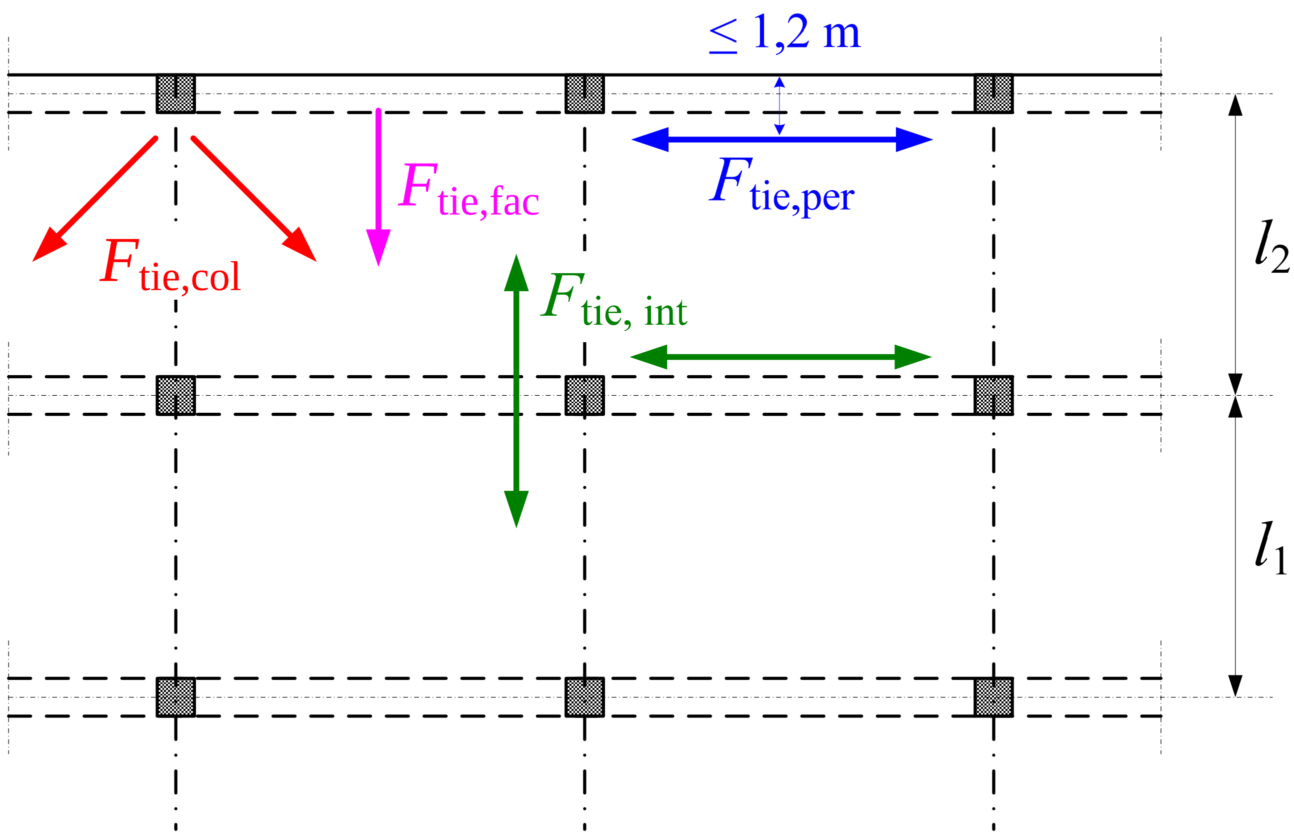
Keyed joint surfaces





10.9 Particular rules for design and detailing

10.9.7 Tying systems (⇒ 9.9)



Peripheral ties:

$F_{tie,per} = l_2 \cdot 10$
≤ 70 kN

Internal ties:

$F_{tie,int} = 20$ kN/m

[$= (l_1 + l_2) \cdot 10 \leq 70$ kN if concentrated along a beam line]

Horizontal ties to edge columns and/or walls:

$F_{tie,col} = 150$ kN

$F_{tie,fac} = 20$ kN/m

Panel build. ≥ 5 storeys: Vertical ties, or alternative structural system

2.7 Requirements for fastenings

Technical Specification ”Design of Fastenings for Use in Concrete” gives the requirements.

Deals with the following types of fasteners:

Cast-in fasteners such as
- headed anchors
- channel bars

Post-installed fasteners such as
- expansion anchors
- undercut anchors
- concrete screws
- bonded anchors
- bonded expansion anchors
- bonded undercut anchors

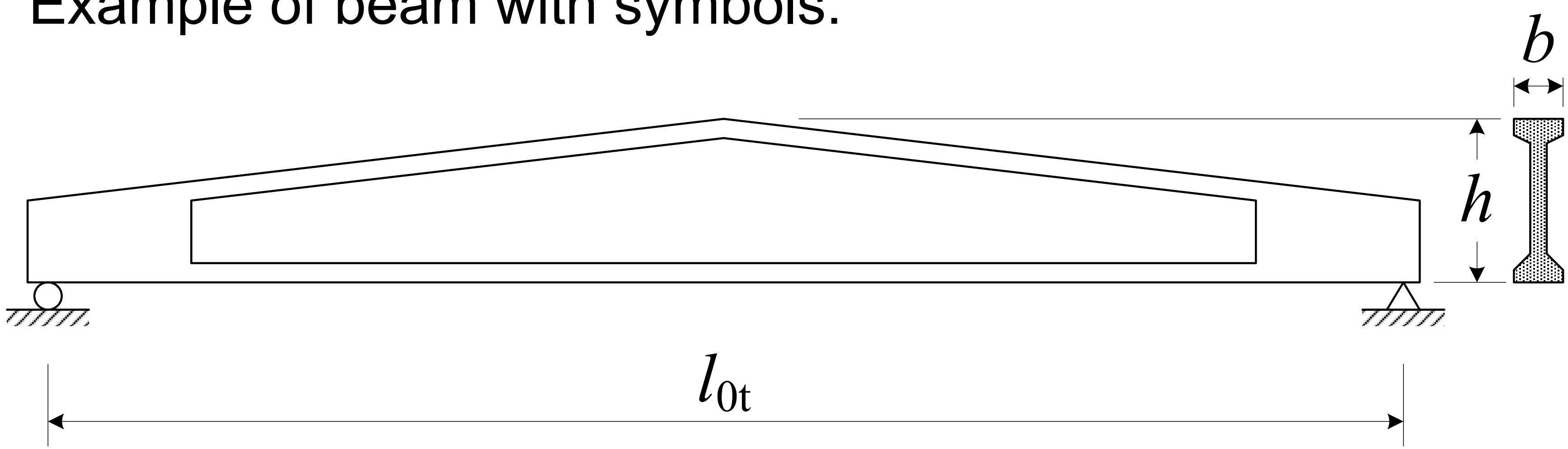
5.9 Lateral instability of slender beams

Second order effects in connection with lateral instability may be ignored if

$$\frac{l_{0t}}{b} \le \frac{50}{(h/b)^{1/3}} \quad \text{and} \quad h/b \le 2{,}5 \quad \text{in persistent situations}$$

$$\frac{l_{0t}}{b} \le \frac{70}{(h/b)^{1/3}} \quad \text{and} \quad h/b \le 3{,}5 \quad \text{in transient situations}$$

Example of beam with symbols:



5.10 Prestressed members and structures

Maximum prestressing force:

$$P_{\mathrm{max}} = A_{\mathrm{p}} \sigma_{\mathrm{p,max}}$$

$$\sigma_{\mathrm{p,max}} = \begin{cases} 0{,}8\, f_{\mathrm{pk}} \\ 0{,}9\, f_{\mathrm{p0,1k}} \end{cases}$$

0,8 and 0,9 are NDP

Temporary overstressing (e.g. in long-line pretensioning):

$$\sigma_{\mathrm{p,max}} \leq 0{,}95\, f_{\mathrm{p0,1k}}$$

0,95 is NDP

Maximum concrete stress at tensioning or release of prestress:

$$\sigma_{\mathrm{c}} \leq 0{,}6\, f_{\mathrm{ck}}(t)$$

At transfer of prestress in pretensioning, if justified by tests or experience:

$$\sigma_{\mathrm{c}} \leq 0{,}7\, f_{\mathrm{ck}}(t)$$

0,95 is NDP

5.10 Prestressed members and structures

Time dependent loss of prestress:

$$\Delta P_{\mathrm{c+s+r}} = A_{\mathrm{p}} \cdot \Delta\sigma_{\mathrm{p,c+s+r}}$$

$$= A_{\mathrm{p}} \cdot \frac{\overbrace{\frac{E_{\mathrm{p}}}{E_{\mathrm{cm}}}\varphi(t,t_0)\cdot\sigma_{\mathrm{c,QP}}}^{\text{Creep}} + \overbrace{\varepsilon_{\mathrm{cs}}E_{\mathrm{p}}}^{\text{Shrinkage}} + \overbrace{0{,}8\Delta\sigma_{\mathrm{pr}}}^{\text{Relaxation}}}{1+\frac{E_{\mathrm{p}}}{E_{\mathrm{cm}}}\frac{A_{\mathrm{p}}}{A_{\mathrm{c}}}\left(1+\frac{A_{\mathrm{c}}}{I_{\mathrm{c}}}z_{\mathrm{cp}}{}^{2}\right)\left[1+0{,}8\varphi(t,t_0)\right]}$$

6.2.2 (2) Shear capacity w.r.t. diagonal tension

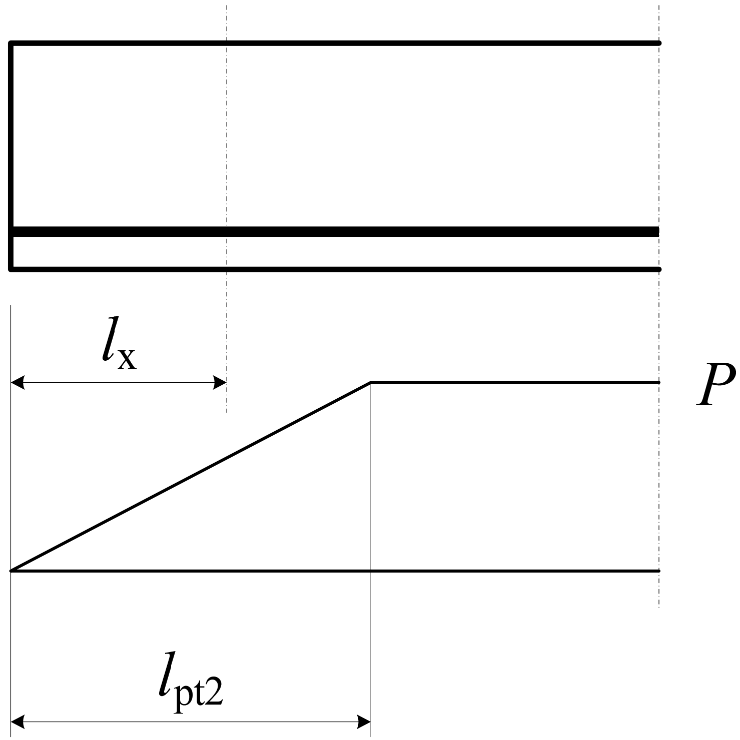
Shear capacity in members without shear reinforcement in regions uncracked in bending:

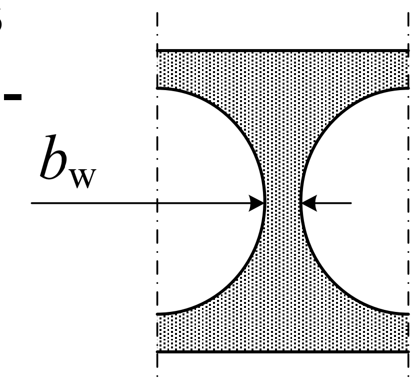
$$V_{\mathrm{Rd,c}} = \frac{I \cdot b_{\mathrm{w}}}{S} \cdot \sqrt{f_{\mathrm{ctd}}^{2} + \alpha_{l} \sigma_{\mathrm{cp}} f_{\mathrm{ctd}}}$$

$$\alpha_{l} = l_{\mathrm{x}} / l_{\mathrm{pt2}} \leq 1{,}0$$

l_{pt2} = upper bound value of transmission length

b_{w} = width of cross section at centroidal axis





for h.c. slab normally the minimum width (but not always)

6.2.5 Shear at interface between different concretes

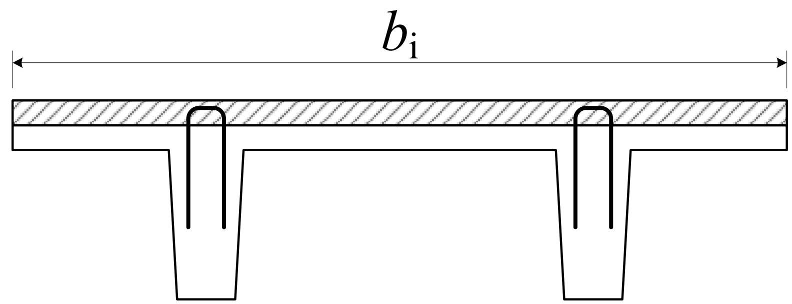
Shear stress in interface for an element with topping:

$$v_{\mathrm{Edi}} = \beta \cdot V_{\mathrm{Ed}} / (b_{\mathrm{i}} z)$$

β = part of longitudinal force acting within topping

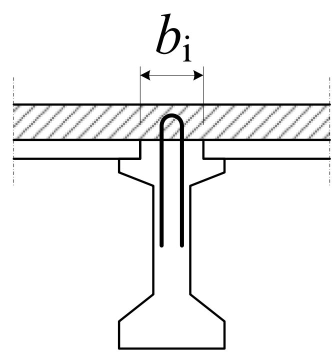
b_{i} = Interface width

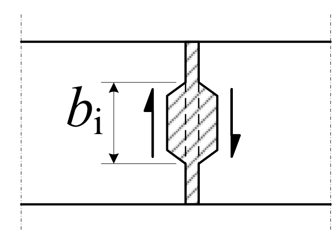
z = internal lever arm

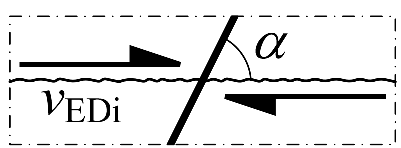


Shear resistance in interface:

$$v_{\mathrm{Rdi}} = c \cdot f_{\mathrm{ctd}} \quad \text{bond}$$
$$+ \mu \cdot \sigma_{\mathrm{cn}} \quad \text{external compression}$$
$$+ \rho \cdot f_{\mathrm{yd}} \cdot (\mu \cdot \sin\alpha + \cos\alpha) \quad \text{reinf.}$$





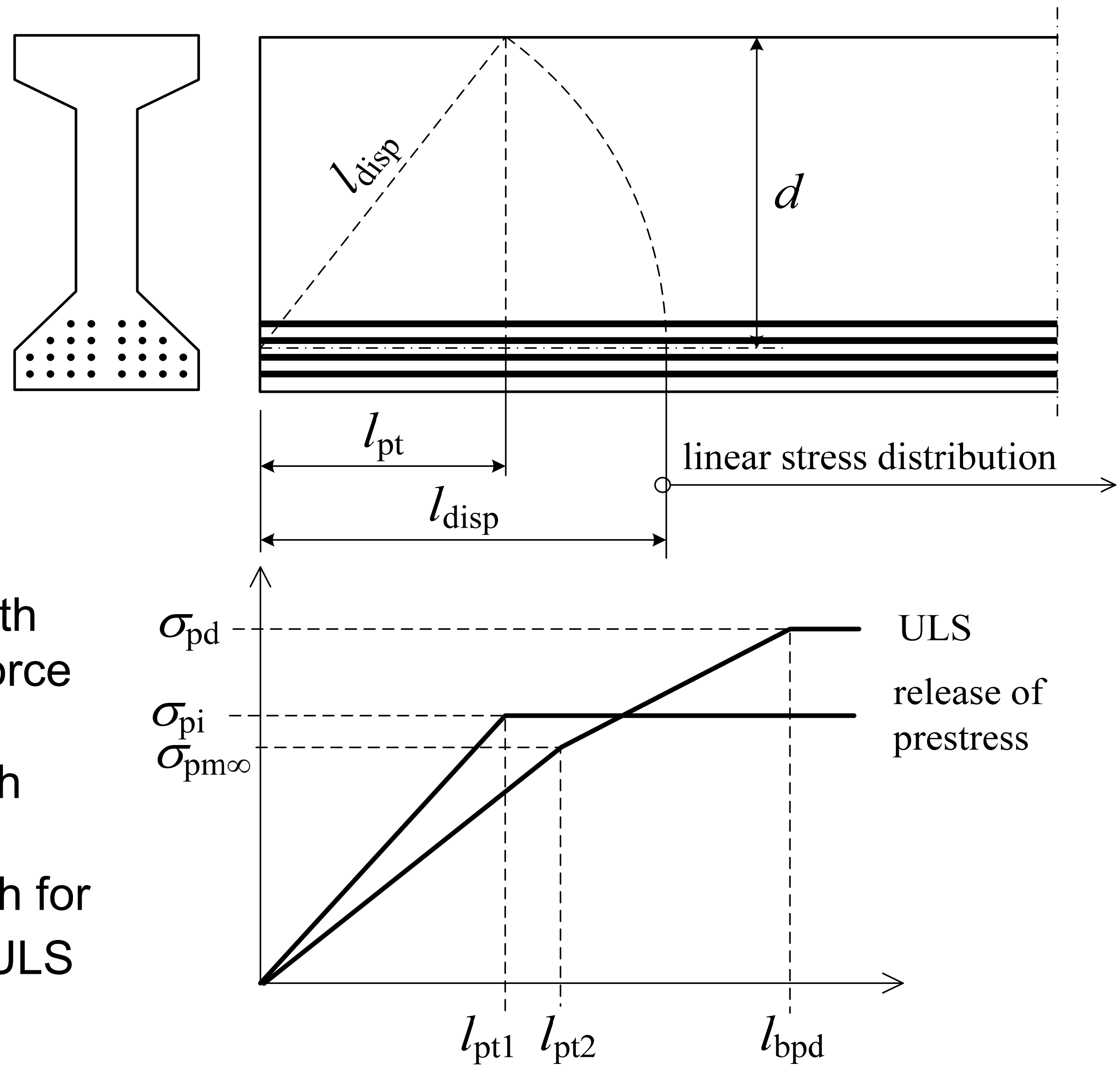


Upper limit:

$$v_{\mathrm{Rdi}} \leq 0{,}5\nu \cdot f_{\mathrm{cd}} \qquad \nu = 0{,}6(1 - f_{\mathrm{ck}}/250)$$

8.10.2 Anchorage of pre-tensioned tendons

8.10.2.1 General



l_{pt} = transmission length for prestressing force

l_{disp} = dispersion length

l_{bpd} = anchorage length for tendon force in ULS

8.10.2 Anchorage of pre-tensioned tendons

8.10.2.2 Transfer of prestress

(1) Bond stress

$$f_{\mathrm{bpt}} = \eta_{\mathrm{p1}} \eta_1 f_{\mathrm{ctd}}(t)$$

η_{p1} = 2,7 for indented wires, 3,2 for strands

η_1 = 1,0 for ”good” bond conditions, 0,7 otherwise

$f_{\mathrm{ctd}}(t)$ = design value of concrete’s tensile strength at time of release

(2) Transmission length

$$l_{\mathrm{pt}} = \alpha_1 \alpha_2 \phi \frac{\sigma_{\mathrm{pm0}}}{f_{\mathrm{bpt}}}$$

α_1 = 1,0 for gradual, 1,25 for sudden release

α_2 = 0,25 for circular units, 0,19 for strands

ϕ = nominal diameter

σ_{pm0} = tendons stress just after release

8.10.2 Anchorage of pre-tensioned tendons

8.10.2.2 Transfer of prestress

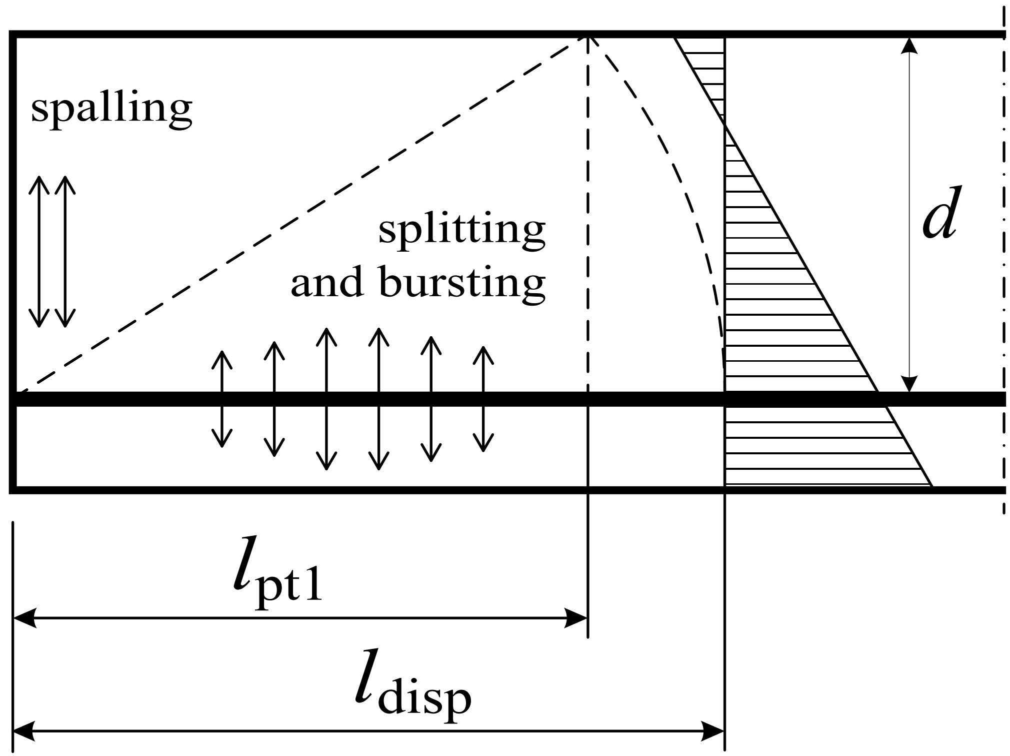
(3) Design values of transmission length

$l_{pt1} = 0{,}8\ l_{pt}$ (spalling, splitting and bursting stresses at release of prestress)

$l_{pt2} = 1{,}2\ l_{pt}$ (shear, anchorage etc. in ULS)

(4) Dispersion length

$$l_{disp} = \sqrt{l_{pt}^{\,2} + d^{\,2}}$$



8.10.2.3 Anchorage of tensile force in ULS

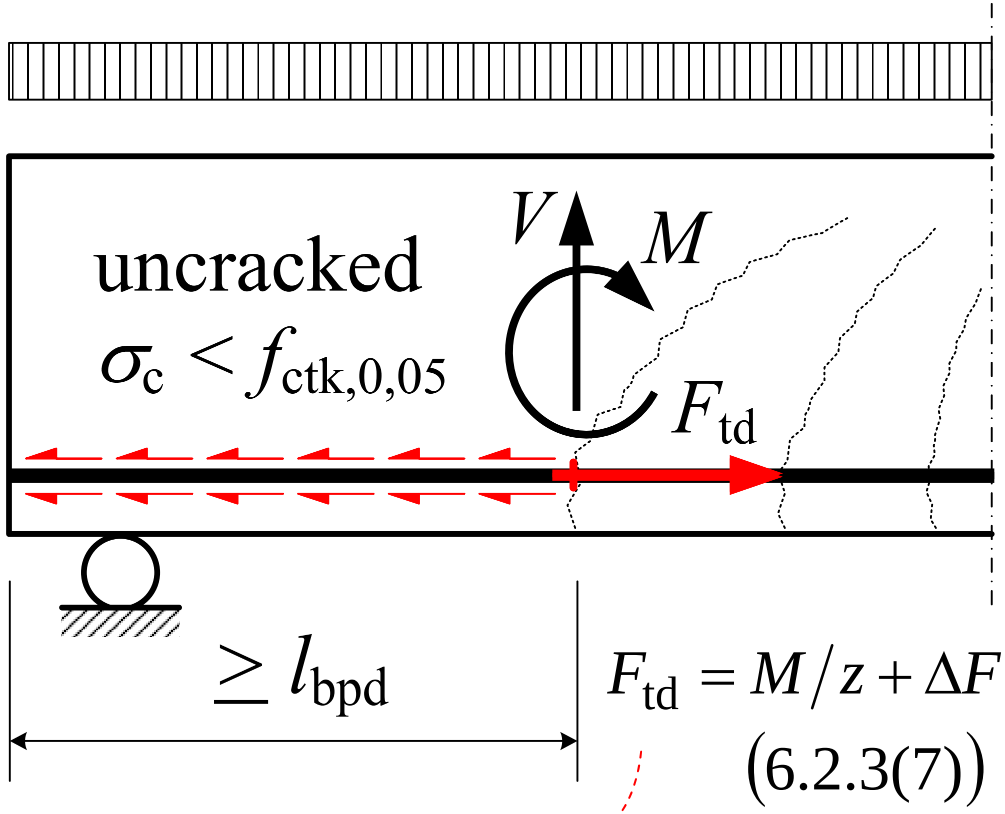
(2) Bond stress

$$f_{\mathrm{bpd}} = \eta_{\mathrm{p2}} \eta_1 f_{\mathrm{ctd}}$$

η_{p1} = 1,4 indented wires
1,2 strands

η_1 as before

$f_{ctk,0,05}$ (and f_{ctd}) are limited to the value for C60/75



(4) Required anchorage length

$$l_{\mathrm{bpd}} = l_{\mathrm{pt2}} + \alpha_2 \phi \left(\sigma_{\mathrm{pd}} - \sigma_{\mathrm{pm}\infty} \right) / f_{\mathrm{bpd}}$$

$$\sigma_{\mathrm{pd}} = F_{\mathrm{td}} / A_{\mathrm{p}}$$

Annex A. Modification of partial factors for materials

Reduction based on quality control and reduced deviations

Dimension $b \backslash h$	Reduced tolerances (mm)	
	Cross-sectional dimension	Effective depth
$\leq$ 150	5 (10)	5 (10)
400	10 (15)	10 (15)
$\geq$ 2500	30 (30)	20 (20)

(normal tolerance)

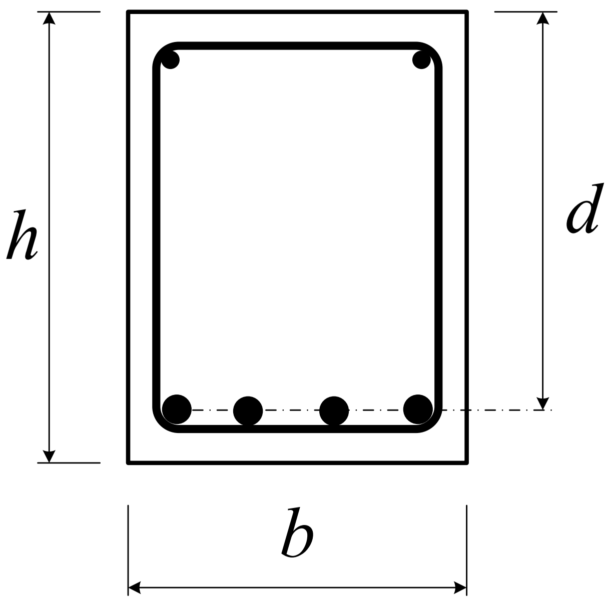
$\gamma_{S,red,1} = 1{,}1$ (1,15)

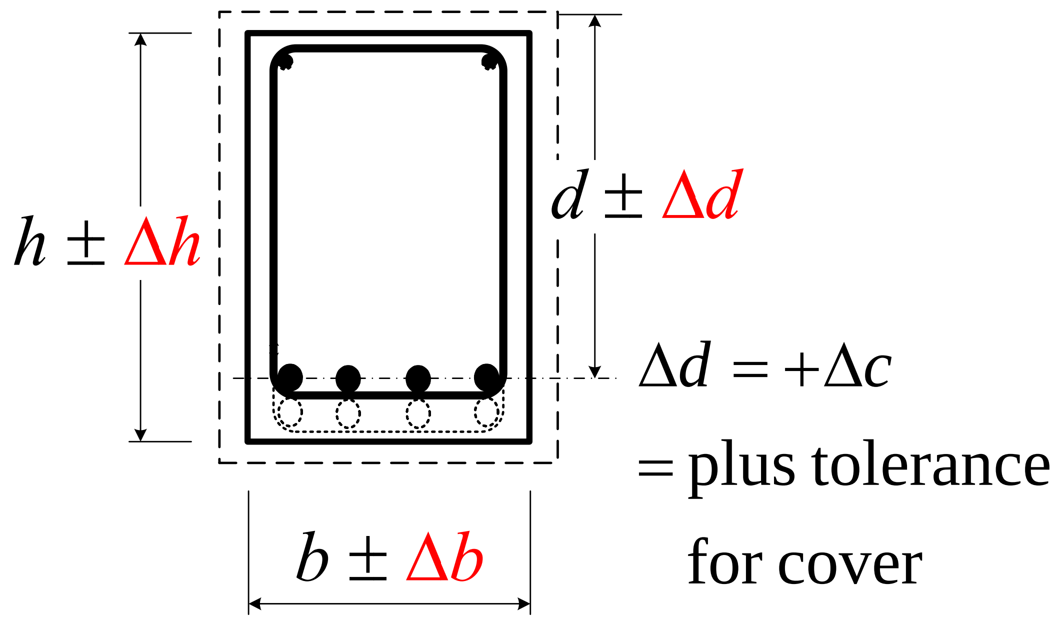
$\gamma_{C,red,1} = 1{,}4$ (1,5)

NDP

Annex A. Modification of partial factors for materials

Reduction based on using reduced or measured geometrcal data in design





$$\gamma_{S,red,2} = 1{,}05 \quad (1{,}15)$$

$$\gamma_{C,red,2} = 1{,}45 \quad (1{,}5)$$

NDP

Applicable also if dimensions are measure in finished structure

Annex A. Modification of partial factors for materials

Reduction based on assessment of concrete strength in finished structure

For concrete strength values based on testing in finished structure or element, γ_c may be reduced by the conversion factor η:

$$\gamma_{C,red,3} = \eta \cdot \gamma_{C,(red)} \geq \gamma_{C,red,4}$$

$\gamma_{C,(red)}$ can be reduced according to previous criteria

$\eta = 0{,}85$ NDP

$\gamma_{C,red,4} = 1{,}3$ - « -

Precast elements – same rules as for in-situ