Course Notes / Note de curs

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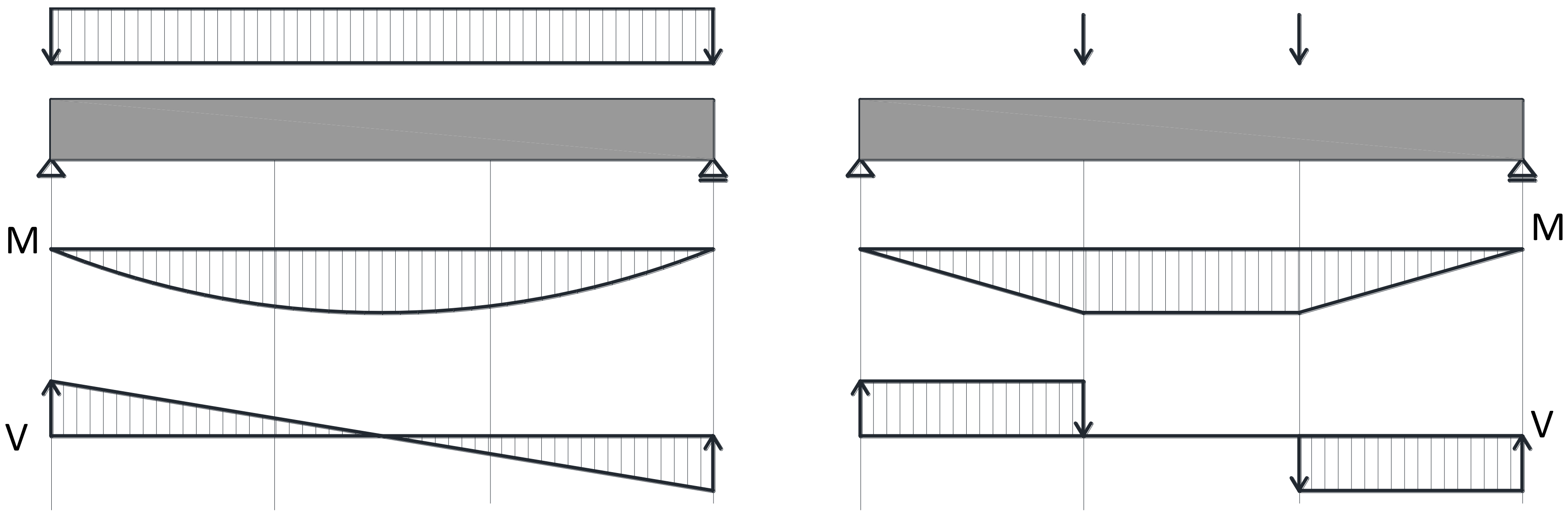
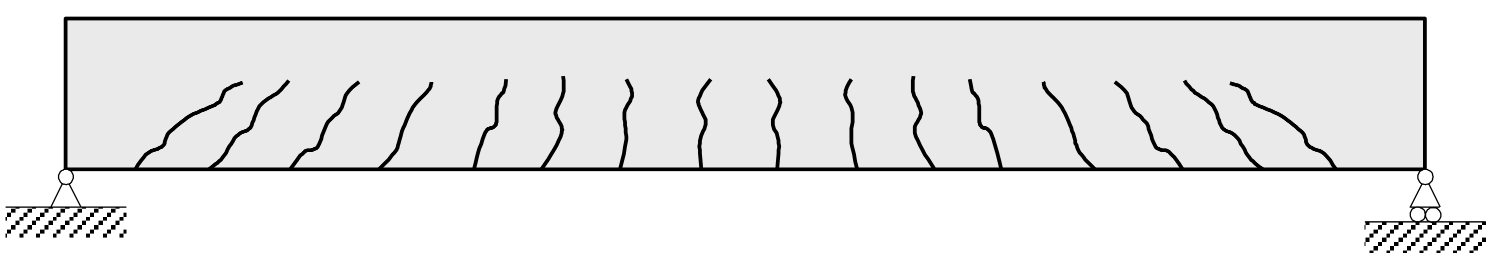
10.1 BEHAVIOR OF BENT ELEMENTS UNDER SHEAR FORCE

Behaviour of bent elements to shear/ Comportarea elementelor încovoiate la forţă tăietoare

Shear force and bending moment generally acts simultaneously!



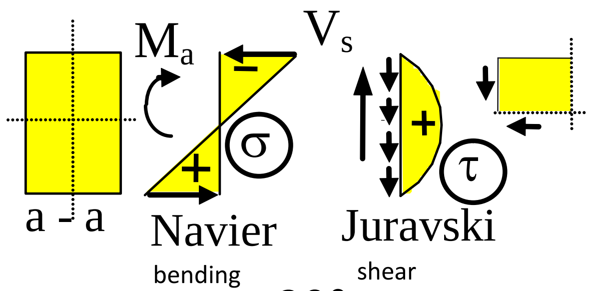


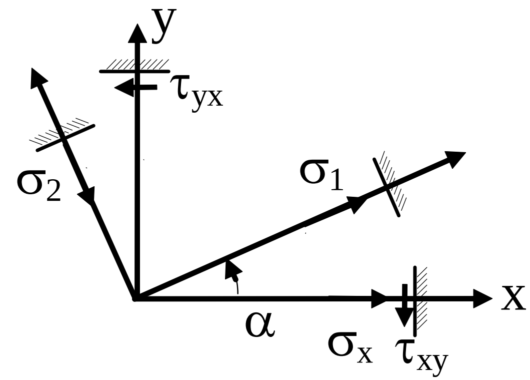
Behaviour of bent elements to shear/ Comportarea elementelor încovoiate la forţă tăietoare

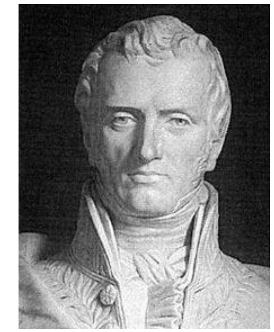
Due to bending moment M in the section arise normal unit stresses $\boldsymbol{\sigma_x}$, while due to shear force V, tangential unit stresse $\boldsymbol{\tau_{xy}}$.

σ_1 – tensile
σ_2 – compression

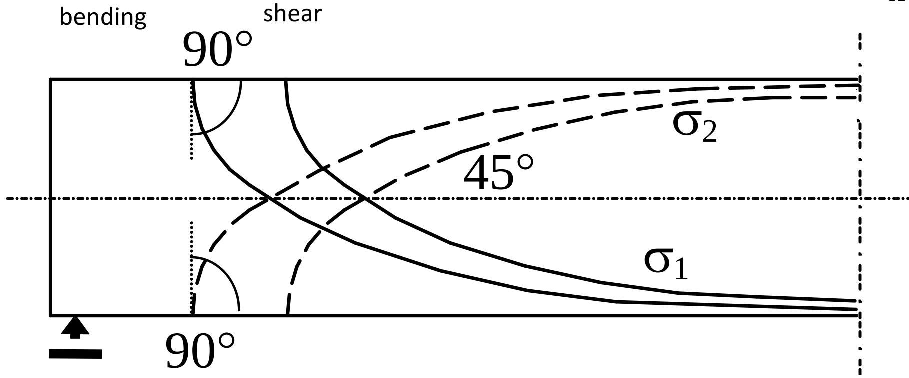
$$\sigma = \frac{M}{I} y = \frac{M}{W}$$



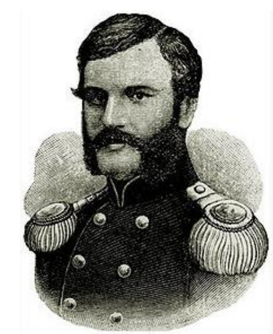




Claude-Louis
Navier



$$\tau = \frac{V S_x}{b I_x}$$



Juravski

Trajectories of principal unit stresses → variation of $\boldsymbol{\sigma_1}$ and $\boldsymbol{\sigma_2}$ enables drawing of trajectories and thus highlights the cracking mode of tensioned concrete.

Behaviour of bent elements to shear/ Comportarea elementelor încovoiate la forţă tăietoare

For a rectangular cross section from plain concrete

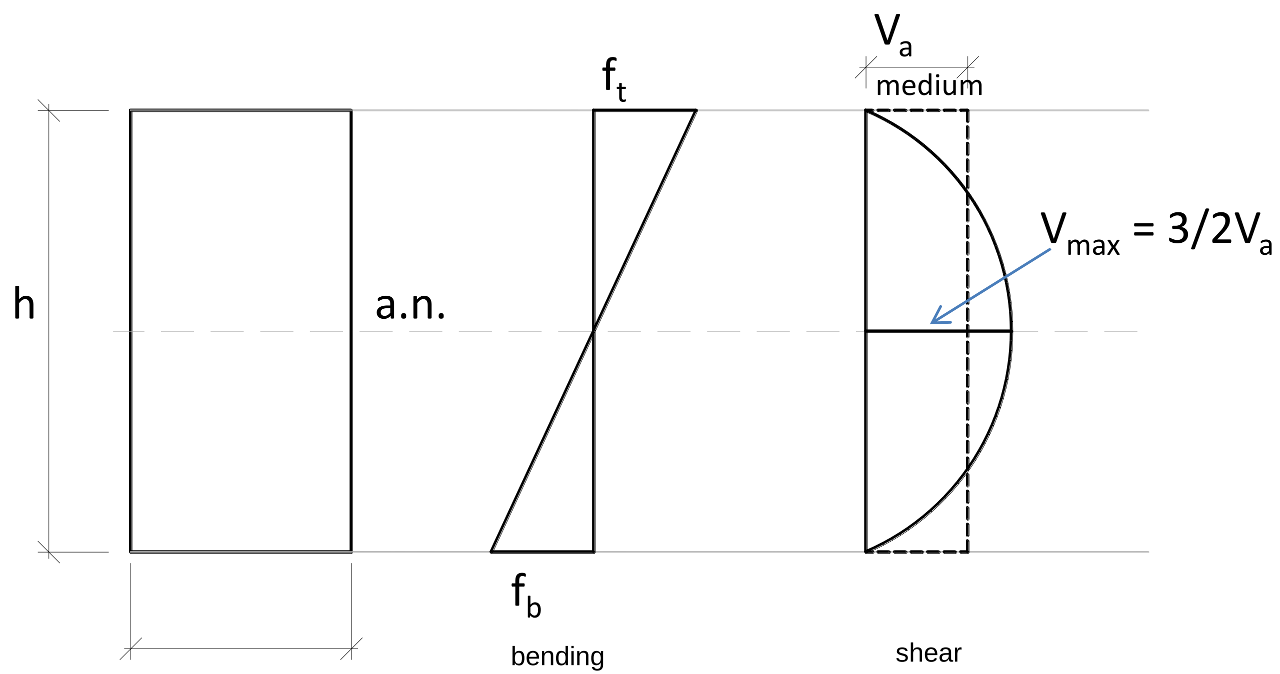
$$\tau = \frac{VS_x}{bI_x} = \frac{3}{2}\left(\frac{V}{bh}\right) = 1.5\tau_{ave}$$

shear

$$I = \frac{bh^3}{12}$$

$$S = \left(\frac{bh}{2}\right)\cdot\left(\frac{h}{4}\right) = \frac{bh^2}{8}$$

At the level of n.a.



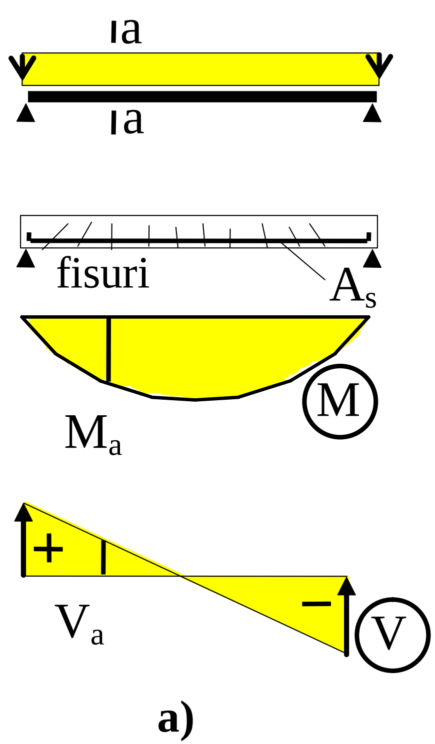
Behaviour of bent elements to shear/ Comportarea elementelor încovoiate la forţă tăietoare

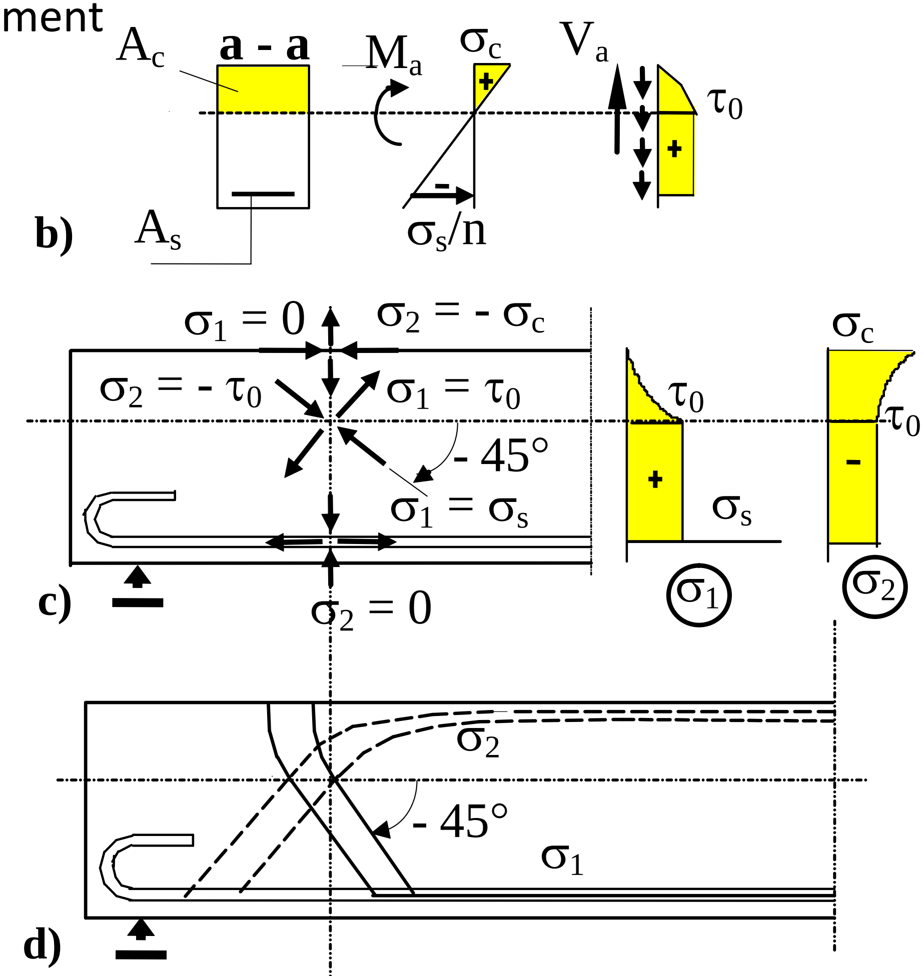
To analyze the state of stresses there will be considered 3 calculation levels, on the height of a simple reinforced cracked cross section

1 – the most compressed fiber

2 – neutral axis

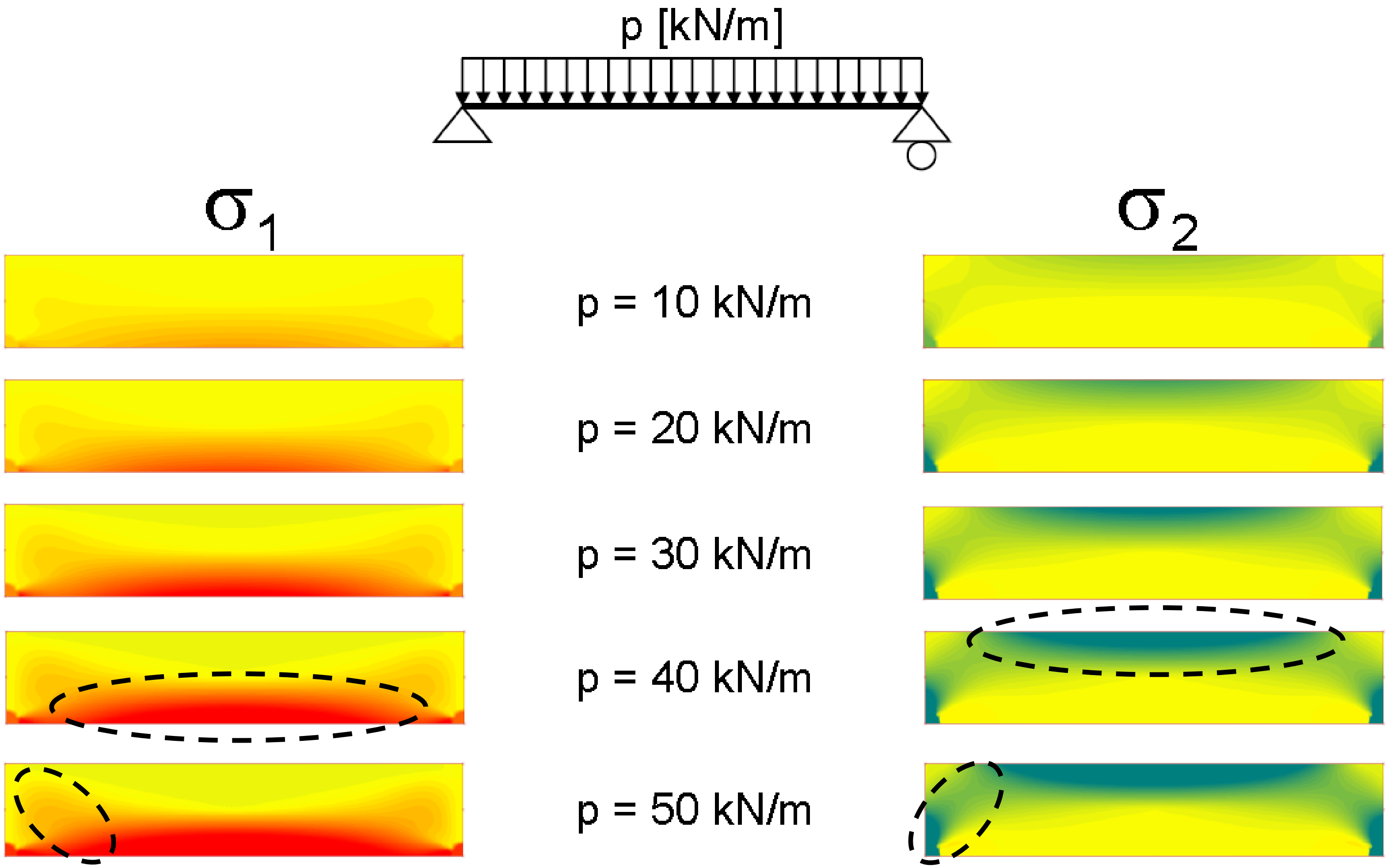
3 – center of gravity of the tensioned reinforcement





Behaviour of bent elements to shear/ Comportarea elementelor încovoiate la forță tăietoare

Principal unit stresses in a reinforced concrete beam subjected to monotonic increasing loads



Tension zone

Compression zone

(Dr. Kovács I., DE)

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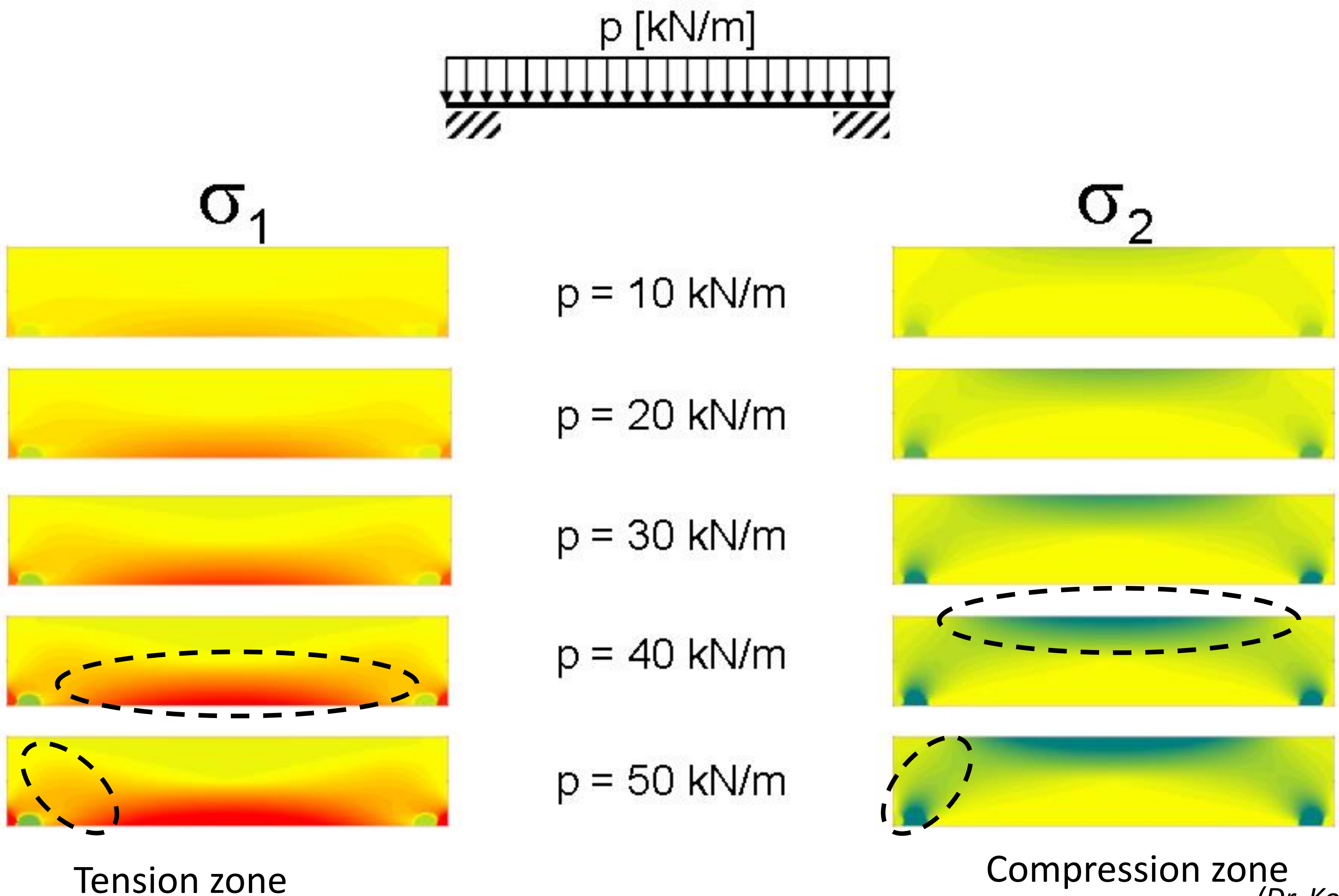
Principal unit stresses in a reinforced concrete beam subjected to monotonic increasing loads



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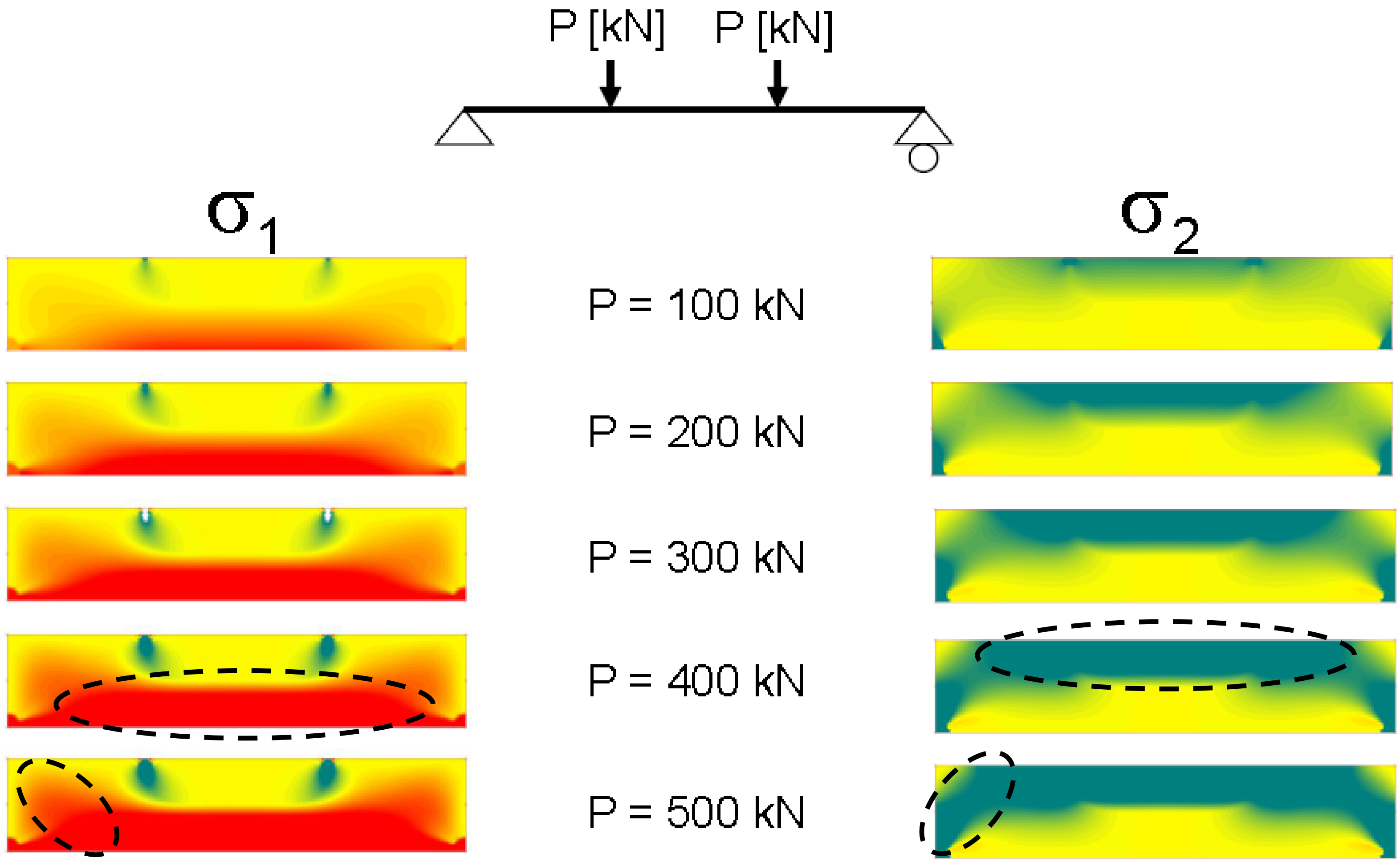
Principal unit stresses in a reinforced concrete beam subjected to monotonic increasing loads



Tension zone

Compression zone

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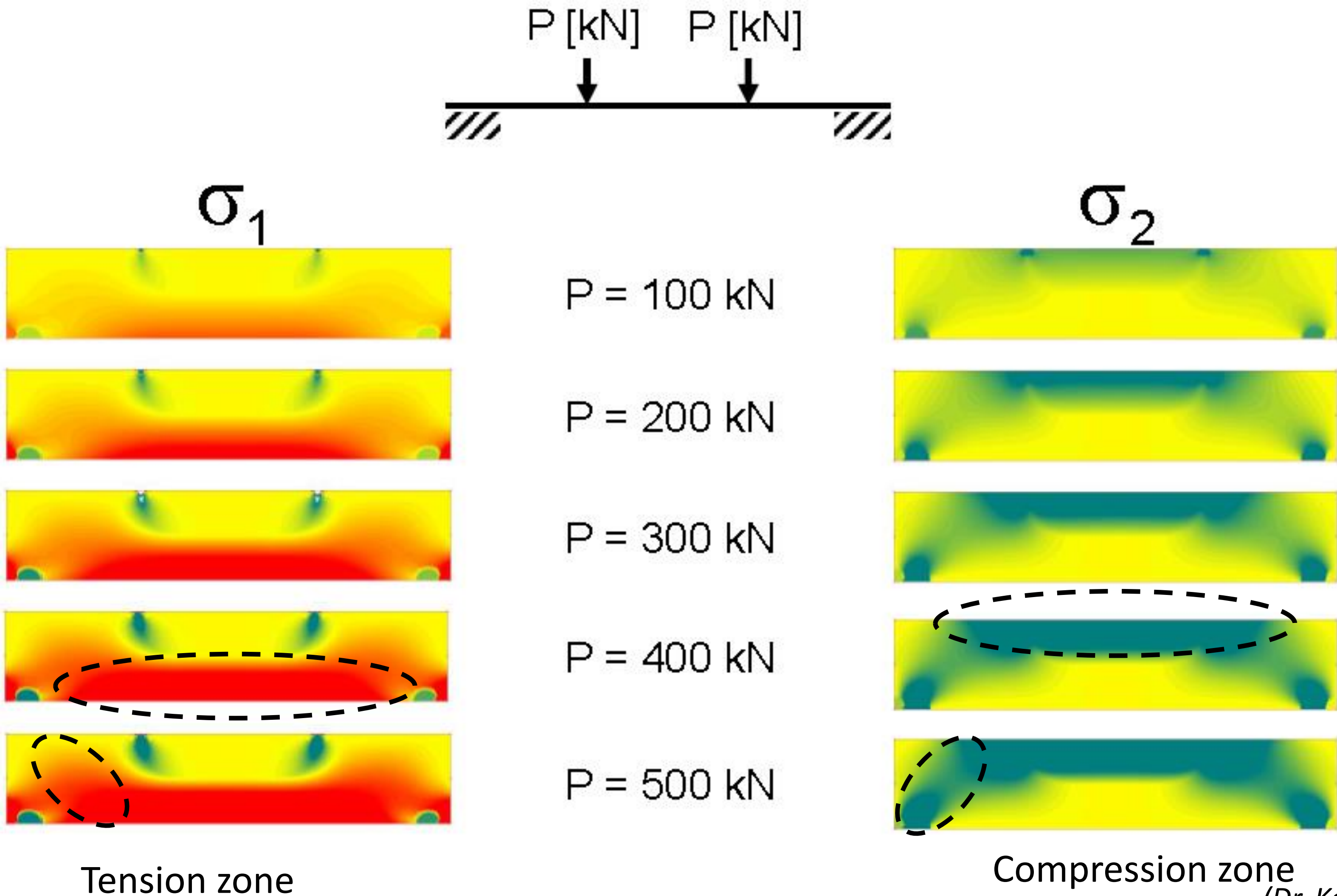
Principal unit stresses in a reinforced concrete beam subjected to monotonic increasing loads



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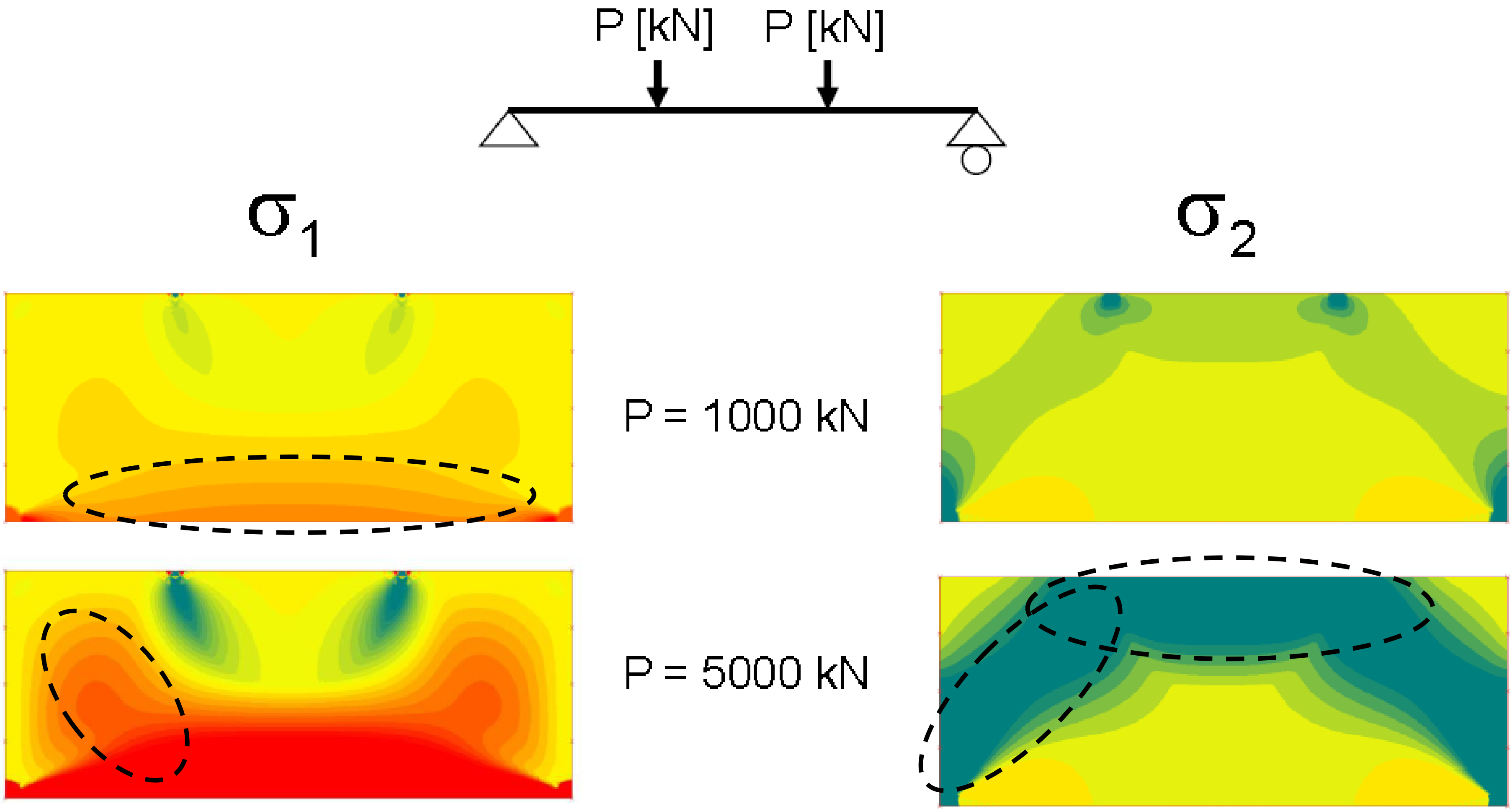
Behaviour of bent elements to shear/ Comportarea elementelor încovoiate la forţă tăietoare

Principal unit stresses in a reinforced concrete high beam subjected to monotonic increasing loads



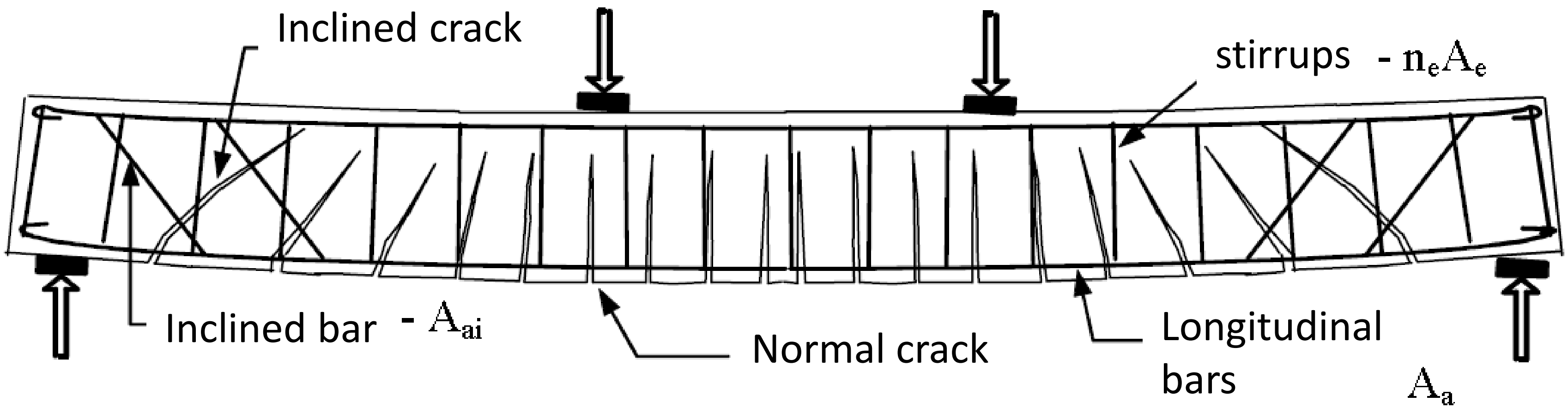
Tension zone

Compression zone

(Dr. Kovács I., DE)

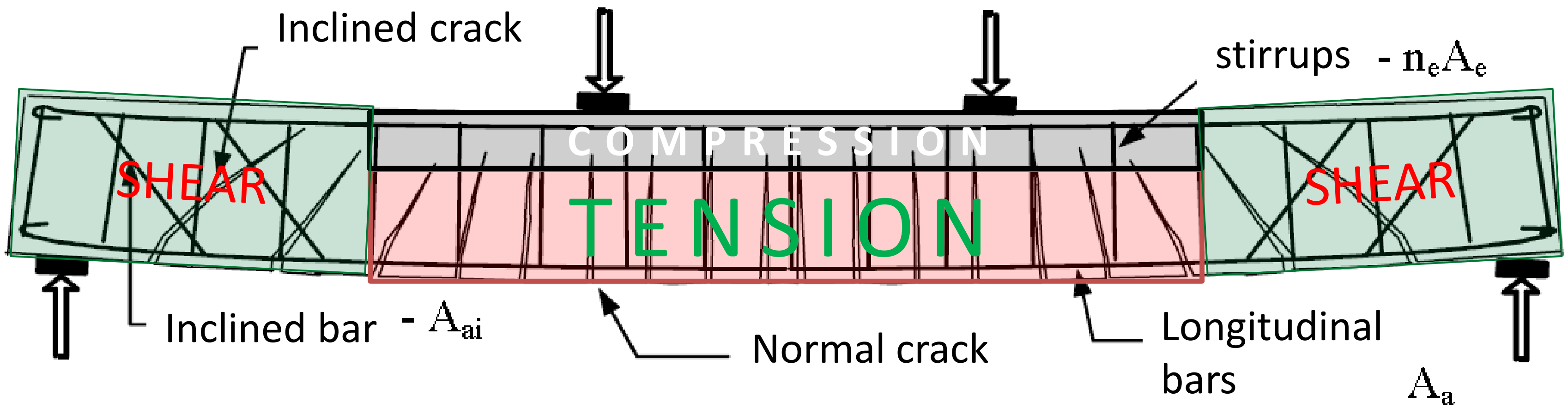
Behaviour of bent elements to shear/ Comportarea elementelor încovoiate la forţă tăietoare

Behavior of bent elements under shear forces



Behaviour of bent elements to shear/ Comportarea elementelor încovoiate la forţă tăietoare

After cracking, the continuity of the reinforced concrete element is ensured through longitudinal and transversal bars and by compressed concrete**.**



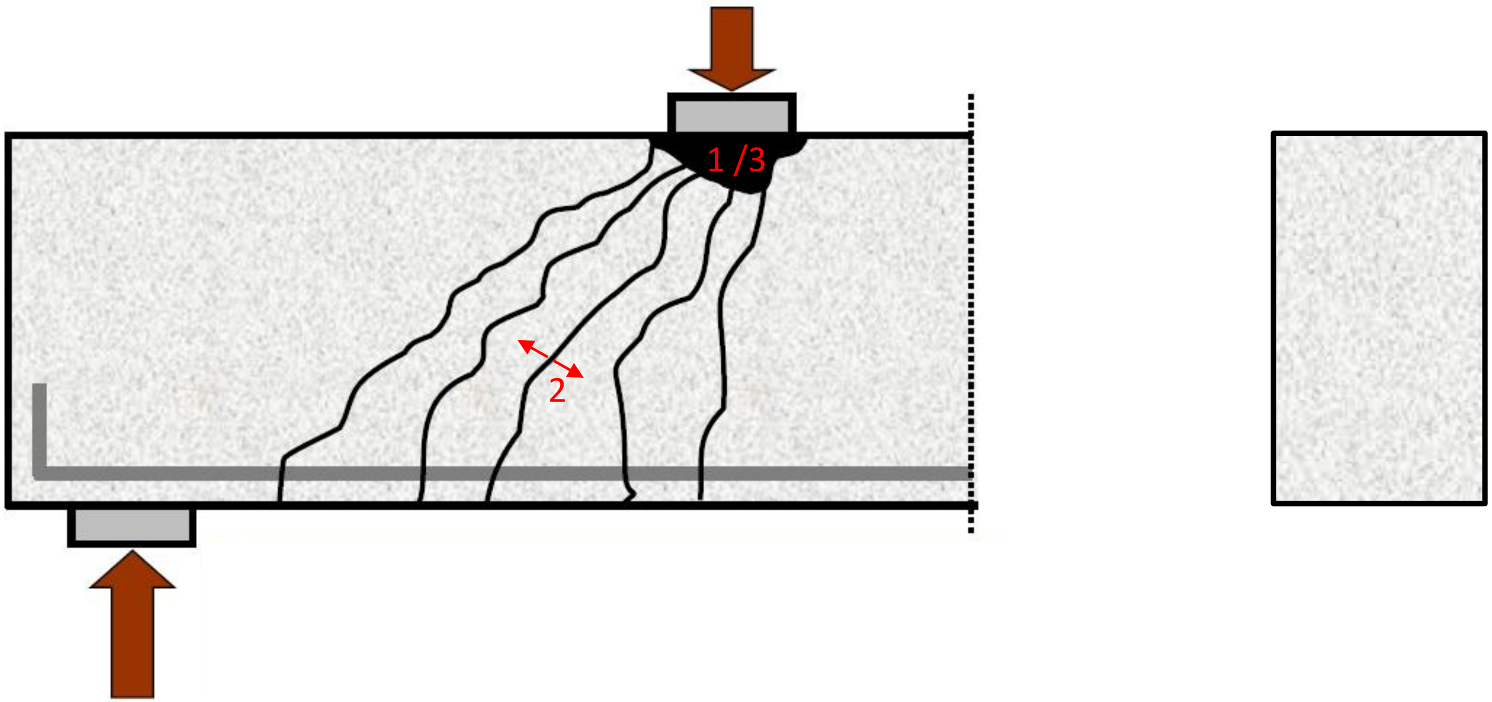
Cracks are perpendicular to the direction of the tensile unit stresses σ_1

→Theoretically, the reinforcements should be placed along the trajectories of the tensile unit stresses σ_1; technologically, this arrangement is not practical!

→ longitudinal reinforcements, inclined bars and stirrups

Behaviour of bent elements to shear/ Comportarea elementelor încovoiate la forţă tăietoare

Shear-bending failure – Mode I.



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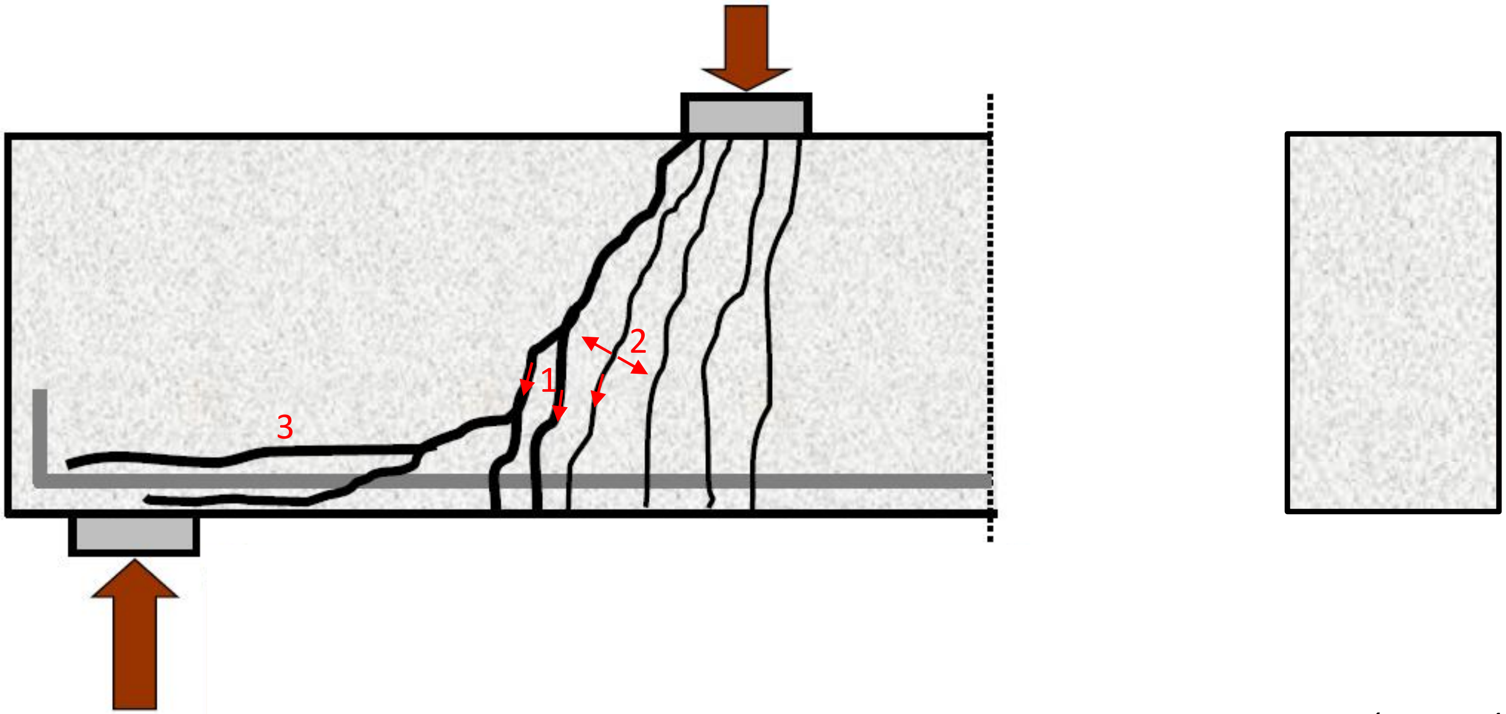
Behaviour of bent elements to shear/ Comportarea elementelor încovoiate la forţă tăietoare

Shear-bending failure – Mode II.



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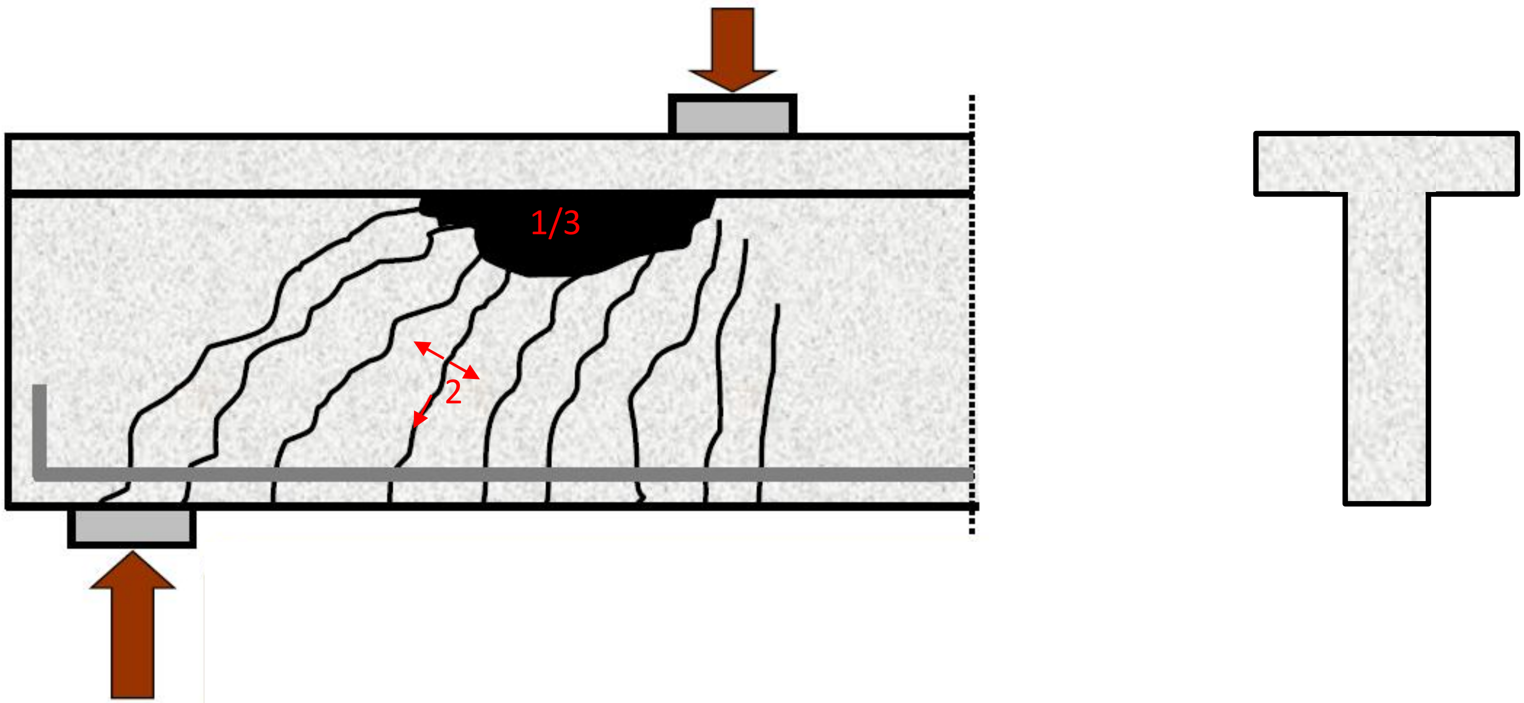
Behaviour of bent elements to shear/ Comportarea elementelor încovoiate la forţă tăietoare

Shear-bending failure – Mode III.



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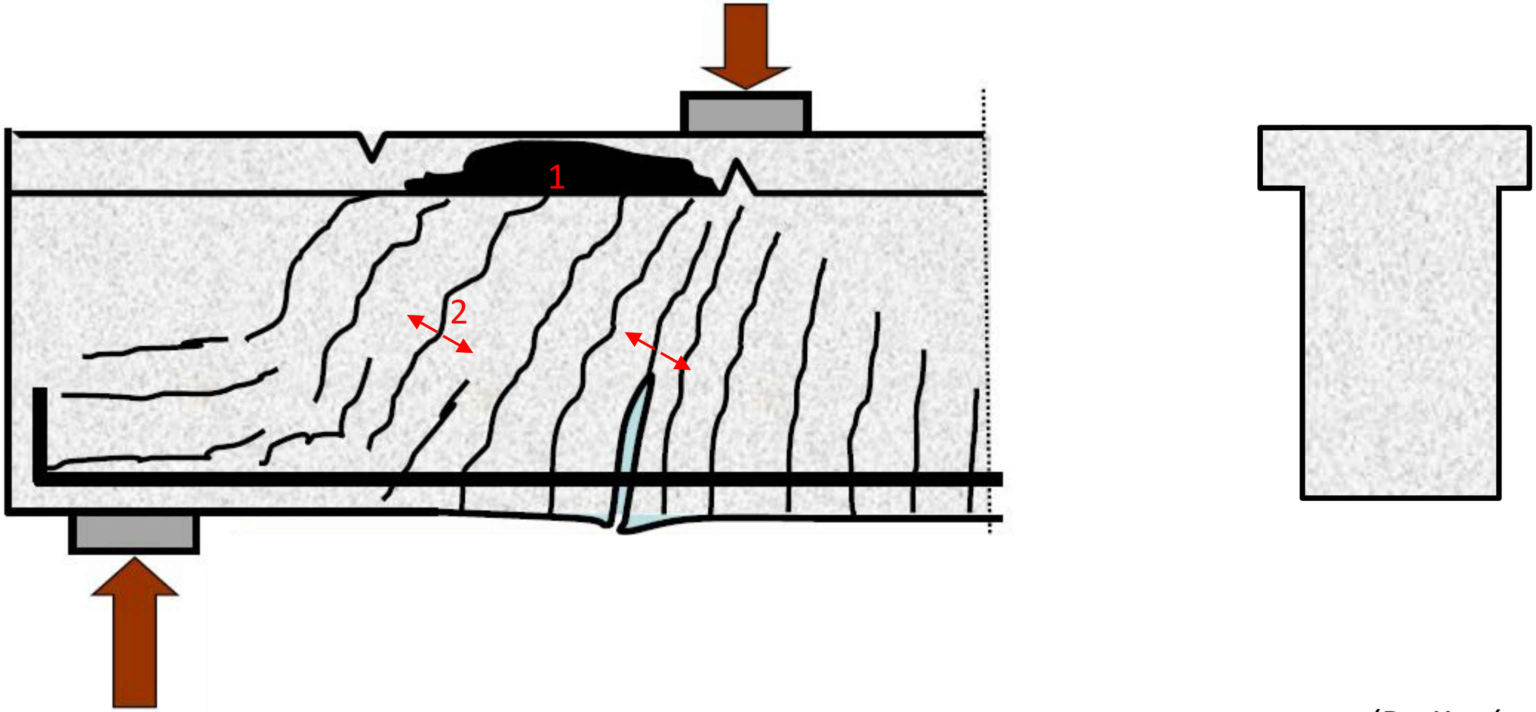
Behaviour of bent elements to shear/ Comportarea elementelor încovoiate la forţă tăietoare

Shear-bending failure – Mode IV.



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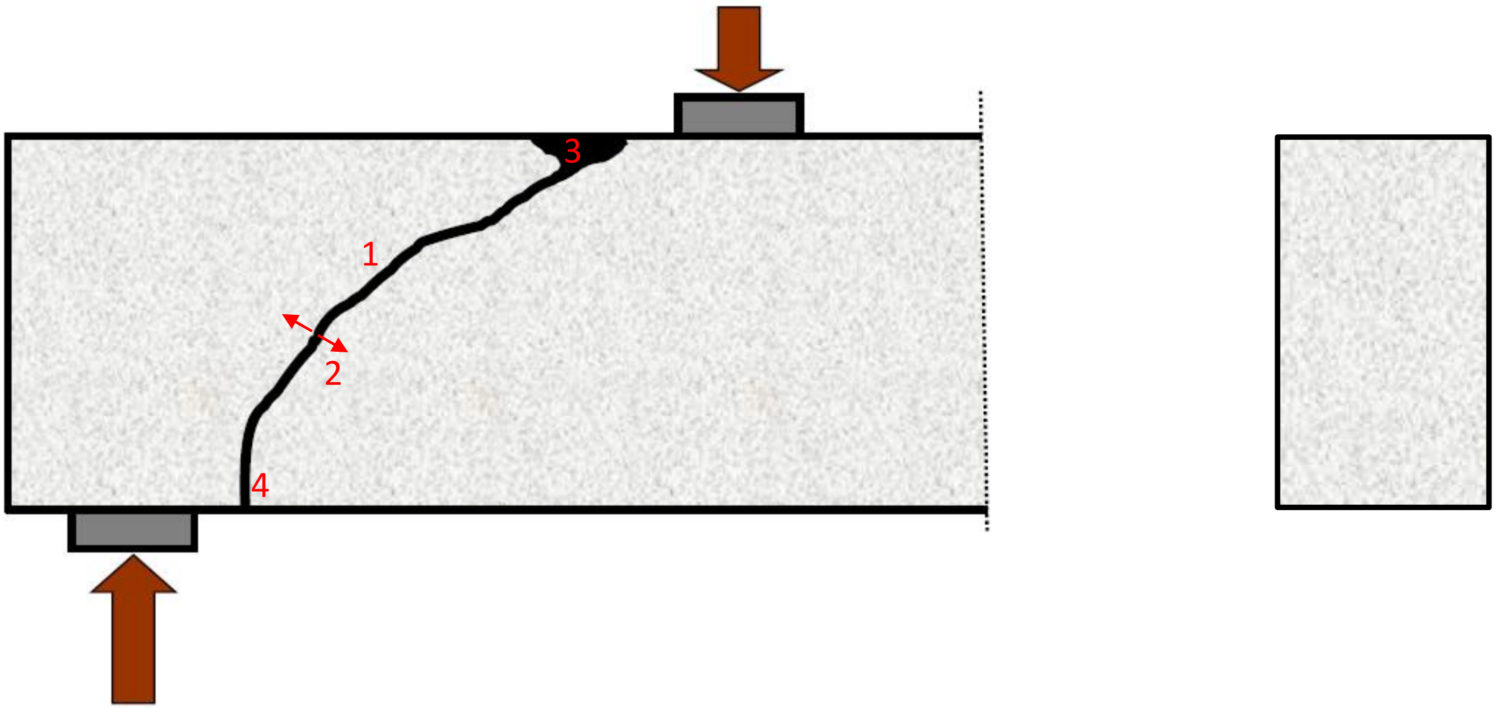
Behaviour of bent elements to shear/ Comportarea elementelor încovoiate la forţă tăietoare

Shear-tension failure



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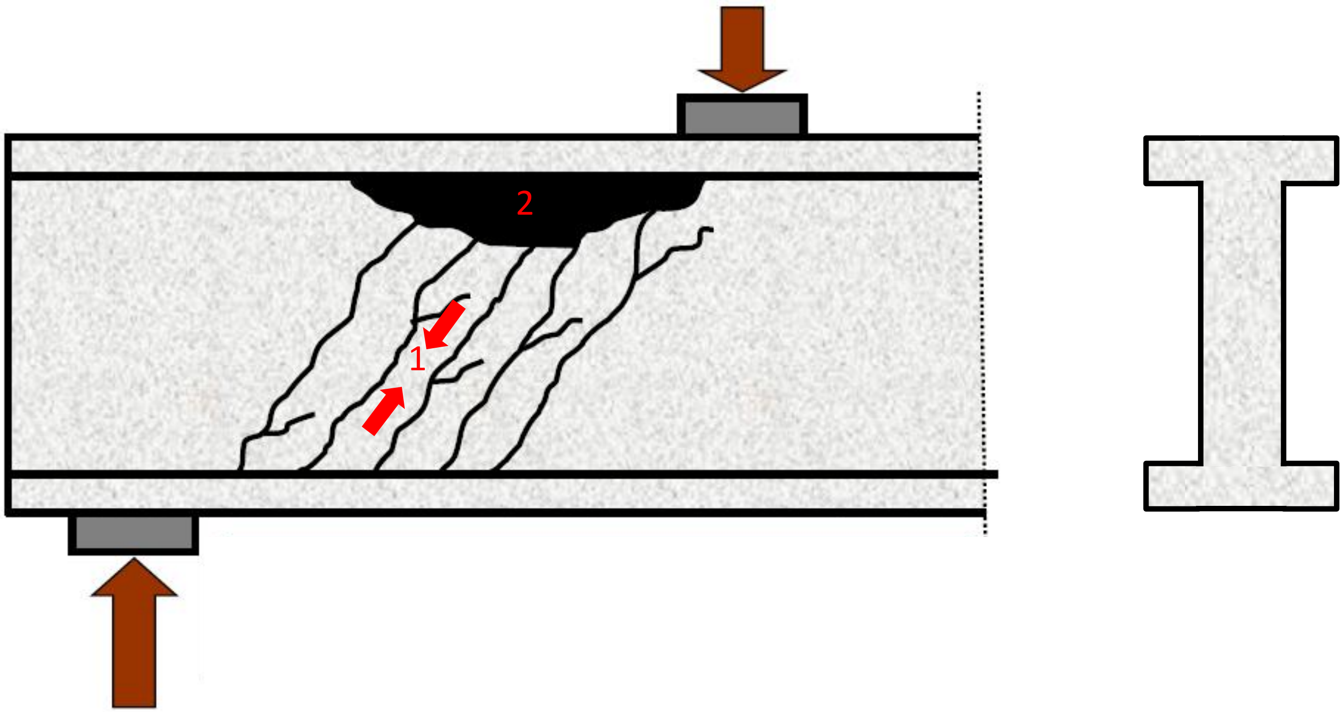
Behaviour of bent elements to shear/ Comportarea elementelor încovoiate la forţă tăietoare

Shear-compression failure – Mode I.



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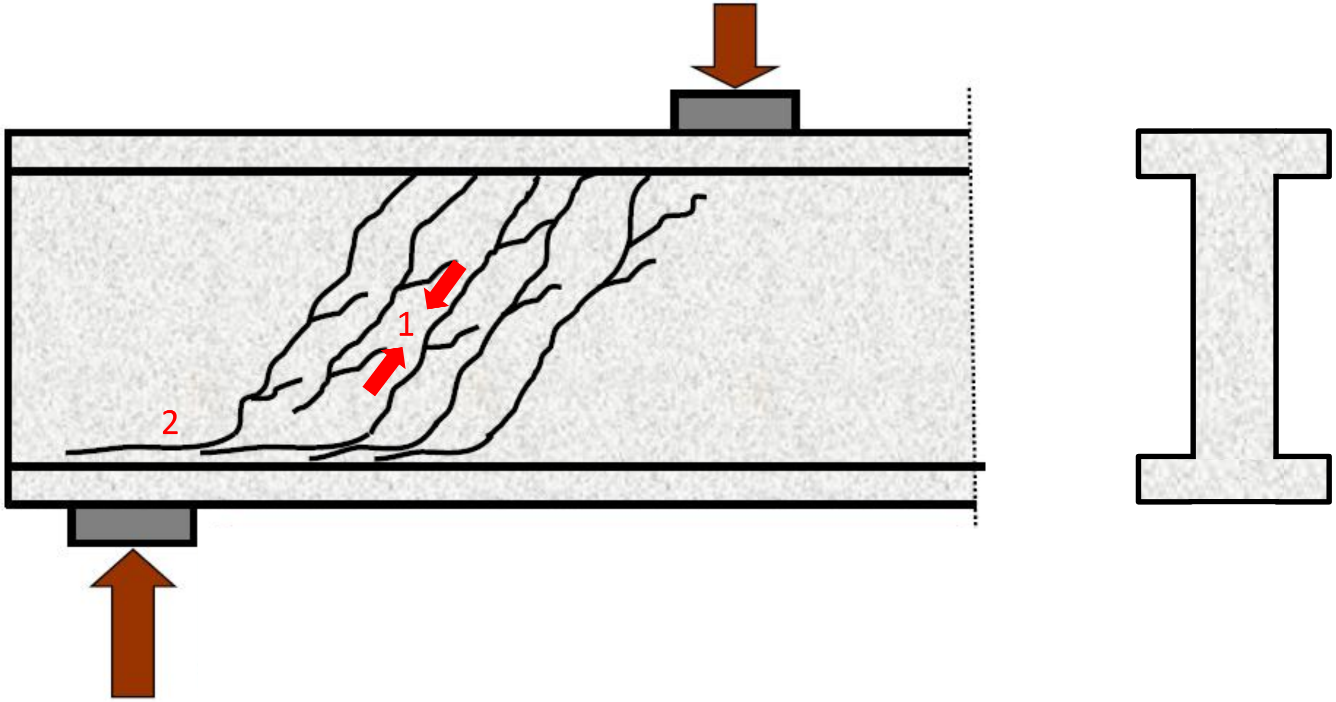
Shear-compression failure – Mode II.



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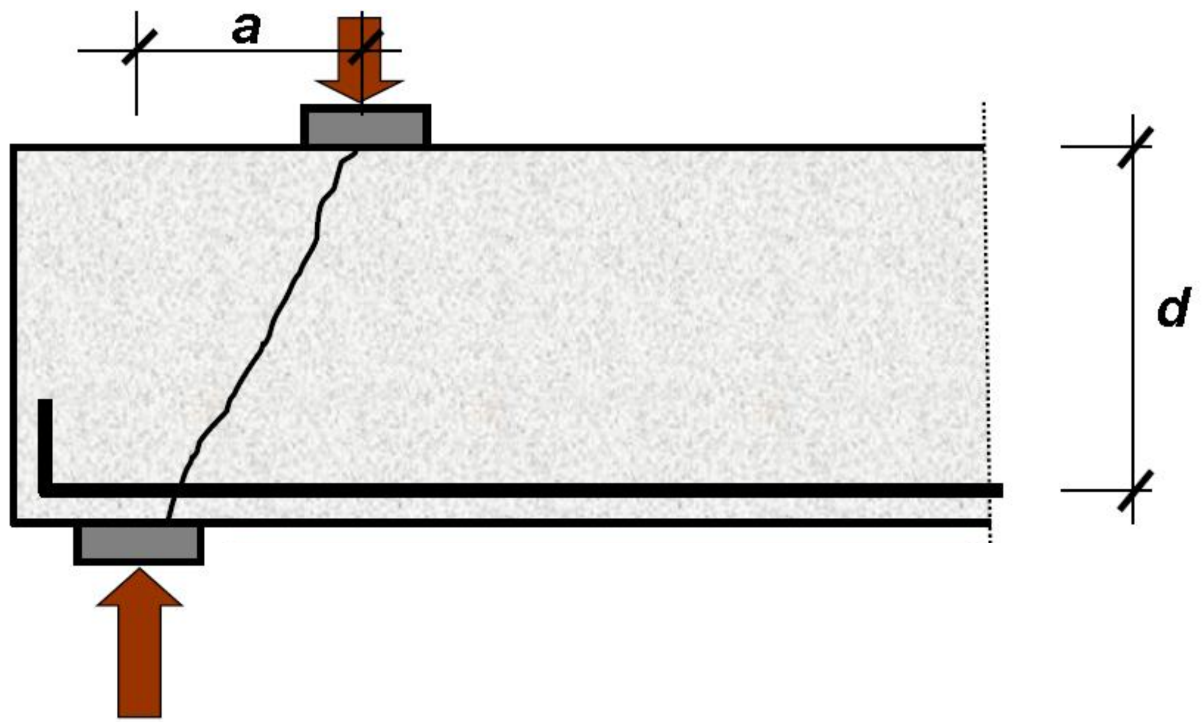
Behaviour of bent elements to shear/ Comportarea elementelor încovoiate la forţă tăietoare

Splitting failure of the end-block



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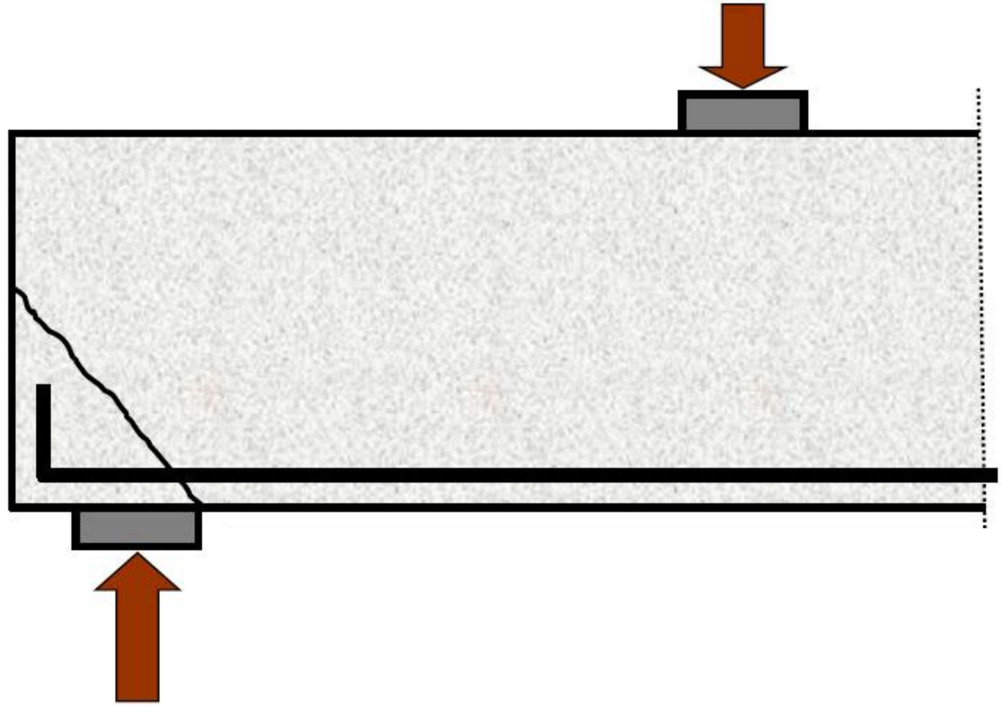
Behaviour of bent elements to shear/ Comportarea elementelor încovoiate la forţă tăietoare

Shear failure of the end-block



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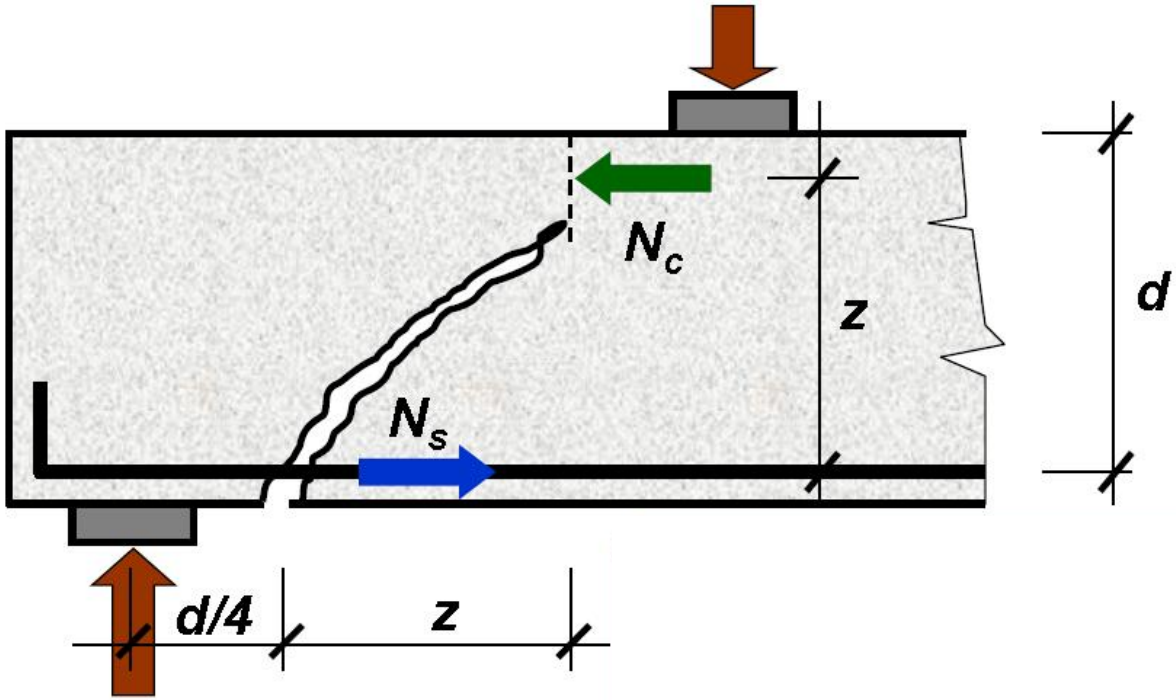
Behaviour of bent elements to shear/ Comportarea elementelor încovoiate la forţă tăietoare

End-block failure due to pull-out of steel bars)



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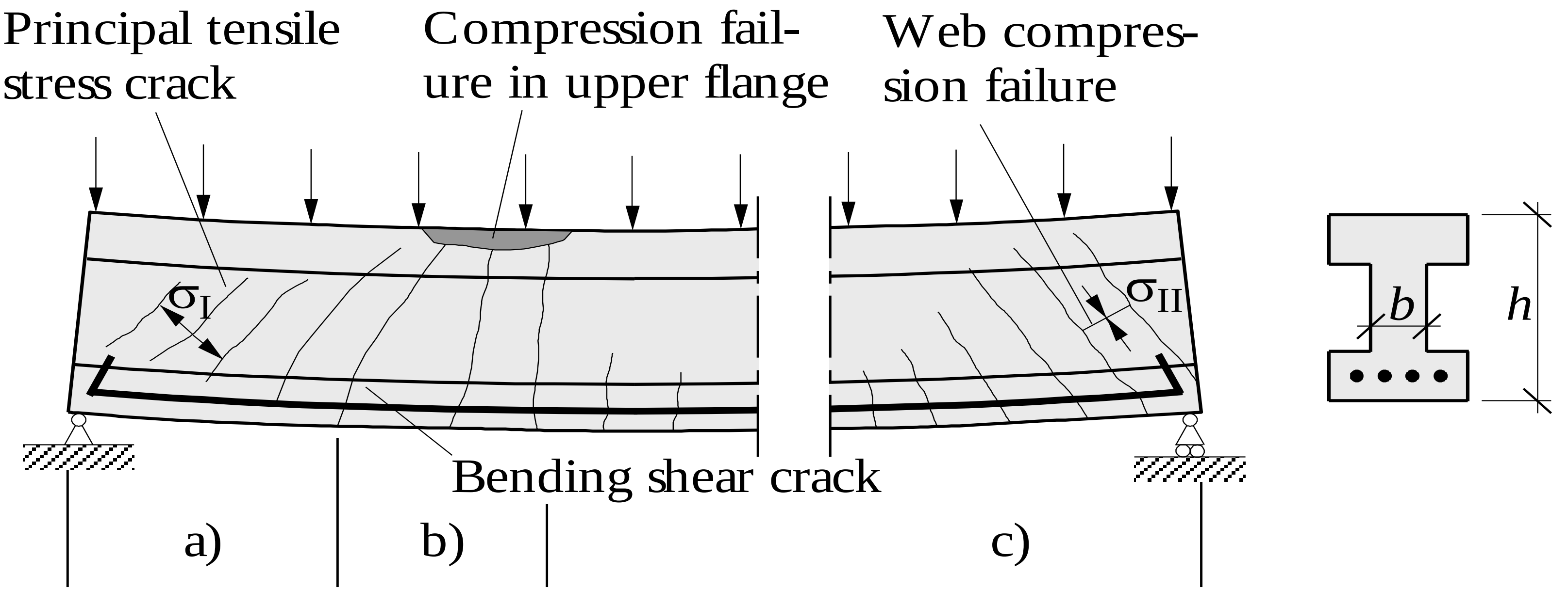
Failure modes – simplified perspective



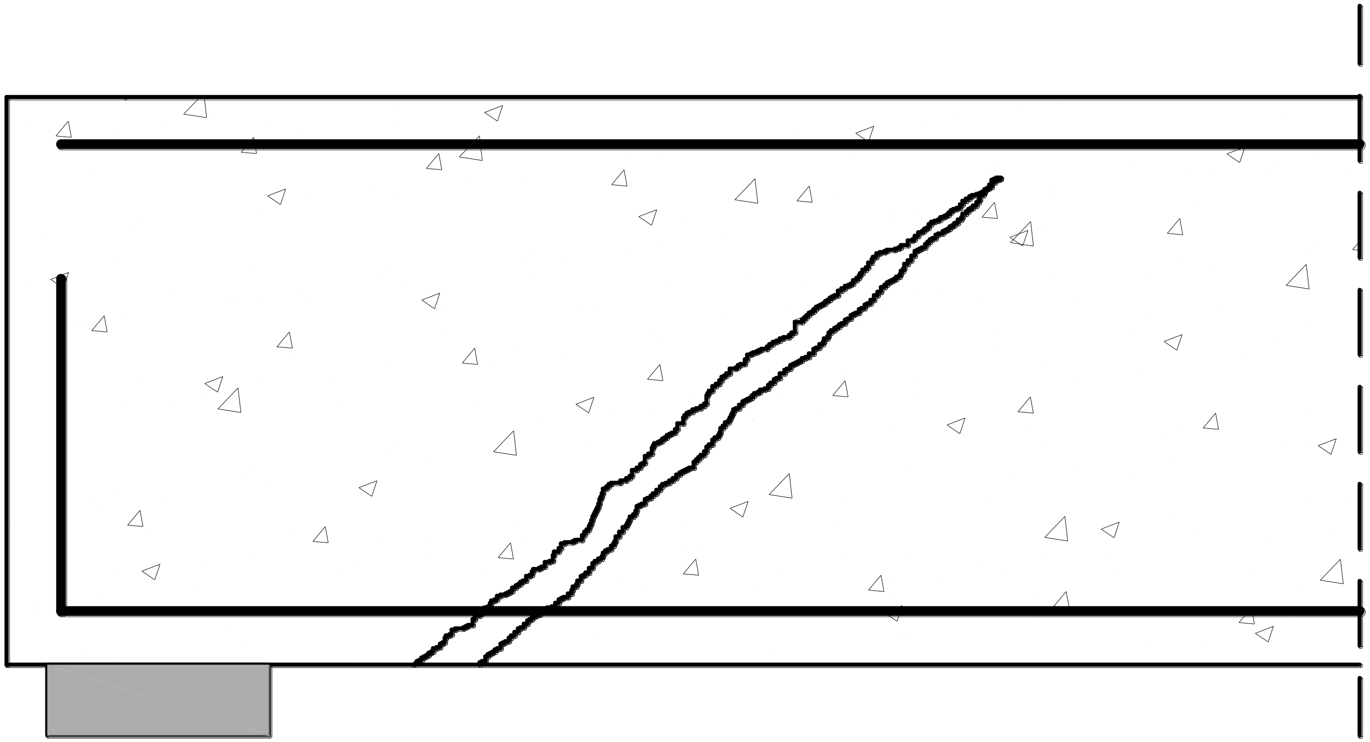
a) Web shear failure – the principal tension stress exceeds the tensile strength

b) Bending shear failure – bending crack that propagates up in the compression zone where finally a compression failure in the concrete occurs

c) Web compression failure – the compression stress exceeds the compression capacity of the concrete

Behaviour of bent elements to shear/ Comportarea elementelor încovoiate la forţă tăietoare

Equilibrium in inclined sections



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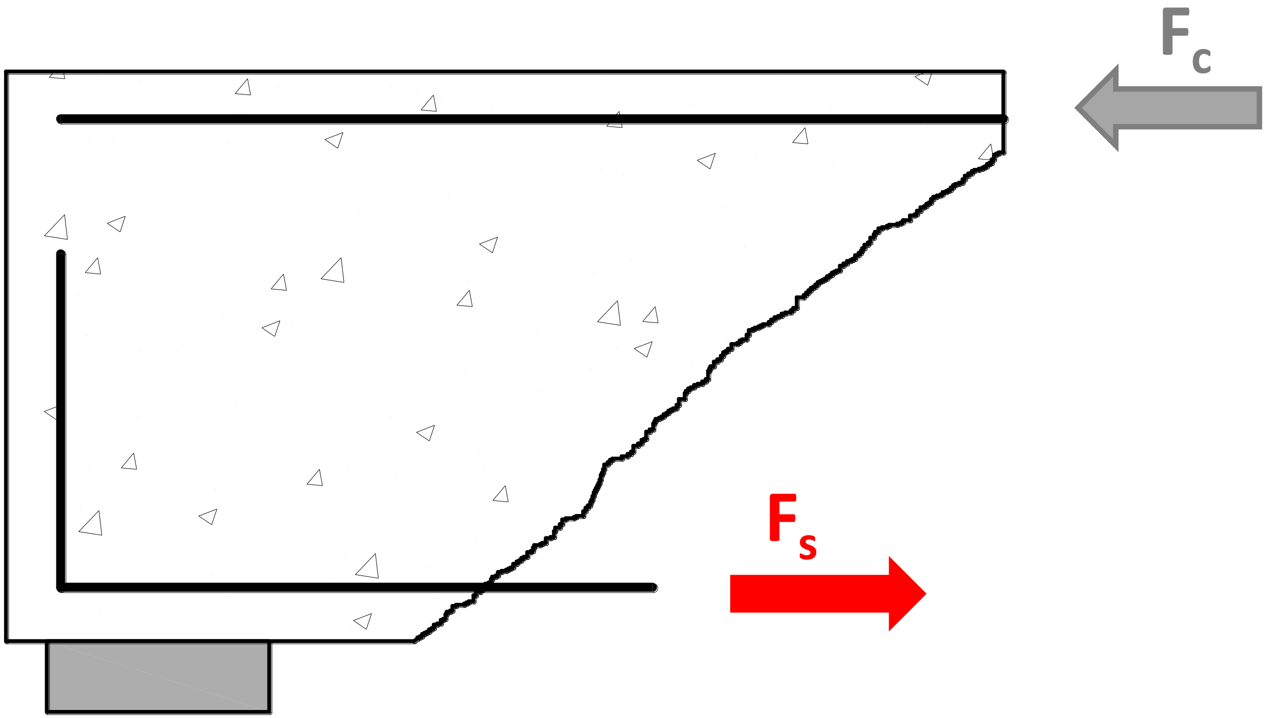

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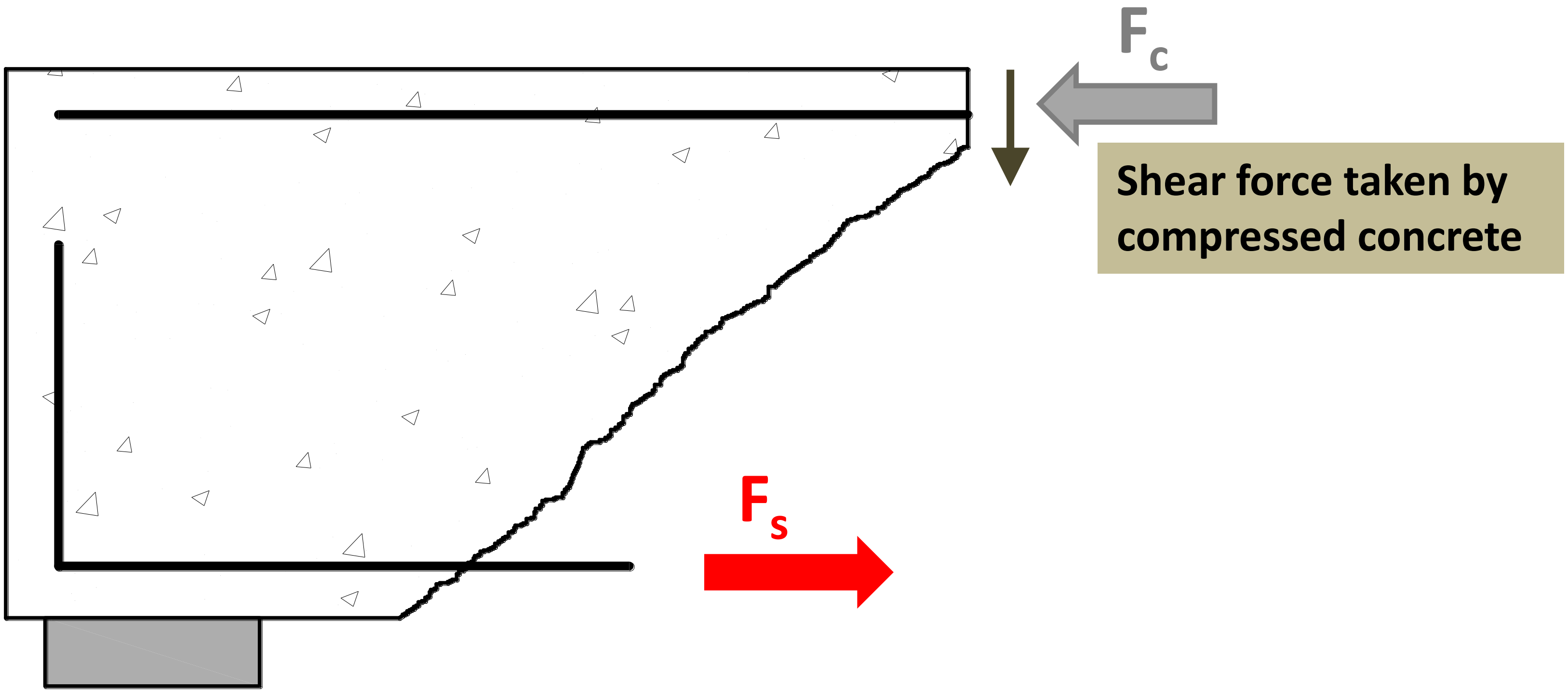

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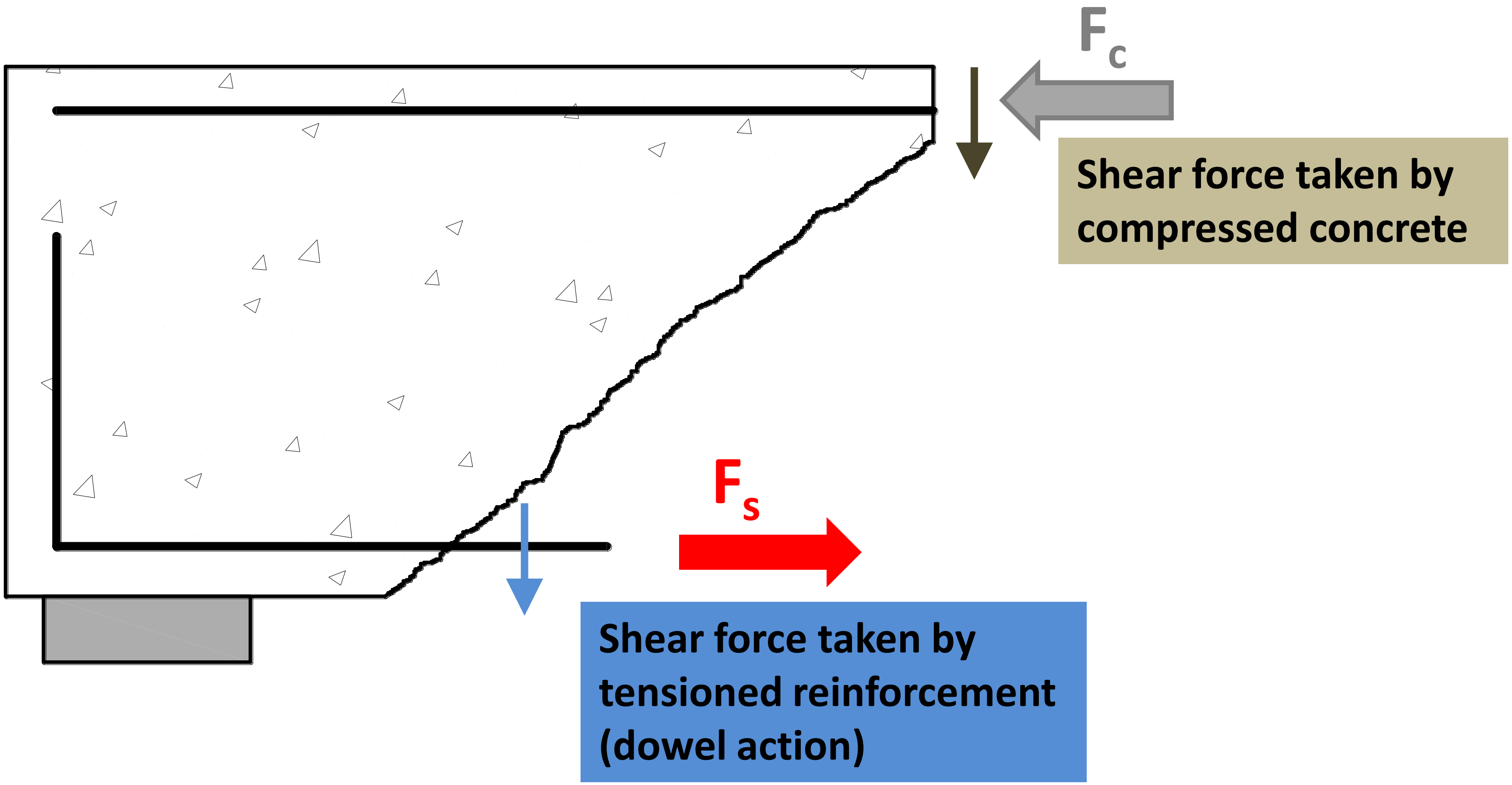

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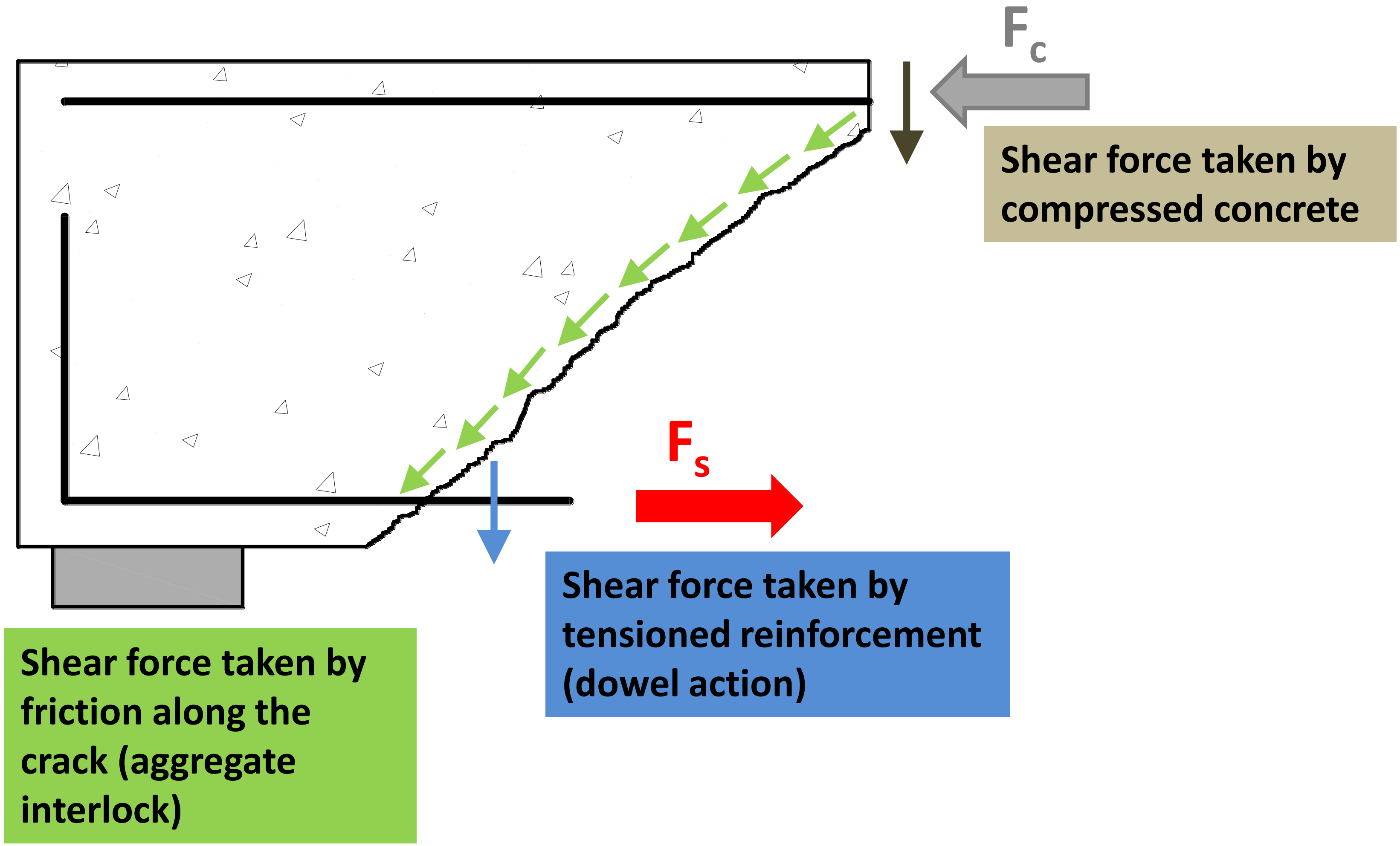

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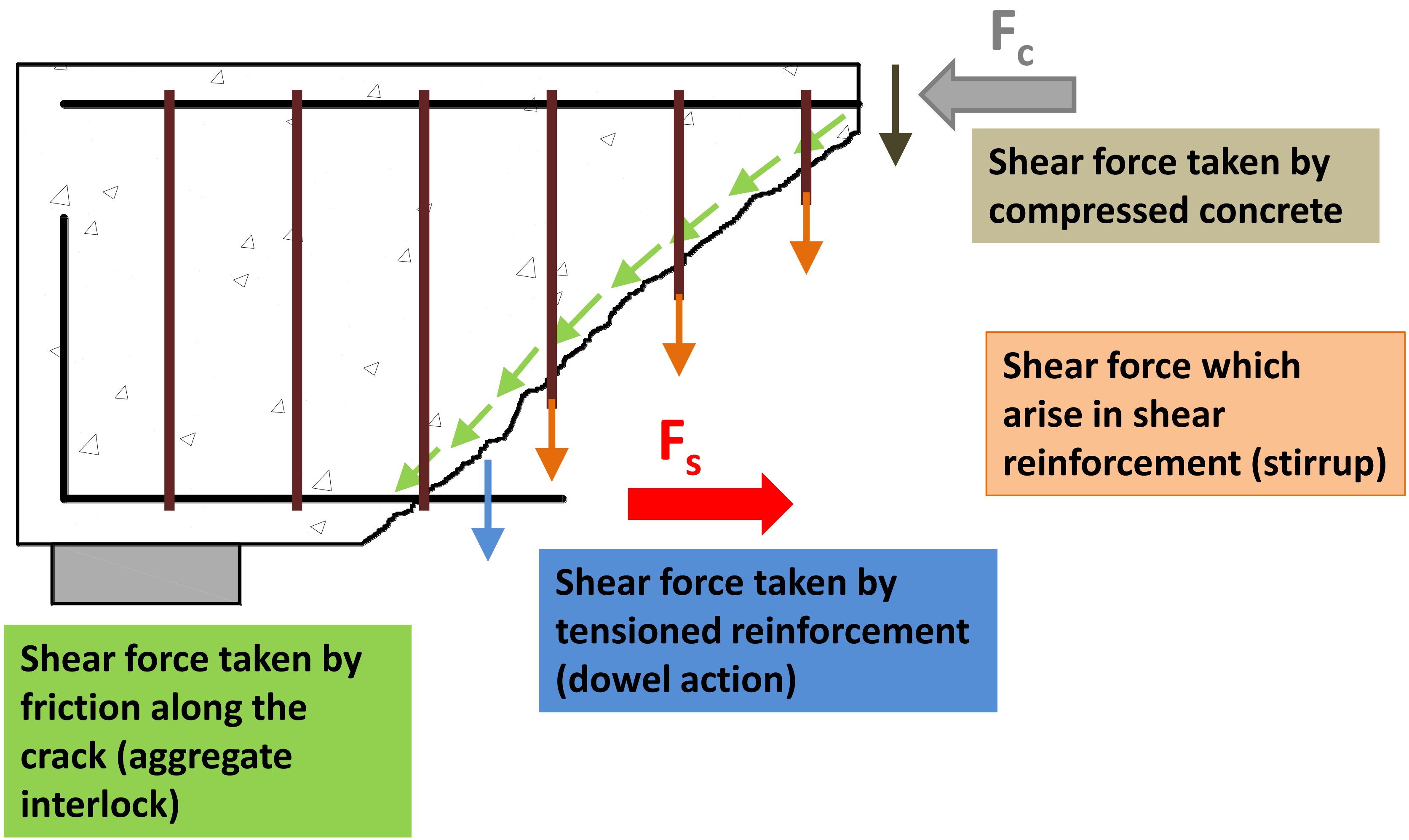

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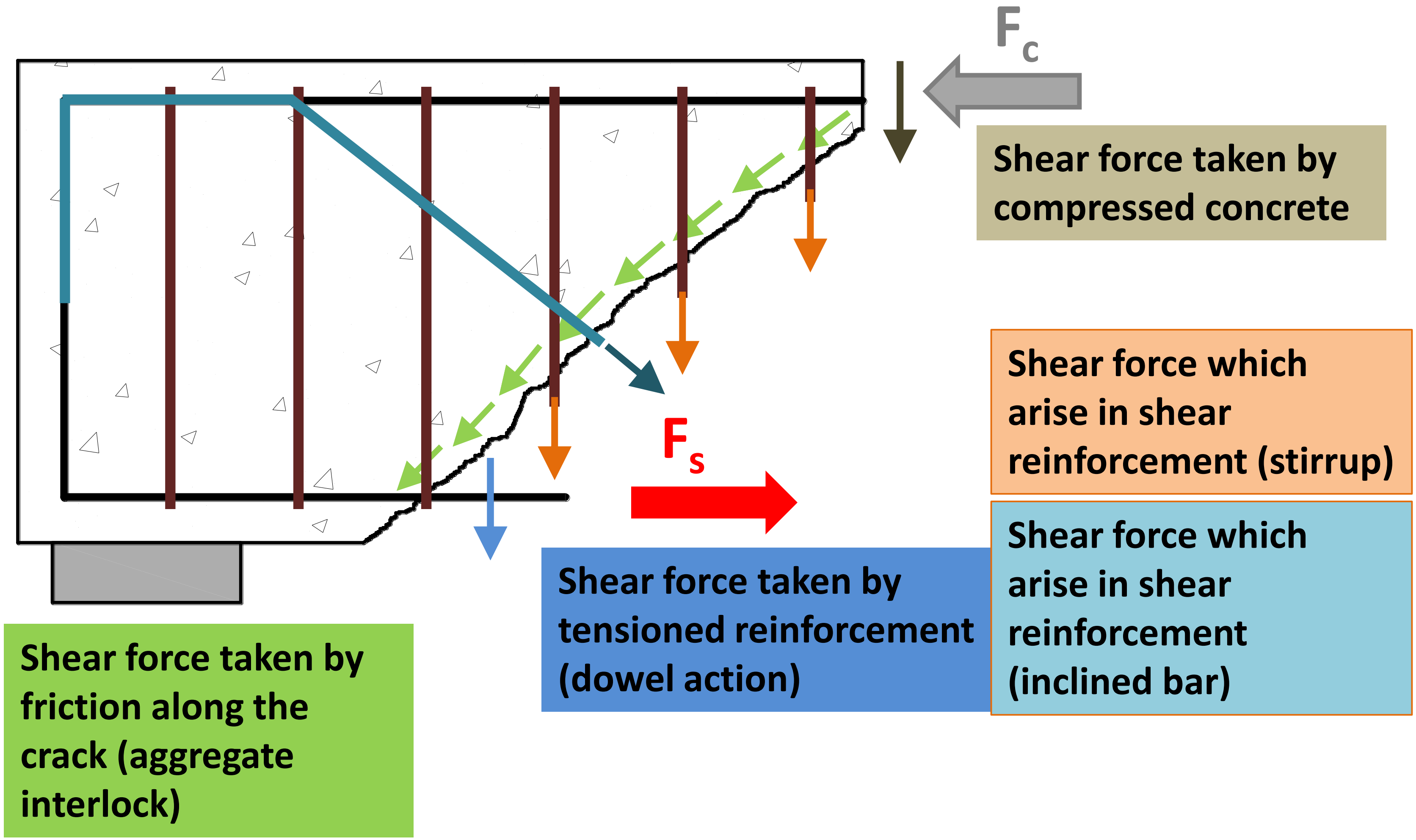
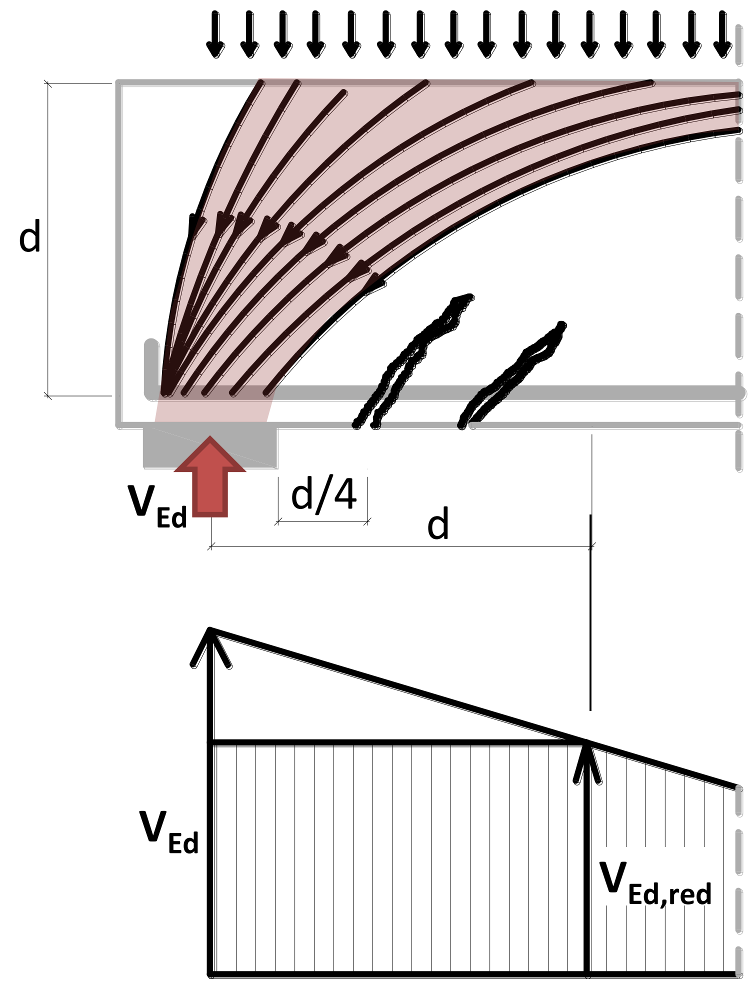


Behaviour of bent elements to shear/ Comportarea elementelor încovoiate la forţă tăietoare

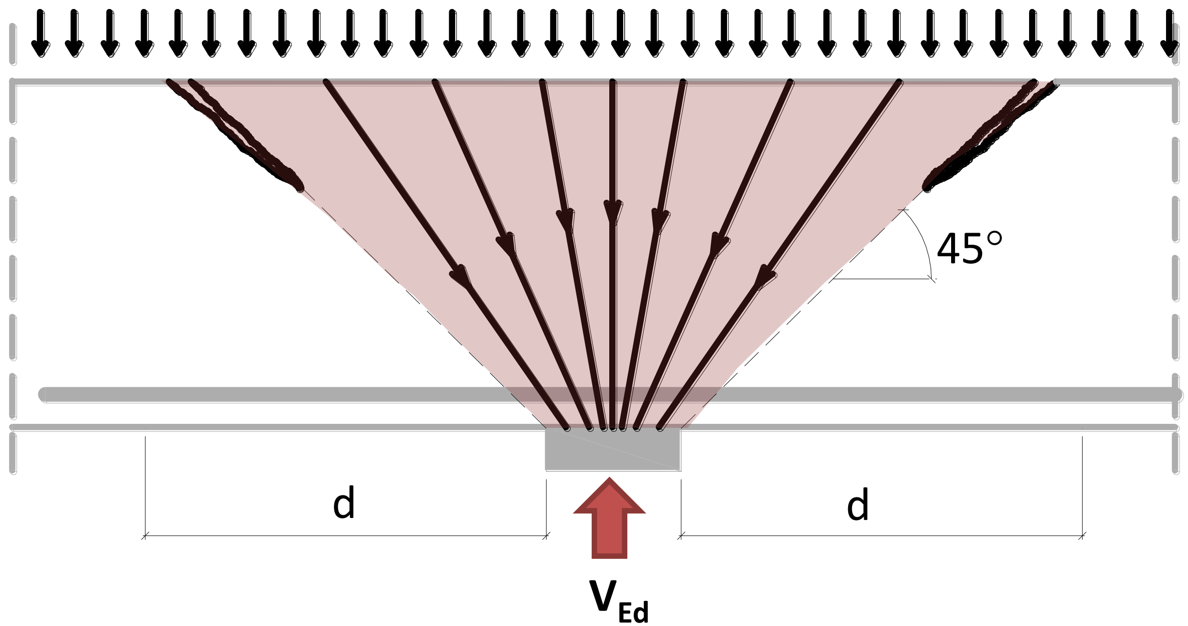
Direct takeover of the uniformly distributed loads – Edge support



Shear force reduction is allowed only if the tensioned longitudinal reinforcement is properly anchored!

Behaviour of bent elements to shear/ Comportarea elementelor încovoiate la forţă tăietoare

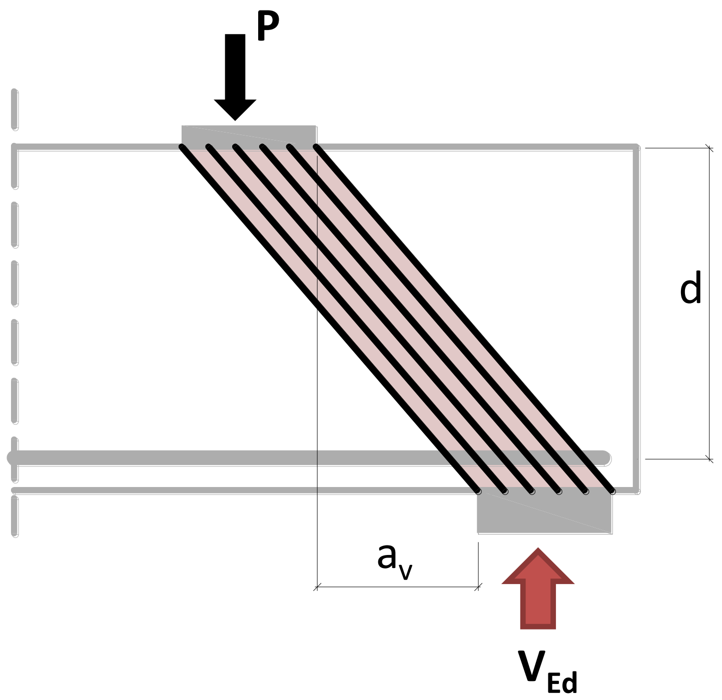
Direct takeover of the uniformly distributed loads – Intermediate support



Shear force reduction is allowed only if the tensioned longitudinal reinforcement is properly anchored!

Behaviour of bent elements to shear/ Comportarea elementelor încovoiate la forţă tăietoare

Direct takeover of the concentrated loads



Shear force reduction is allowed only if the tensioned longitudinal reinforcement is properly anchored!

Design for shear force / Calculul la forţă tăietoare

Calculation steps

- Establishing of the design shear force diagram V_{Ed}

- Correction of the diagram with the possible reductions $(V_{Ed,red})$

- Computation of the shear resistance of the member without shear reinforcement $V_{Rd,c}$

- Verification of the condition $V_{Ed} \le V_{Rd,c}$

- if $V_{Ed} \le V_{Rd,c}$ → shear reinforcement will be provided from detailing conditions

• if $V_{Ed} > V_{Rd,c}$ → computation the shear resistance of concrete compression struts $V_{Rd,max}$

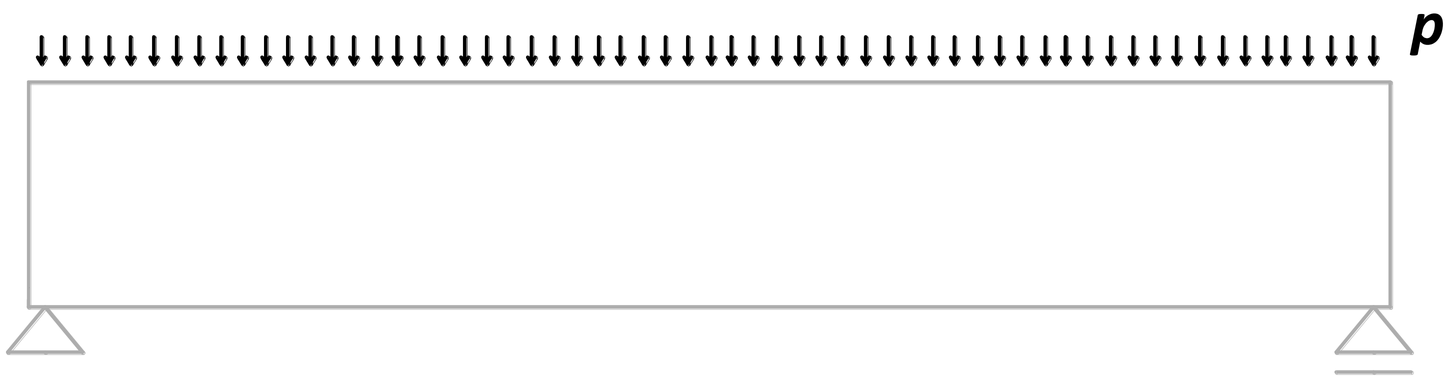
• if $V_{Ed} \ge V_{Rd,max}$ → must increase the concrete cross section

if $V_{Ed} < V_{Rd,max}$ → computation of shear force which can be sustained by the yielding shear reinforcement $V_{Rd,s}$ through choosing a diameter (A_{sw}) and a distance between bars (s) such that

$$V_{Ed} \le V_{Rd,s}$$

Design for shear force / Calculul la forţă tăietoare

The link between the beam model and truss model



Design for shear force / Calculul la forţă tăietoare

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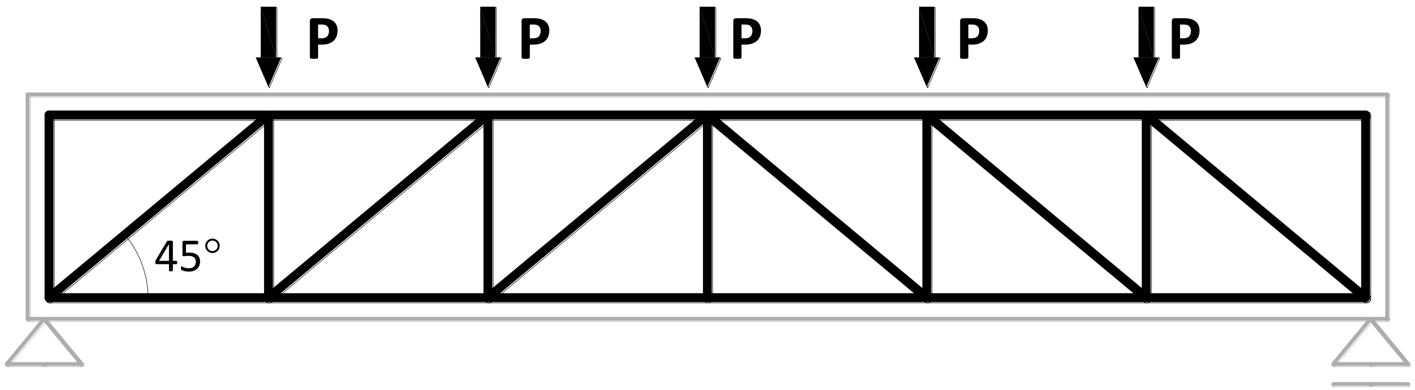

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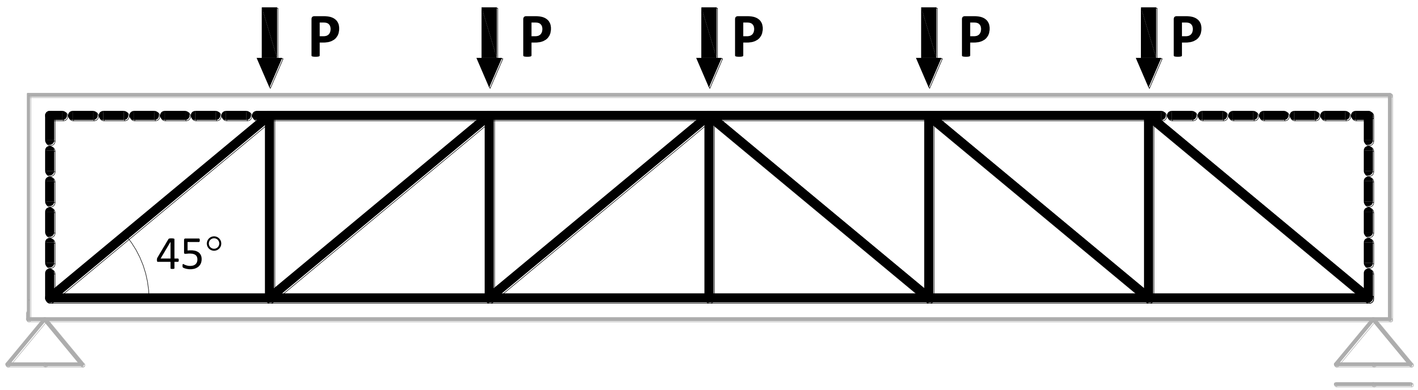

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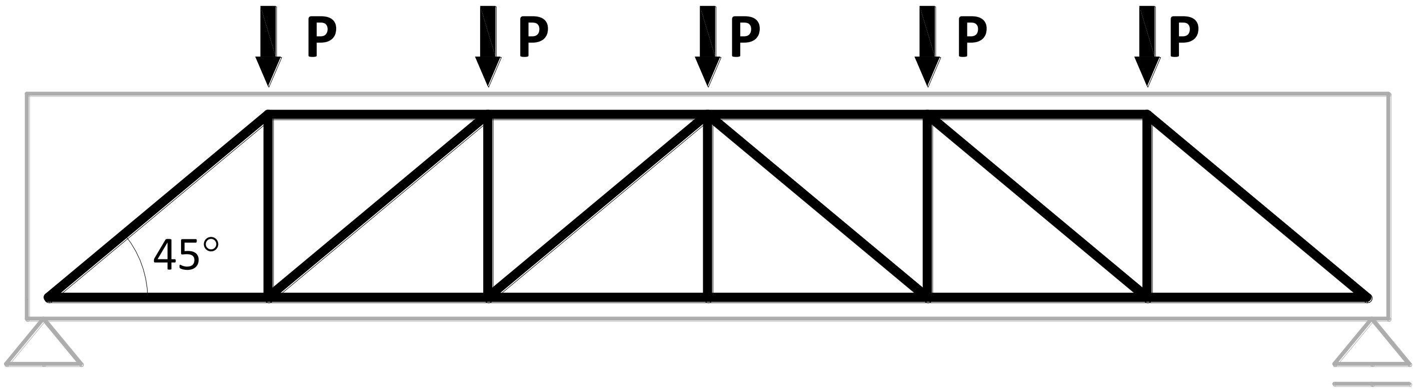

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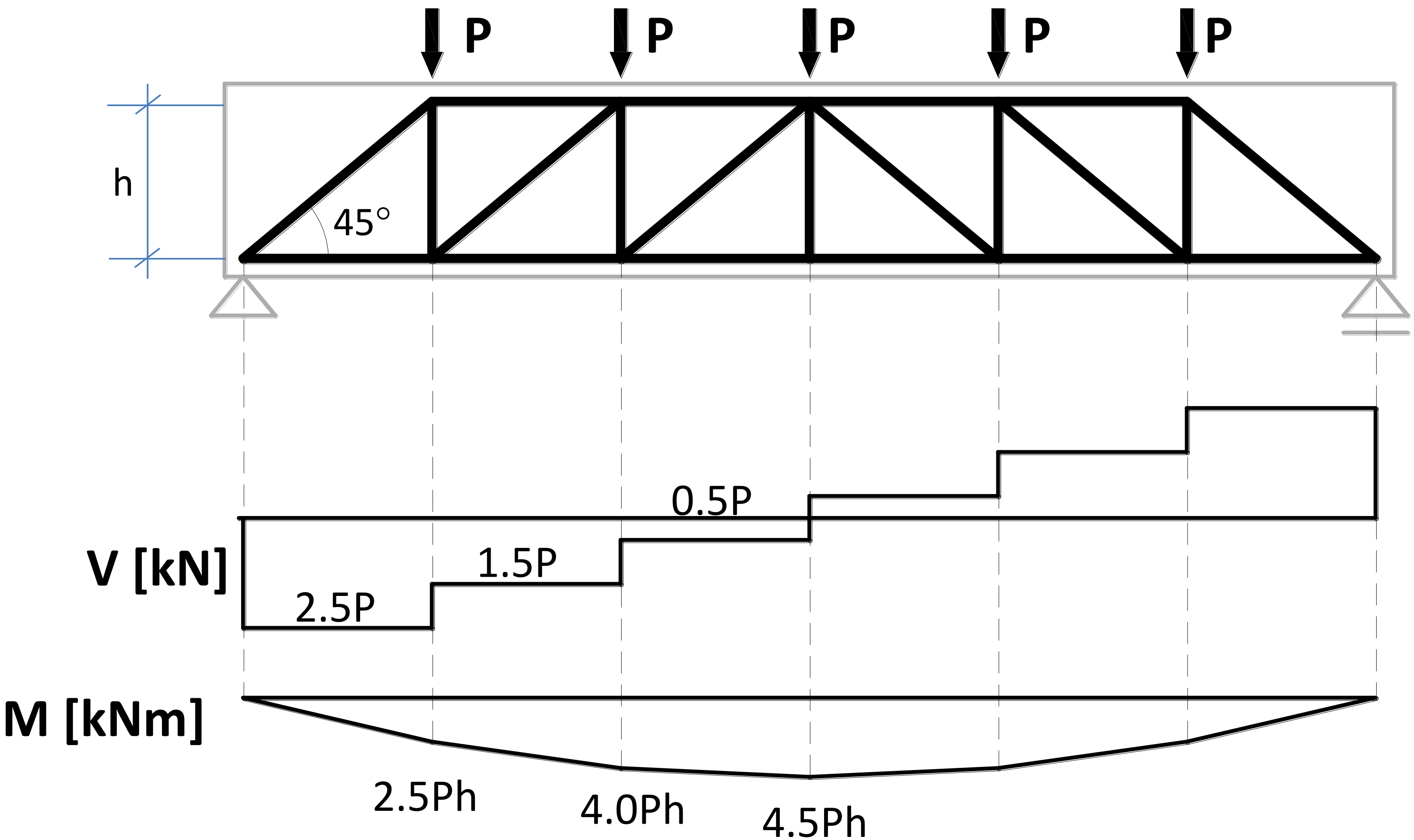

Design for shear force / Calculul la forţă tăietoare

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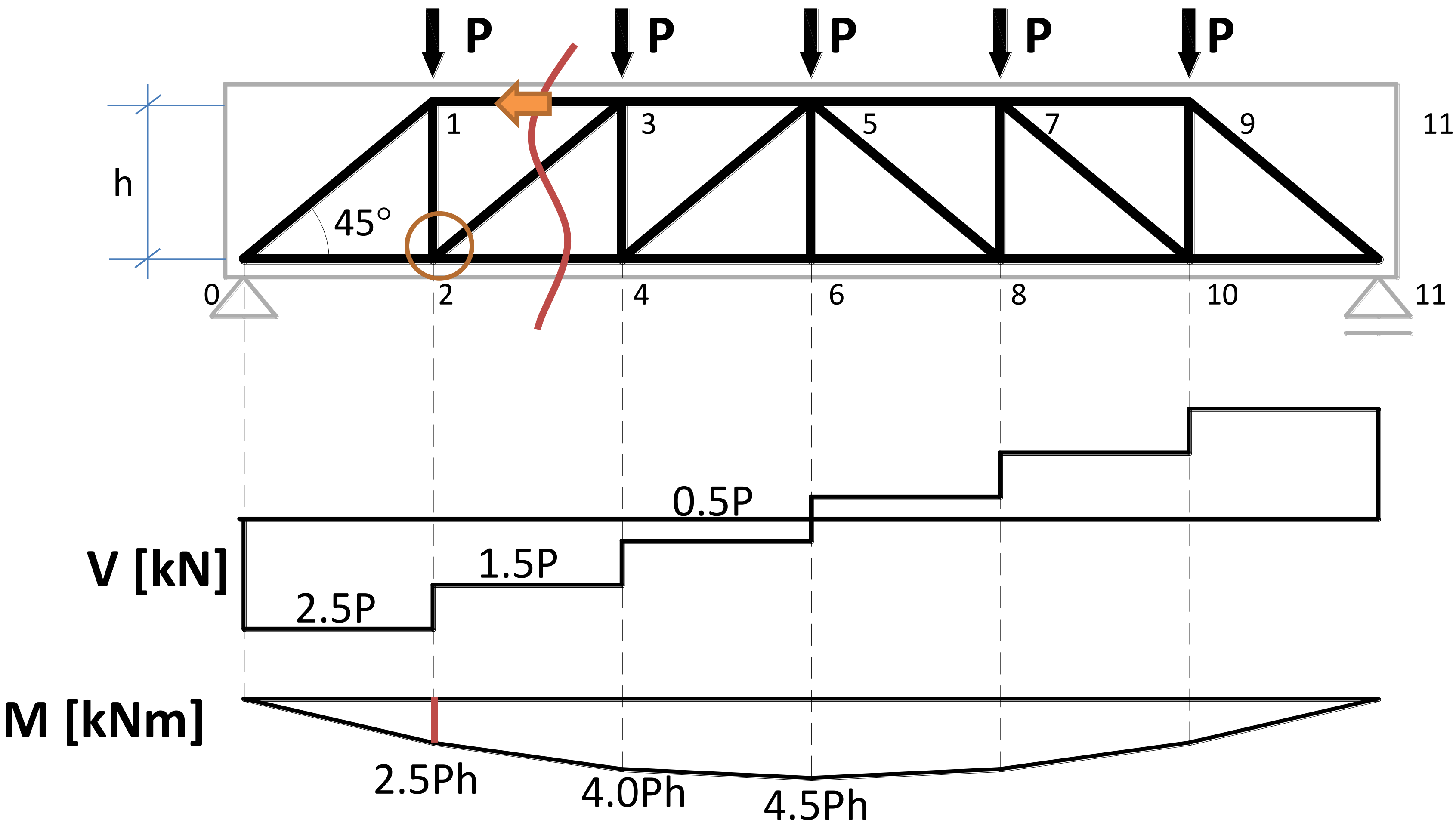
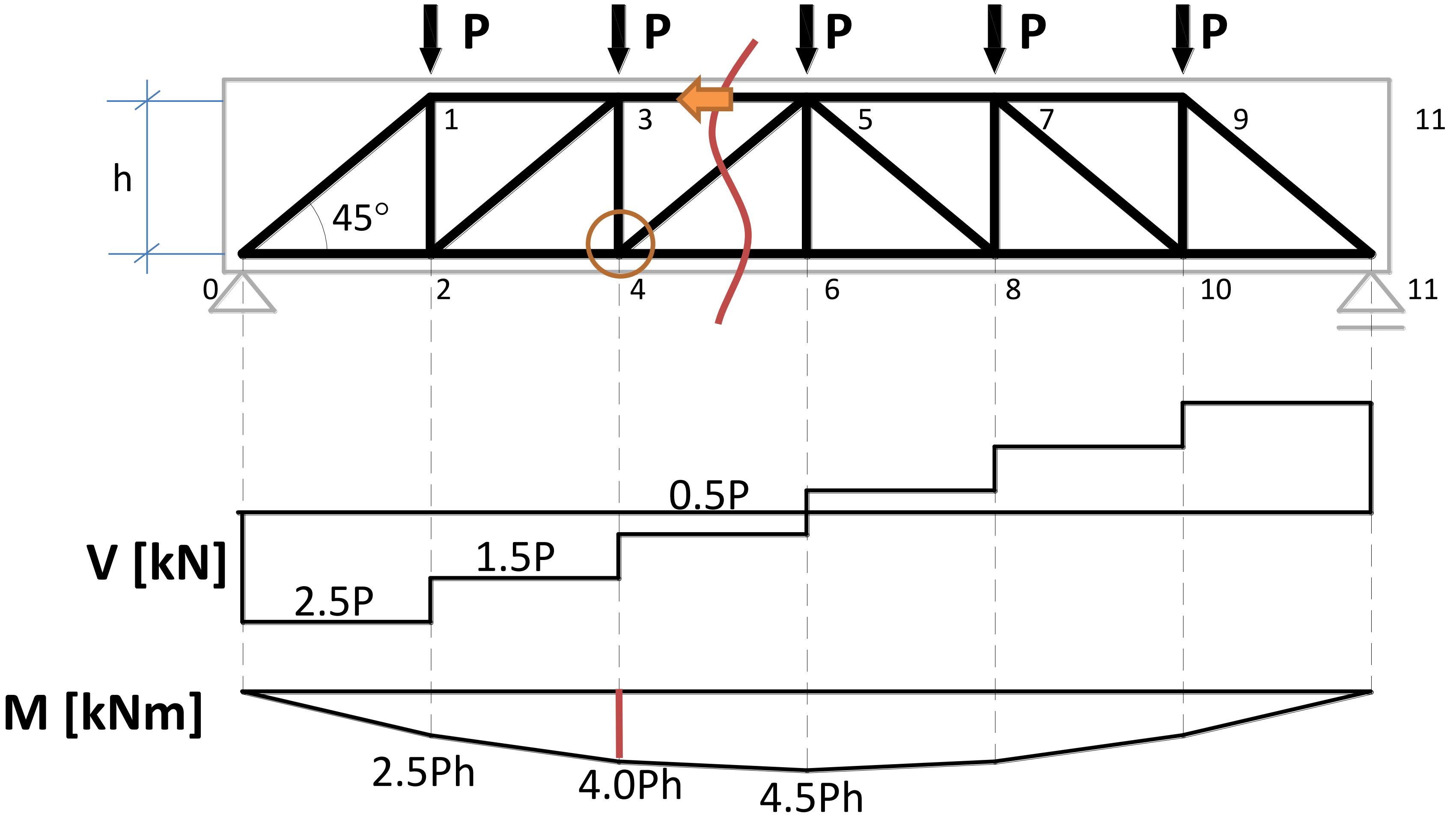


$\Sigma M_2 = 0 \quad \Rightarrow 2{,}5 \cdot P \cdot h - S_{1\text{-}3} \cdot h = 0 \quad \Rightarrow S_{1\text{-}3} = 2{,}5 \cdot P \cdot h / h = 2{,}5 \cdot P\ (-)$

Force in element $S_{1\text{-}3}$ is a ratio between bending moment in section (2) and the distance between the flanges.

Design for shear force / Calculul la forţă tăietoare

The link between the beam model and truss model

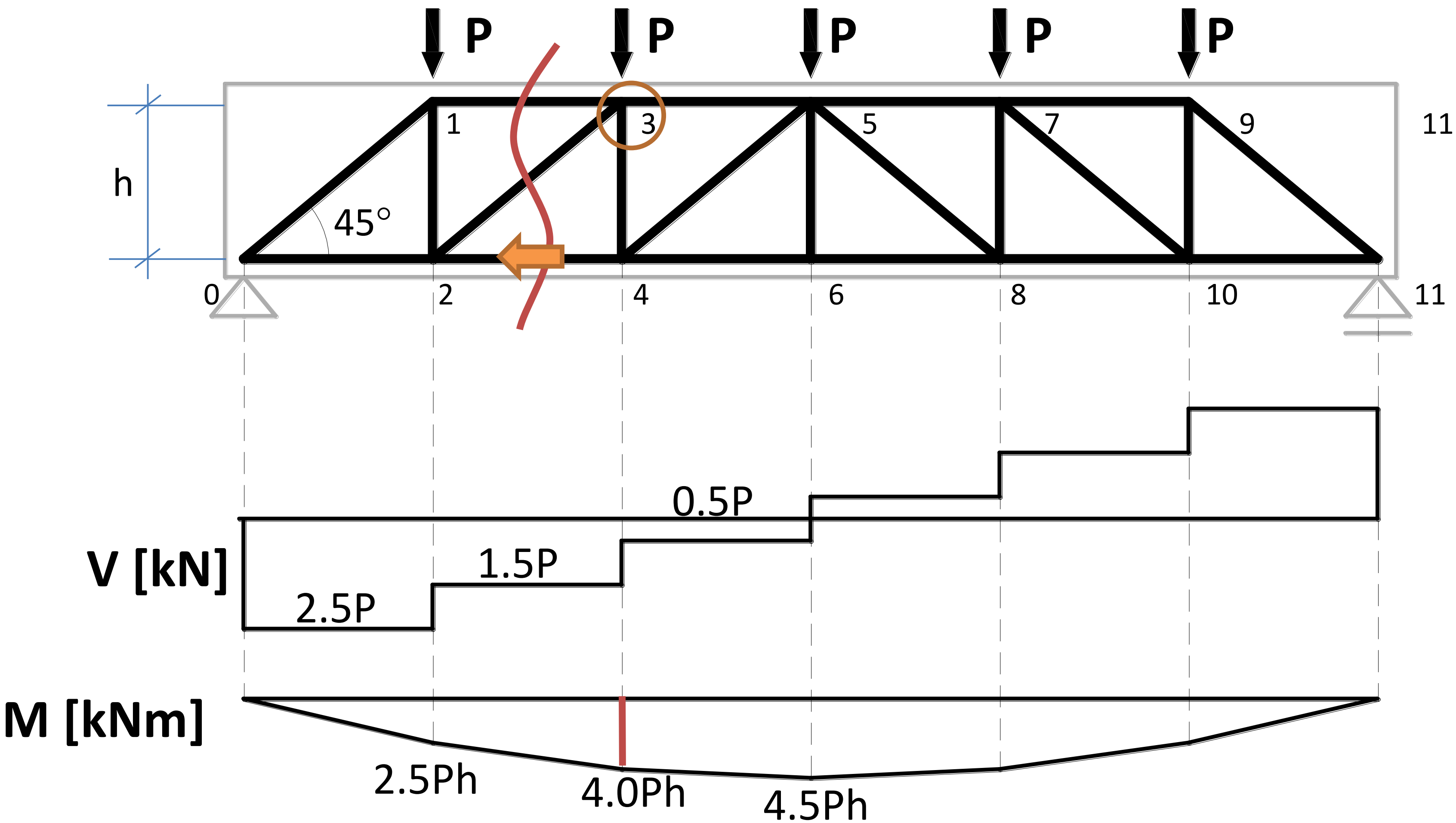


$\Sigma M_4 = 0 \quad \Rightarrow 2{,}5 \cdot P \cdot 2h - P \cdot h - S_{3\text{-}5} \cdot h = 0 \quad \Rightarrow S_{3\text{-}5} = 4 \cdot P \cdot h / h = 4 \cdot P \ (-)$

Force in element $S_{3\text{-}5}$ is a ratio between bending moment in section (4) and the distance between the flanges.

Design for shear force / Calculul la forţă tăietoare

The link between the beam model and truss model

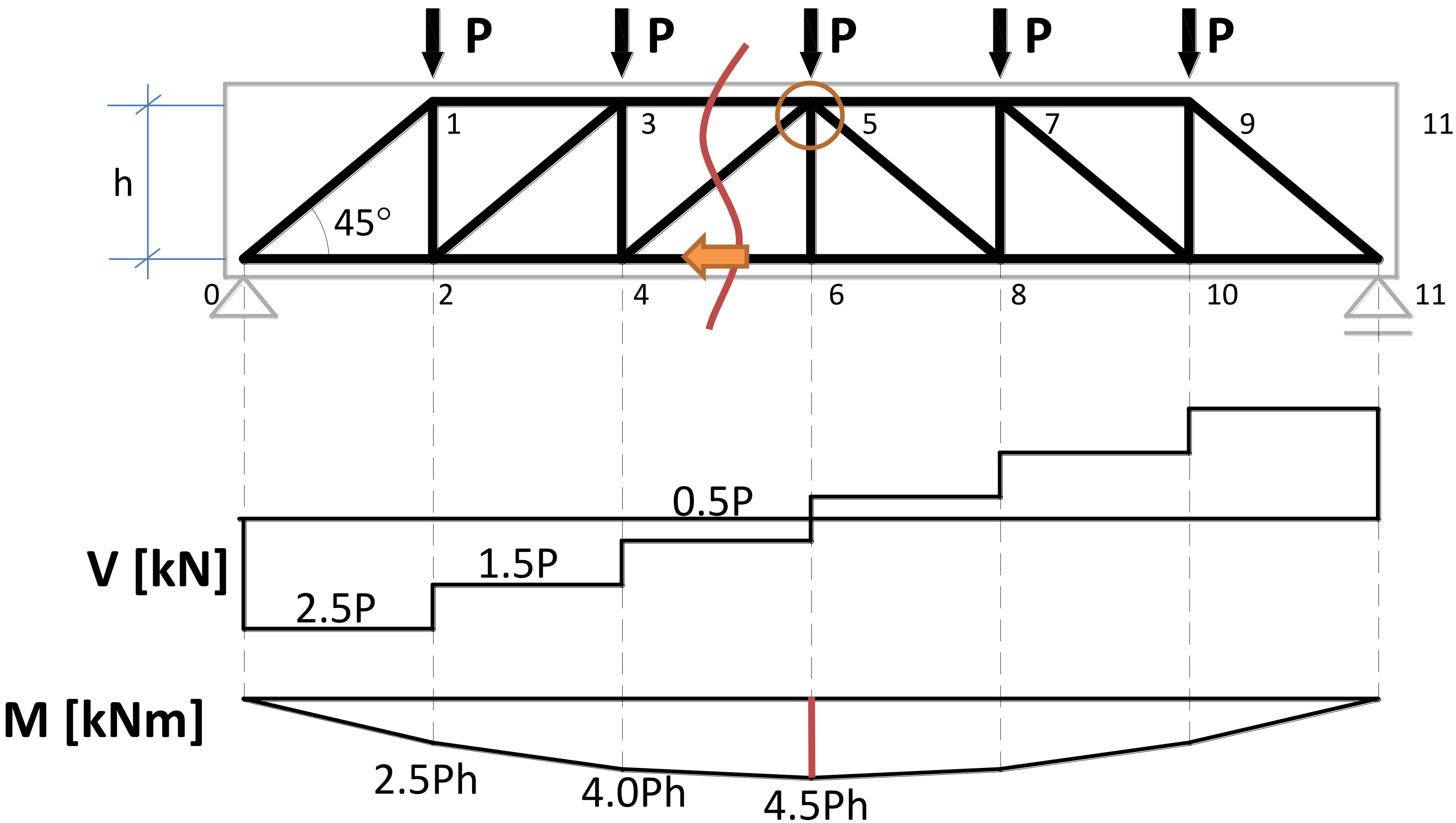


$\Sigma M_3 = 0 \quad \Rightarrow 2{,}5 \cdot P \cdot 2h - P \cdot h - S_{2\text{-}4} \cdot h = 0 \quad \Rightarrow S_{2\text{-}4} = 4 \cdot P \cdot h / h = 4 \cdot P \ (+)$

Force in element $S_{2\text{-}4}$ is a ratio between bending moment in section (3) and the distance between the flanges.

Design for shear force / Calculul la forţă tăietoare

The link between the beam model and truss model

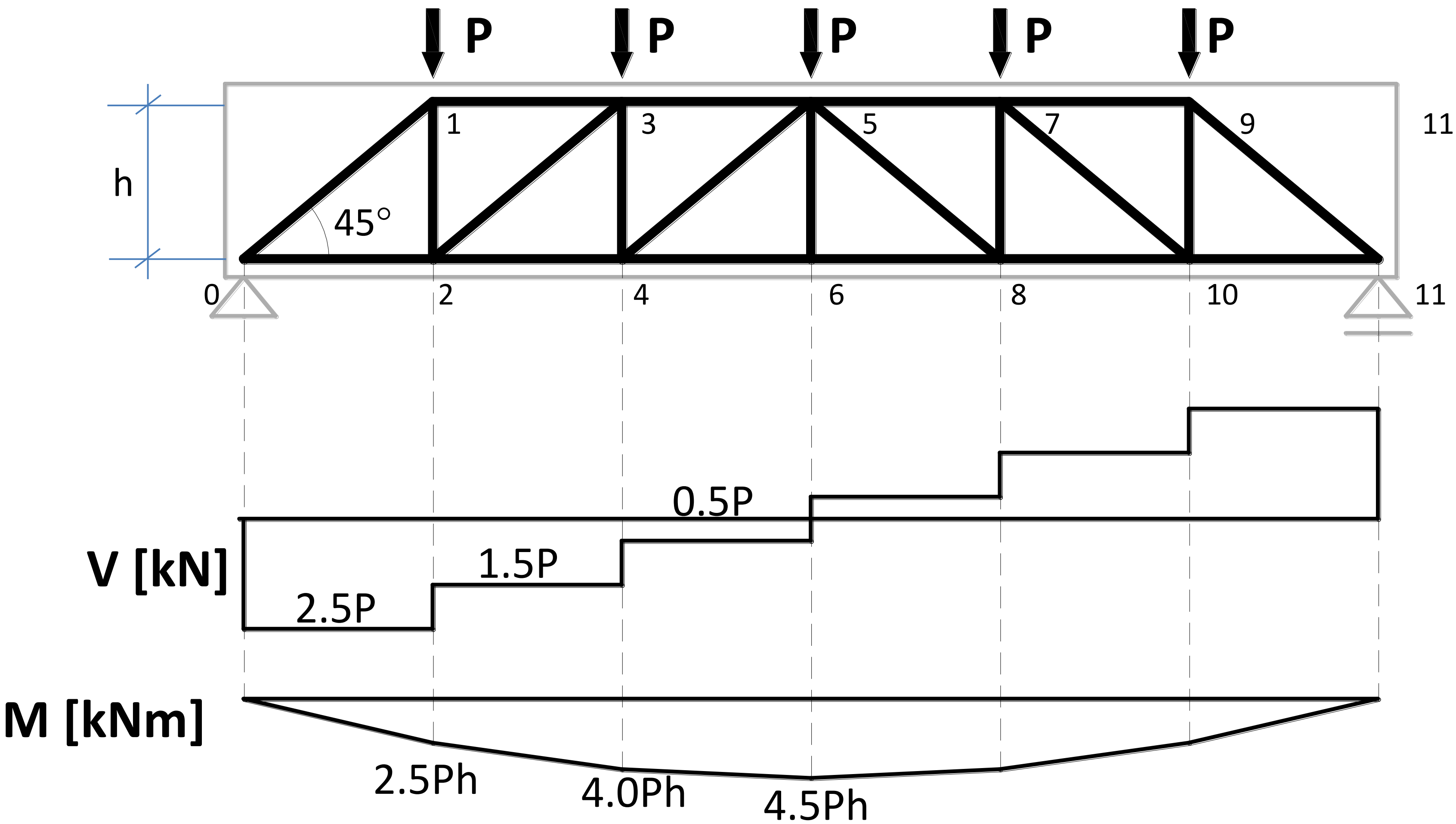


$\Sigma M_5 = 0 \quad \Rightarrow 2{,}5 \cdot P \cdot 3h - P \cdot 2h - P \cdot h - S_{4\text{-}6} \cdot h = 0 \Rightarrow S_{4\text{-}6} = 4{,}5 \cdot P \cdot h / h = 4{,}5 \cdot P\ (+)$

Force in element $S_{4\text{-}6}$ is a ratio between bending moment in section (5) and the distance between the flanges.

Design for shear force / Calculul la forţă tăietoare

The link between the beam model and truss model

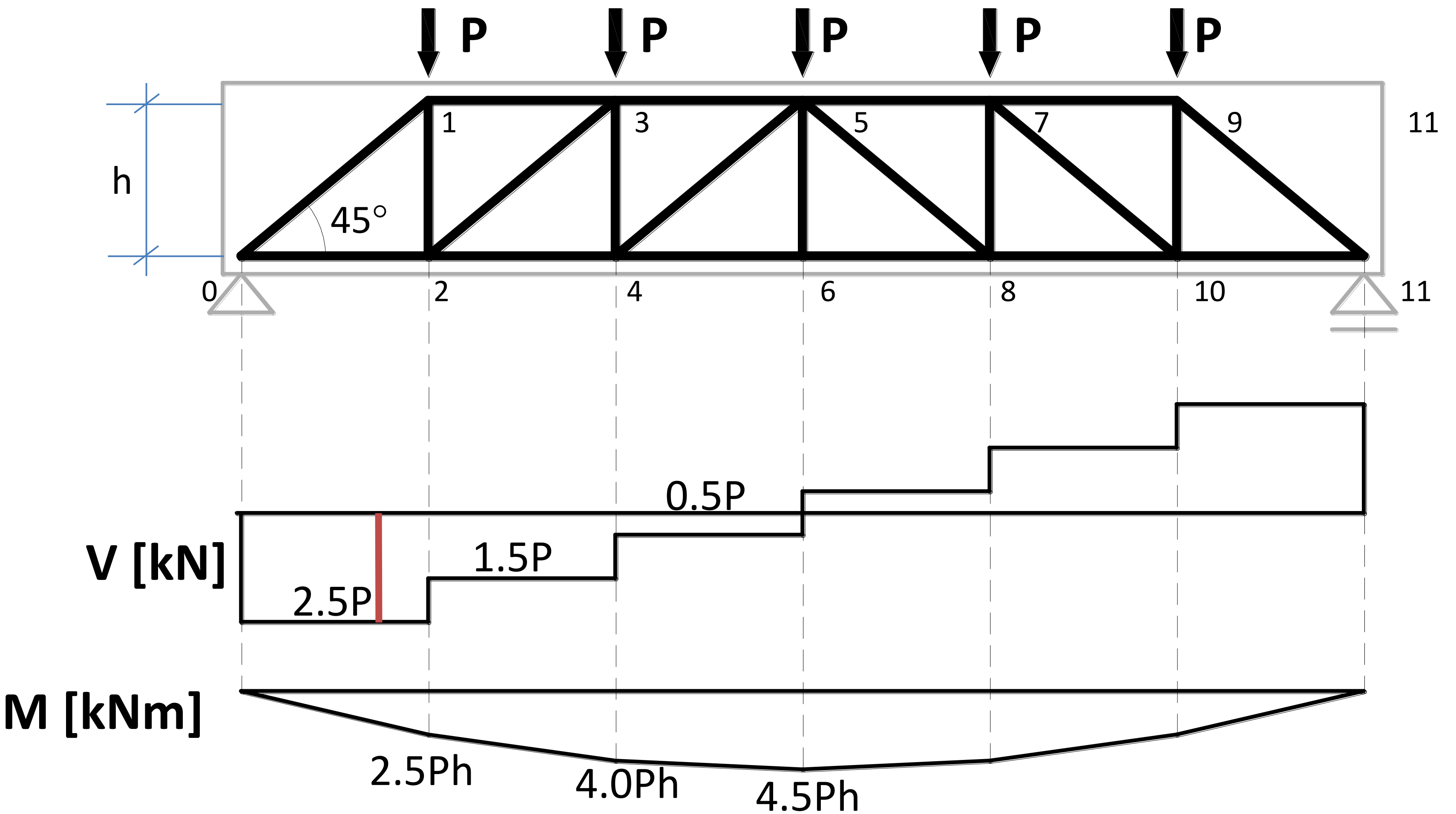


$$\Rightarrow S_{0\text{-}2} = 2{,}5 \cdot P\ (+)$$

Force in element $S_{0\text{-}2}$ is determined from vectorial equation (triangle) written in node 0.

Design for shear force / Calculul la forţă tăietoare

The link between the beam model and truss model

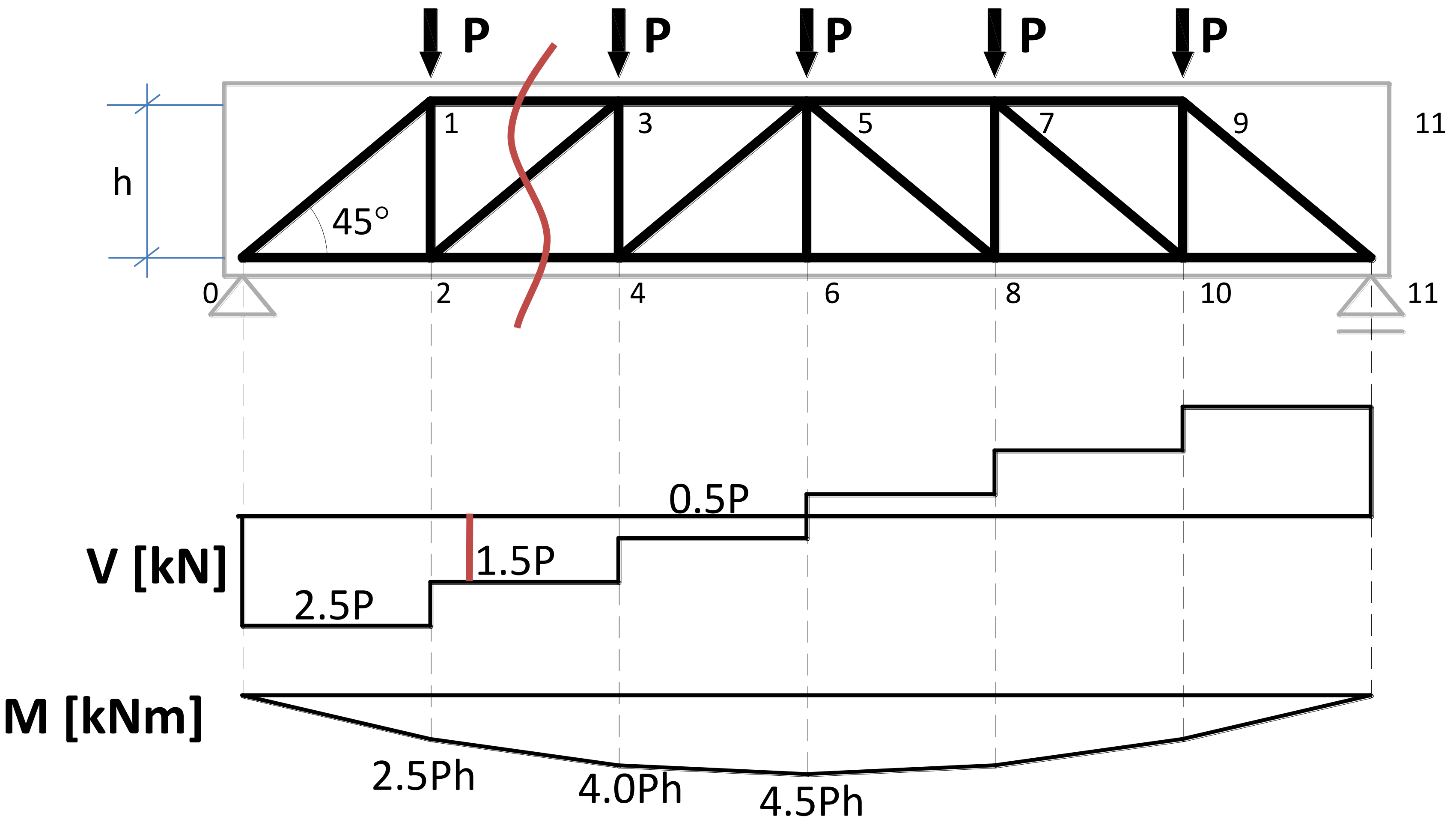


$\Sigma F_y = 0 \quad \Rightarrow 2{,}5 \cdot P - S_{0\text{-}1} \cdot \sin\alpha = 0 \quad \Rightarrow S_{0\text{-}1} = 2{,}5P / \sin\alpha = \sqrt{2} \cdot 2{,}5P \ (-)$

Force in element $S_{0\text{-}1}$ is determined from vertical projection equation written in node 0.

Design for shear force / Calculul la forţă tăietoare

The link between the beam model and truss model

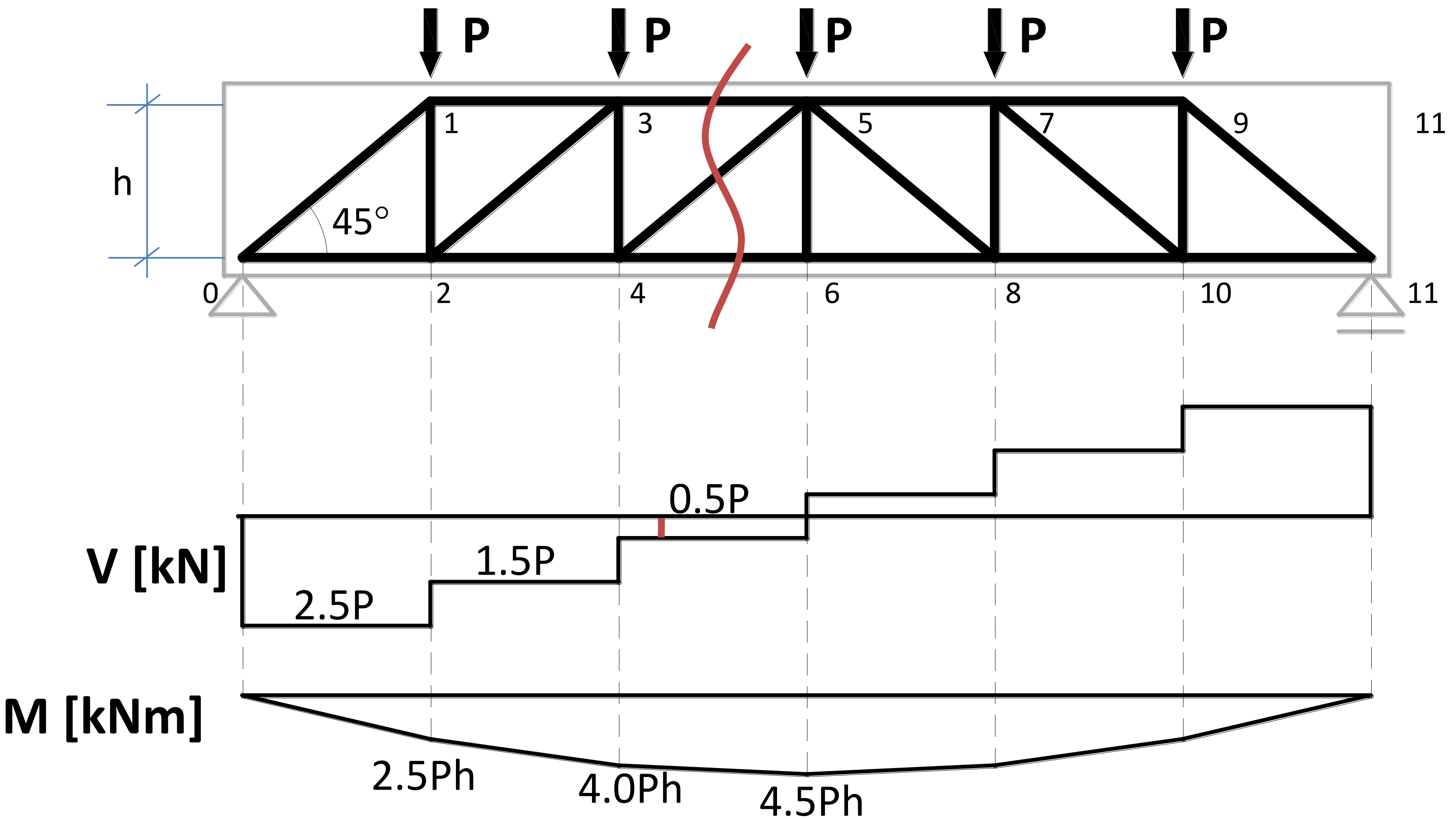


$\Sigma F_y = 0 \quad \Rightarrow 2{,}5\cdot P - P - S_{2\text{-}3}\cdot \sin\alpha = 0 \Rightarrow S_{2\text{-}3} = 1{,}5P / \sin\alpha = \sqrt{2}\cdot 1{,}5P\ (-)$

Force in element $S_{2\text{-}3}$ is determined from vertical projection equation written in section.

Design for shear force / Calculul la forţă tăietoare

The link between the beam model and truss model

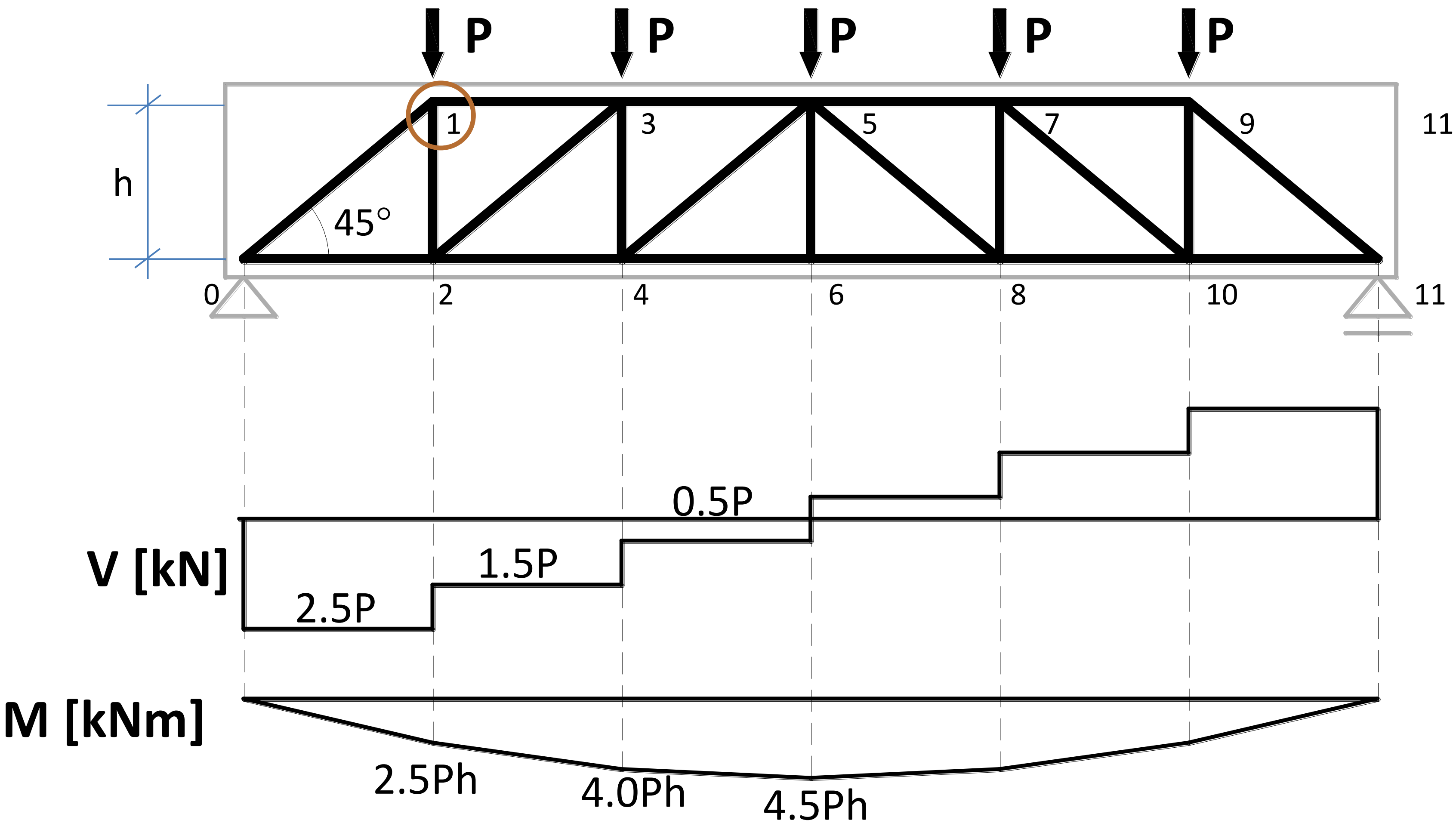


$\Sigma F_y=0 \quad \Rightarrow 2{,}5 \cdot P - P - P - S_{4\text{-}5} \cdot \sin\alpha = 0 \qquad \Rightarrow S_{4\text{-}5} = 0{,}5P / \sin\alpha = \sqrt{2} \cdot 0{,}5P \; (-)$

Force in element $S_{4\text{-}5}$ is determined from vertical projection equation written in section.

Design for shear force / Calculul la forţă tăietoare

The link between the beam model and truss model

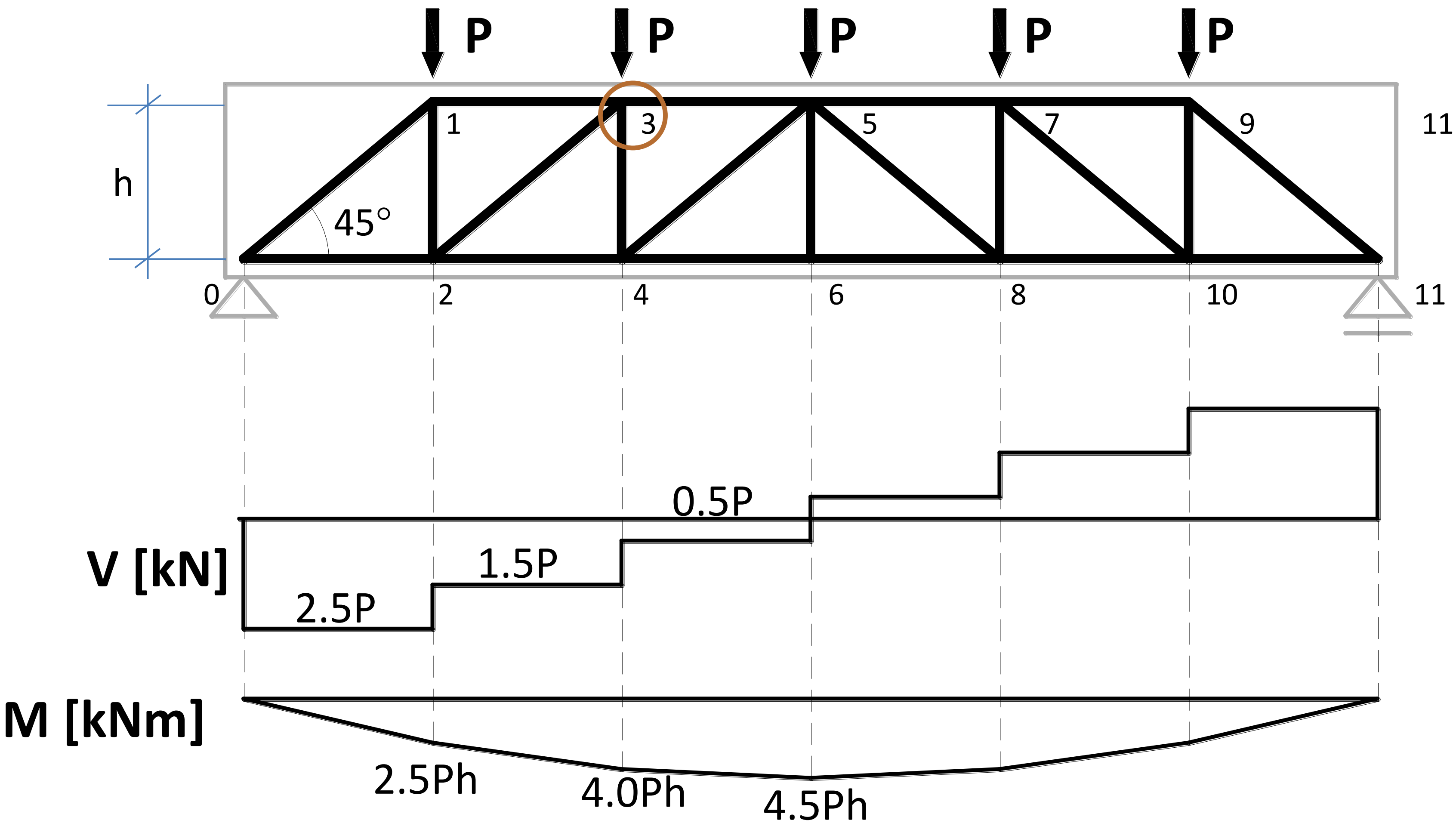


$\Sigma F_y=0 \quad \Rightarrow S_{0\text{-}1,y} - P - S_{1\text{-}2} = 2{,}5P - P - S_{1\text{-}2} = 0 \quad \Rightarrow \quad S_{1\text{-}2} = 1{,}5P\ (+)$

Force in element $S_{1\text{-}2}$ is determined from vertical projection written in node (1).

Design for shear force / Calculul la forţă tăietoare

The link between the beam model and truss model

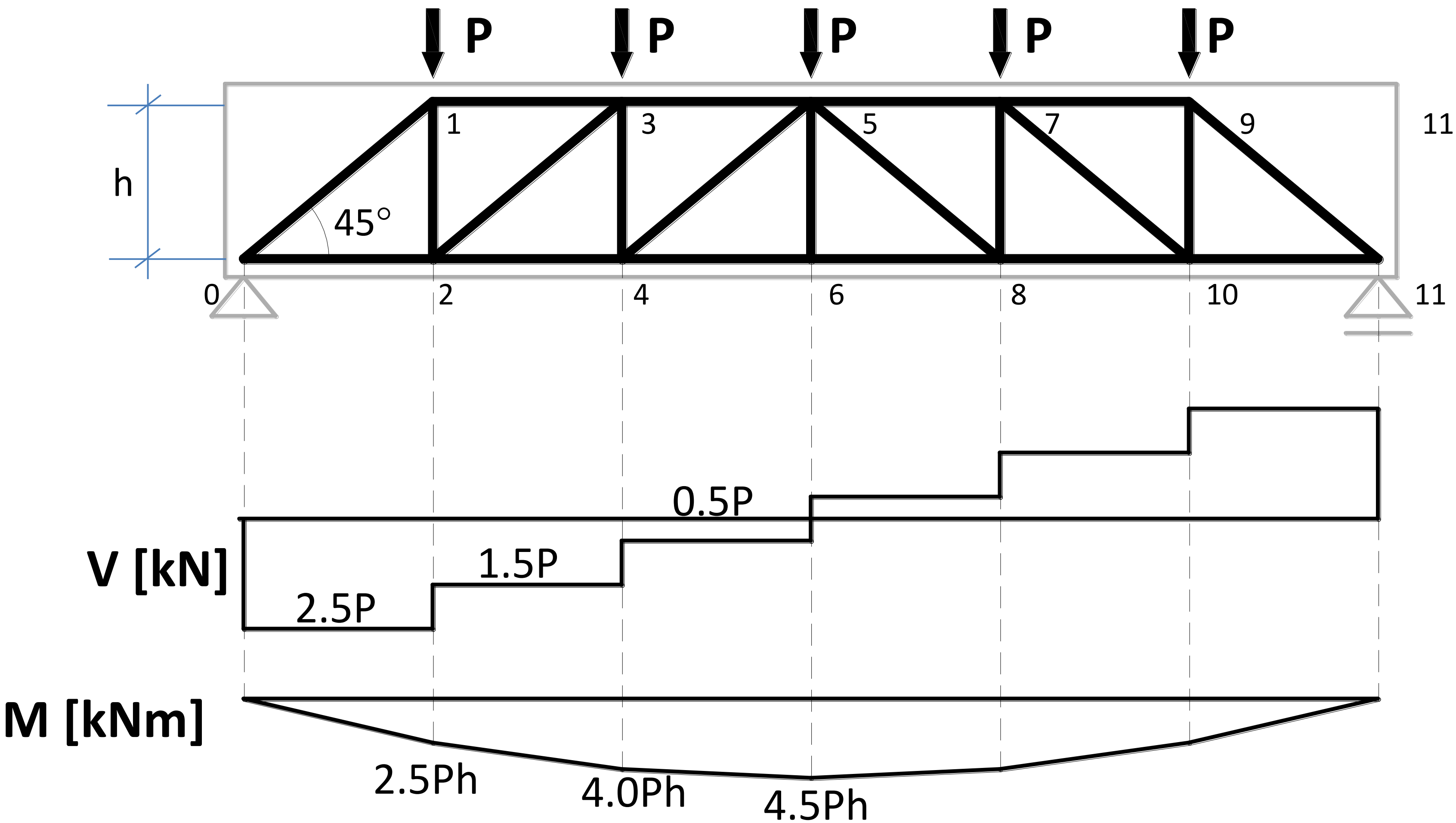


$\Sigma F_y = 0 \quad \Rightarrow S_{2\text{-}3,y} - P - S_{3\text{-}4} = 1{,}5P - P - S_{3\text{-}4} = 0 \quad \Rightarrow \quad S_{3\text{-}4} = 0{,}5P\ (+)$

Force in element $S_{3\text{-}4}$ is determined from vertical projection written in node (3).

Design for shear force / Calculul la forţă tăietoare

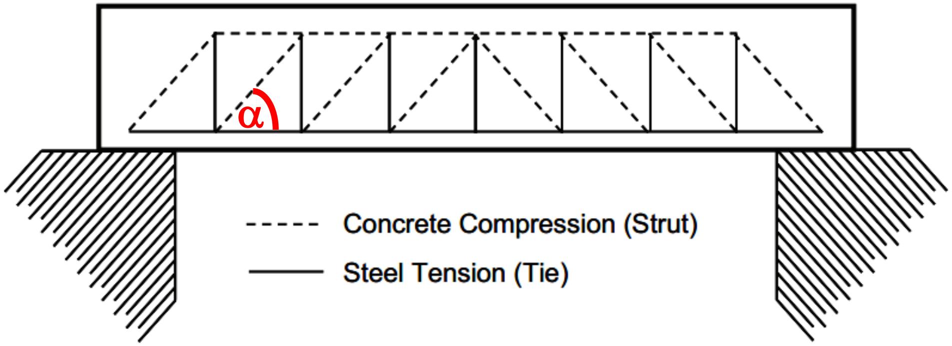
The link between the beam model and truss model



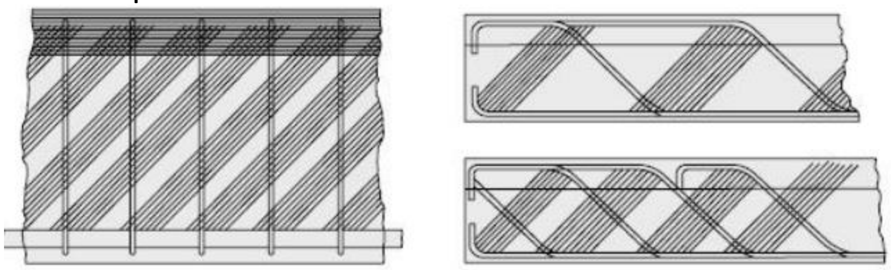
FLANGES → take over **BENDING MOMENTS**!
TIES → take over **SHEAR FORCES**!

Design for shear force / Calculul la forţă tăietoare

Strut-and-tie models used for shear capacity calculation of RC beams



Original model of **Ritter** (1899)



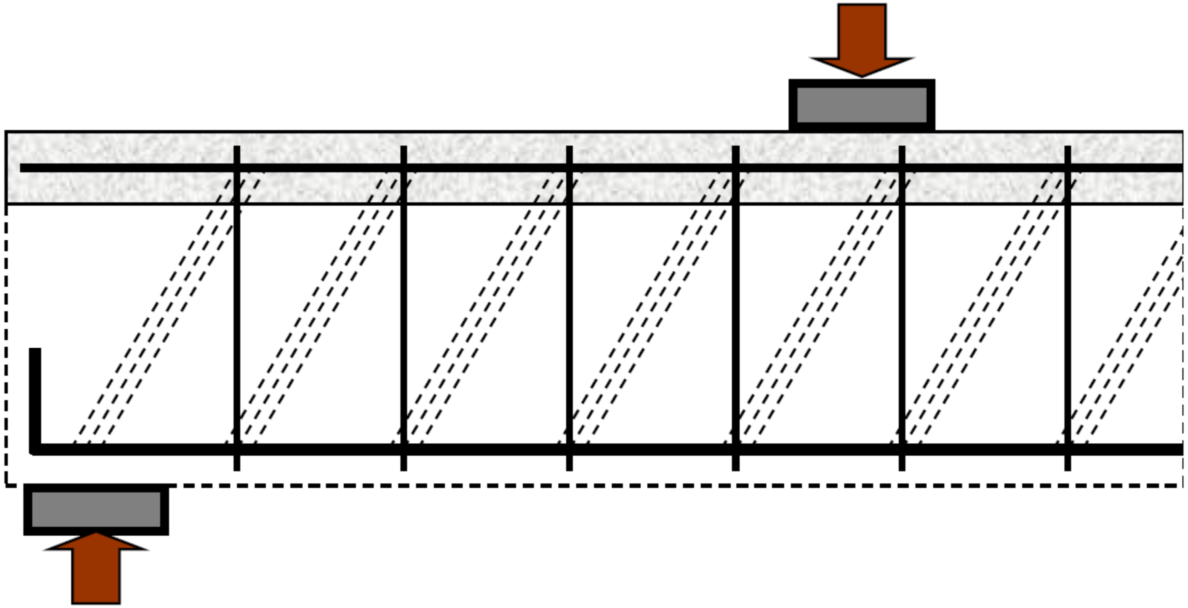
Mörsch model (1909) – modified Ritter model→ diagonals were replaced with compression fileds

$$\alpha = 25° - 45°$$

Top flange:	COMPRESSED CONCRETE
Bottom flange:	TENSION REINFORCEMENT
Diagonals:	COMPRESSED CONCRETE
Vertical ties:	STIRRUPS

Design for shear force / Calculul la forţă tăietoare

Strut-and-tie models used for shear capacity calculation of RC beams



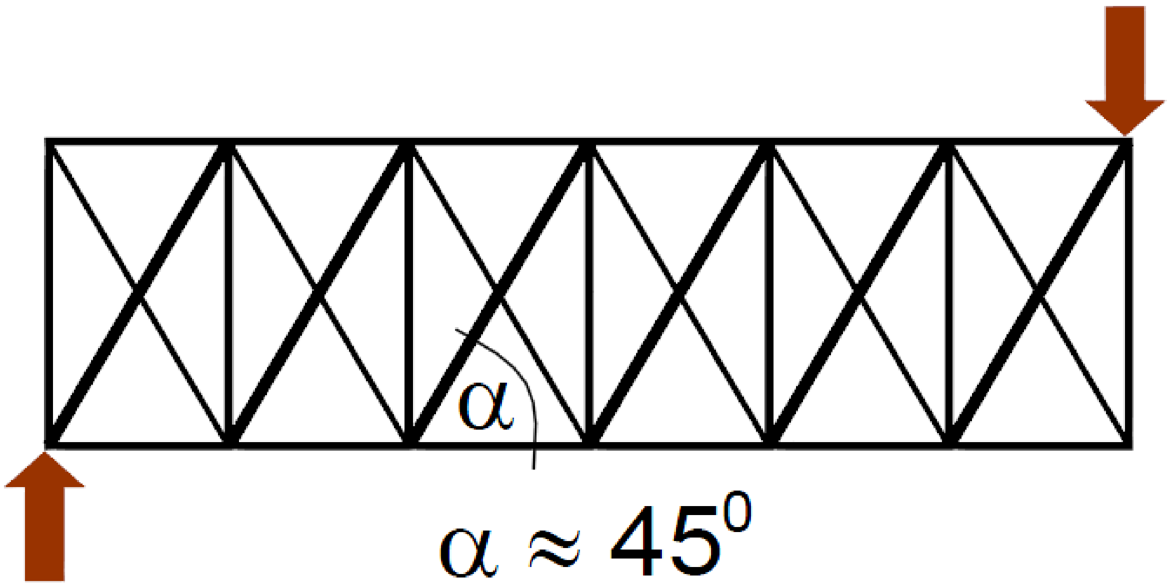
Ritter – Mörsch – Thürlimann type model

Top flange:	COMPRESSED CONCRETE
Bottom flange:	TENSION REINFORCEMENT
Diagonals:	COMPRESSED CONCRETE
Vertical ties:	STIRRUPS

(Dr. Kovács I., DE)

Design for shear force / Calculul la forţă tăietoare

Strut-and-tie models used for shear capacity calculation of RC beams



$$\alpha \approx 45^0$$

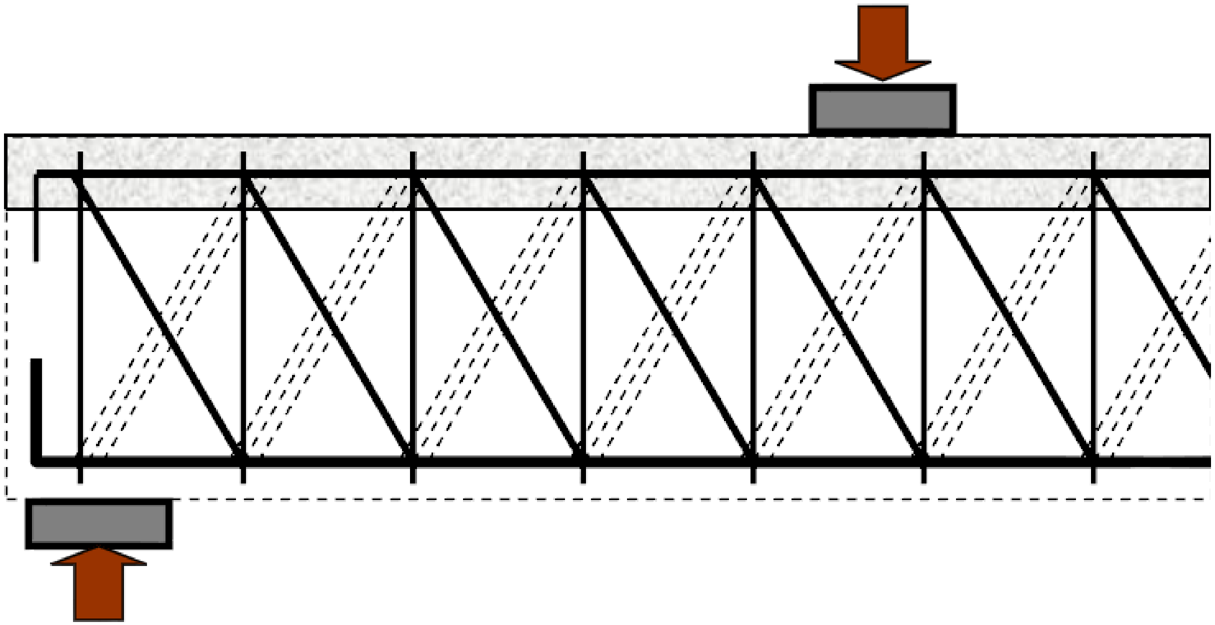
Mörsch type model with 2 diagonals

Top flange:	COMPRESSED CONCRETE
Bottom flange:	TENSION REINFORCEMENT
Compressed diagonals:	COMPRESSED CONCRETE
Tensioned diagonals:	INCLINED REINFORCEMENT
Vertical ties:	STIRRUPS

(Dr. Kovács I., DE)

Design for shear force / Calculul la forţă tăietoare

Strut-and-tie models used for shear capacity calculation of RC beams



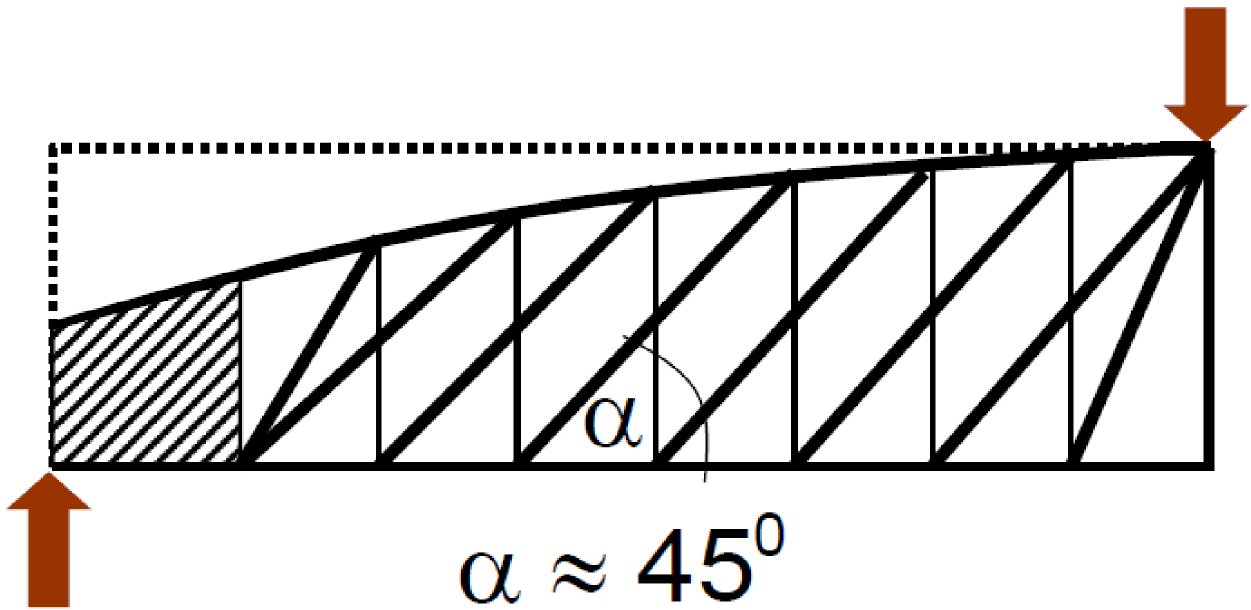
Mörsch type model with 2 diagonals

Top flange:	COMPRESSED CONCRETE
Bottom flange:	TENSION REINFORCEMENT
Compressed diagonals:	COMPRESSED CONCRETE
Tensioned diagonals:	INCLINED REINFORCEMENT
Vertical ties:	STIRRUPS

(Dr. Kovács I., DE)

Design for shear force / Calculul la forţă tăietoare

Strut-and-tie models used for shear capacity calculation of RC beams



$$\alpha \approx 45^0$$

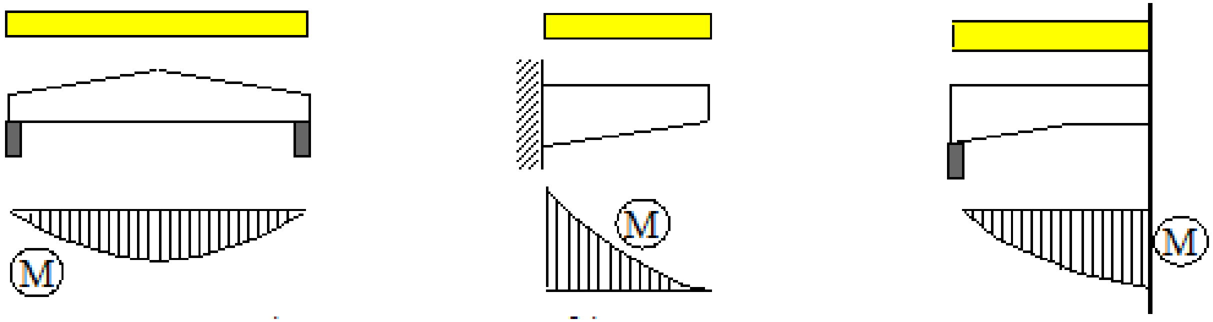
Leonhardt type model

Top flange:	VARIABLE CROSS SECTION COMPRESSED CONCRETE
Bottom flange:	TENSION REINFORCEMENT
Diagonals:	COMPRESSED CONCRETE
Vertical ties:	STIRRUPS

(Dr. Kovács I., DE)

Design for shear force / Calculul la forţă tăietoare

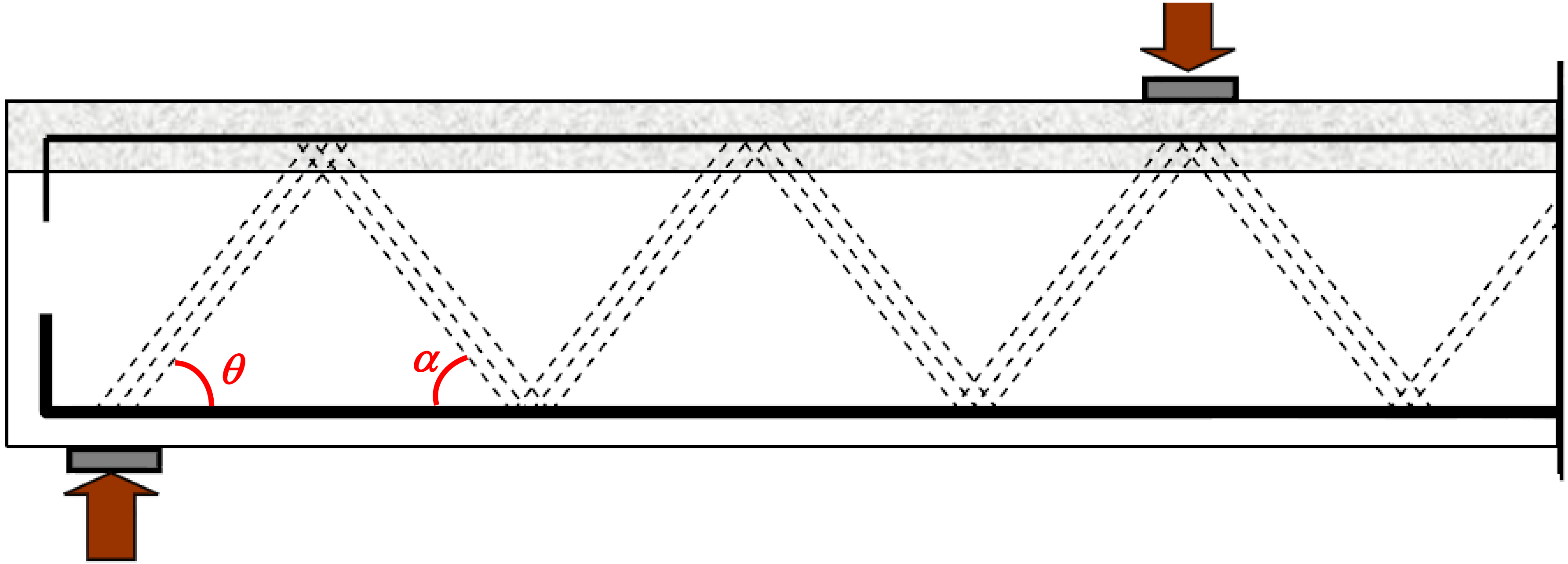
Members with inclined chords



10.3 ELEMENTS WITHOUT SHEAR REINFORCEMENT

Design for shear force / Calculul la forţă tăietoare

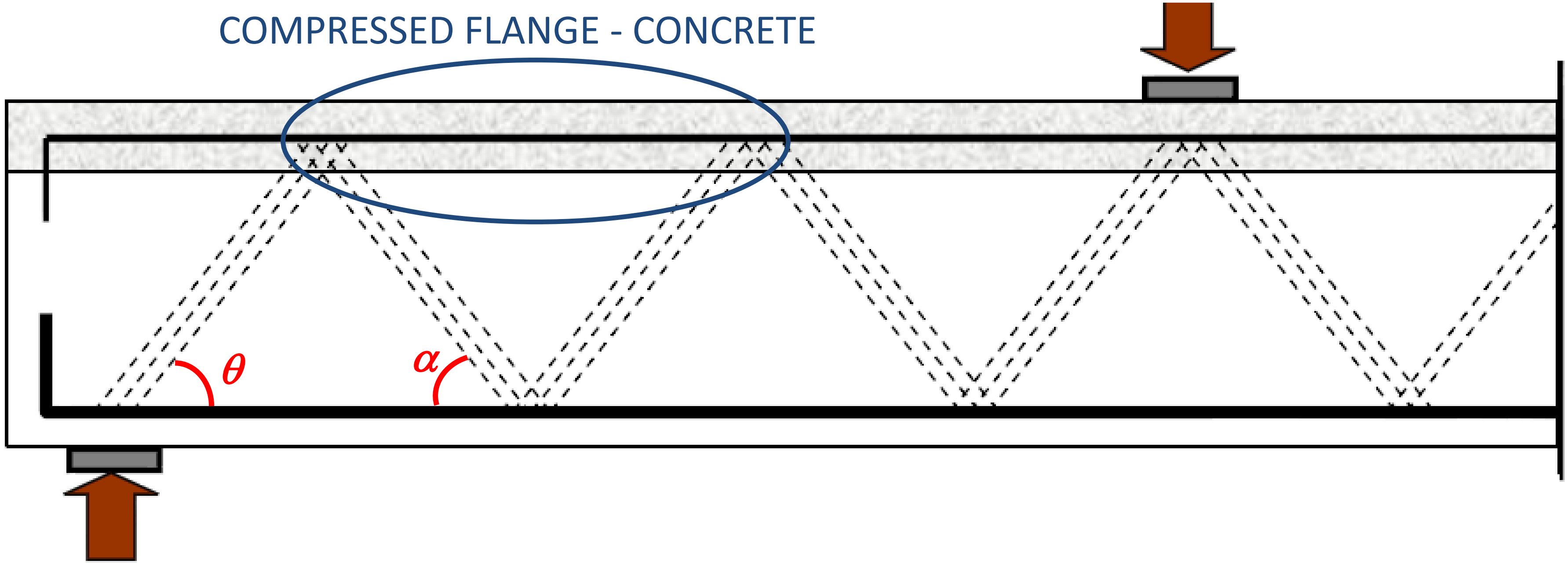
Strut-and-tie models used for shear capacity calculation of RC beams WITHOUT SHEAR REINFORCEMENT



(Dr. Kovács I., DE)

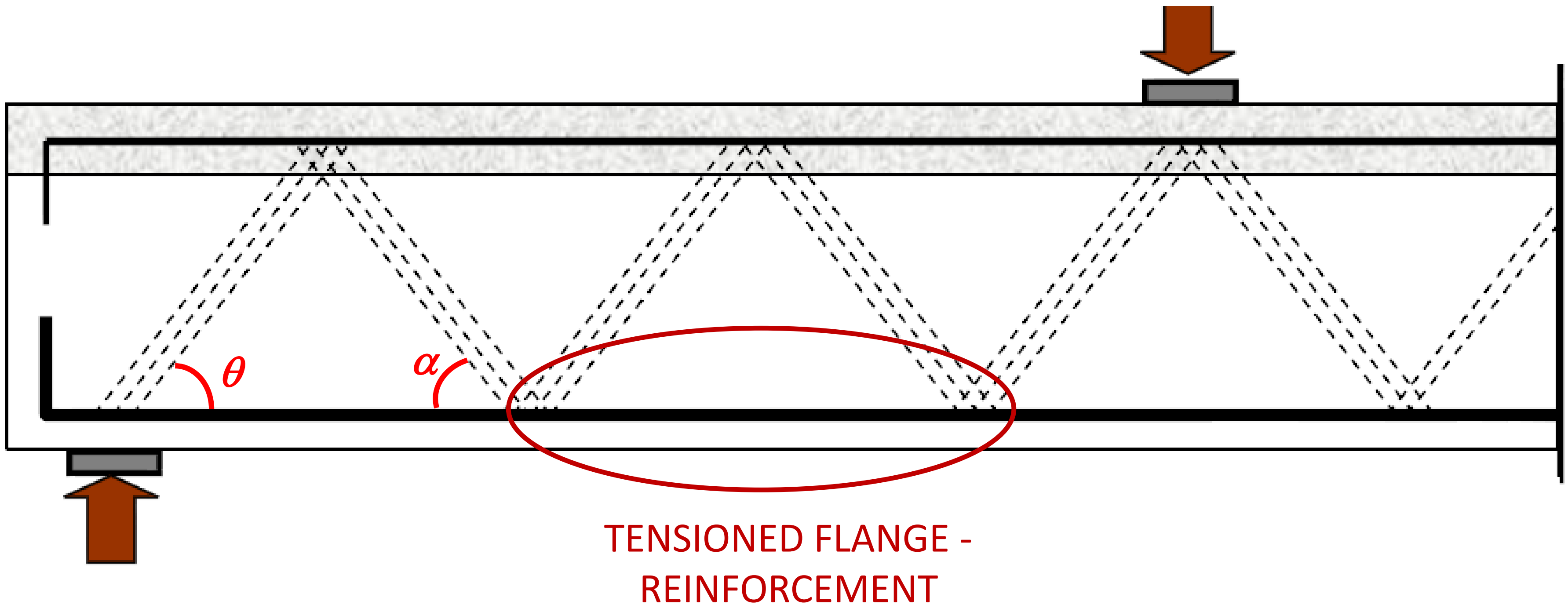
Design for shear force / Calculul la forţă tăietoare

Strut-and-tie models used for shear capacity calculation of RC beams WITHOUT SHEAR REINFORCEMENT



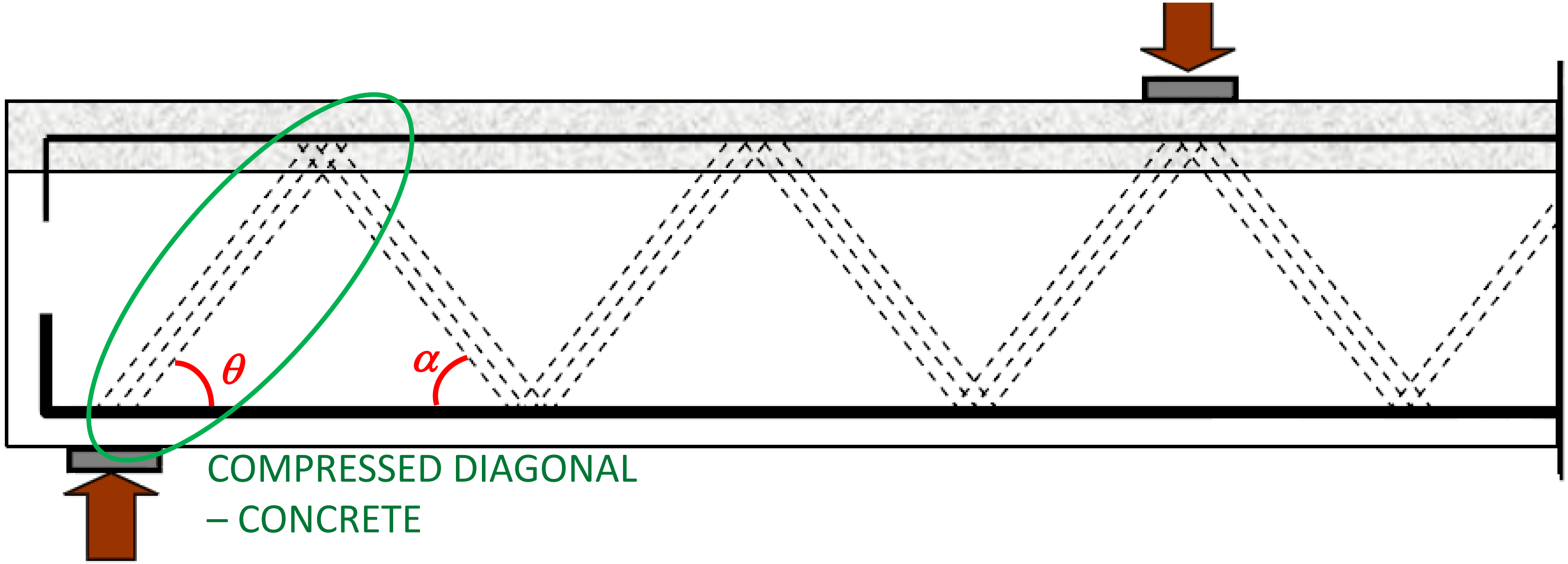
Design for shear force / Calculul la forţă tăietoare

Strut-and-tie models used for shear capacity calculation of RC beams WITHOUT SHEAR REINFORCEMENT



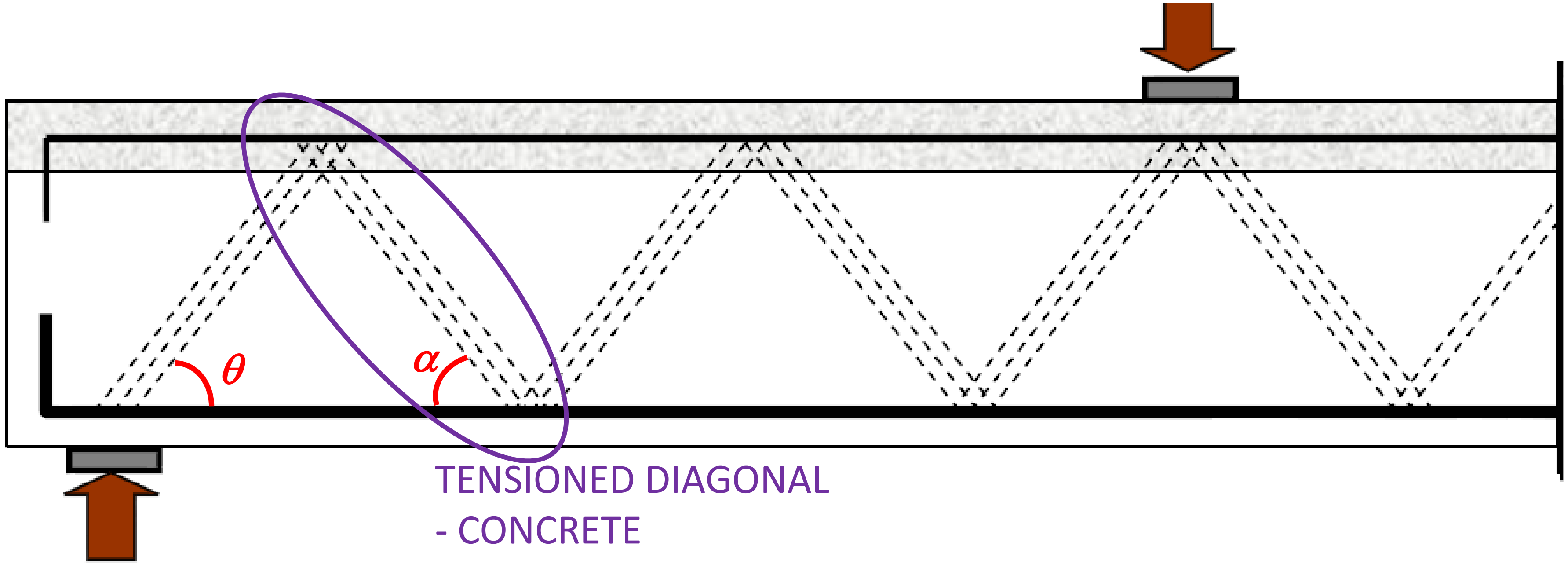
Design for shear force / Calculul la forţă tăietoare

Strut-and-tie models used for shear capacity calculation of RC beams WITHOUT SHEAR REINFORCEMENT



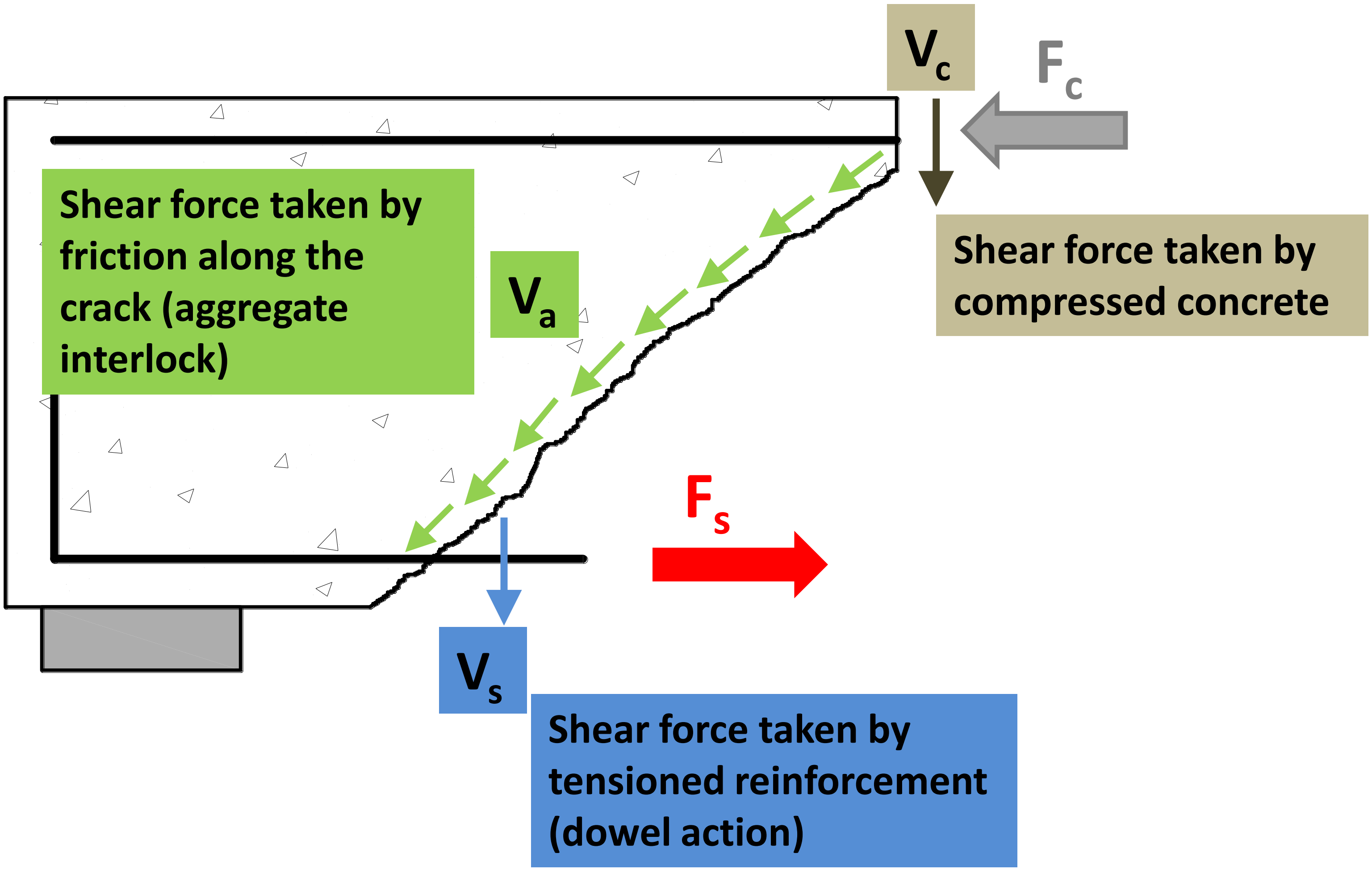
Design for shear force / Calculul la forţă tăietoare

Strut-and-tie models used for shear capacity calculation of RC beams WITHOUT SHEAR REINFORCEMENT



Design for shear force / Calculul la forţă tăietoare

FAILURE MODE OF THE ELEMENTS WITHOUT SHEAR REINFORCEMENT



→ **Shear force taken over by plain concrete**

$$V_{Rd,c} \approx V_c + V_a + V_s$$

Design for shear force / Calculul la forţă tăietoare

Design shear resistance of the member without shear reinforcement

$$V_{Rd,c} = \max\begin{pmatrix}\left[C_{Rd,c}k(100\rho_l f_{ck})^{1/3} + k_1\sigma_{cp}\right]b_w d \\ (v_{min} + k_1\sigma_{cp})b_w d\end{pmatrix}$$

where

$C_{Rd,c} = 0{,}18/\gamma_c$ - from A.N.

$k = 1 + \sqrt{\frac{200}{d}} \leq 2$ $\rho_l = \frac{A_{sl}}{b_w d} \leq 0.02$

$k_1 = 0{,}15$ - from A.N.

$\sigma_{cp} = N_{Ed}/A_c < 0{,}2f_{cd}$

N_{Ed} - axial force in section ($N_{Ed} > 0$ for compression)

$v_{min} = 0{,}035k^{3/2} \cdot f_{ck}^{1/2}$

Design for shear force / Calculul la forţă tăietoare

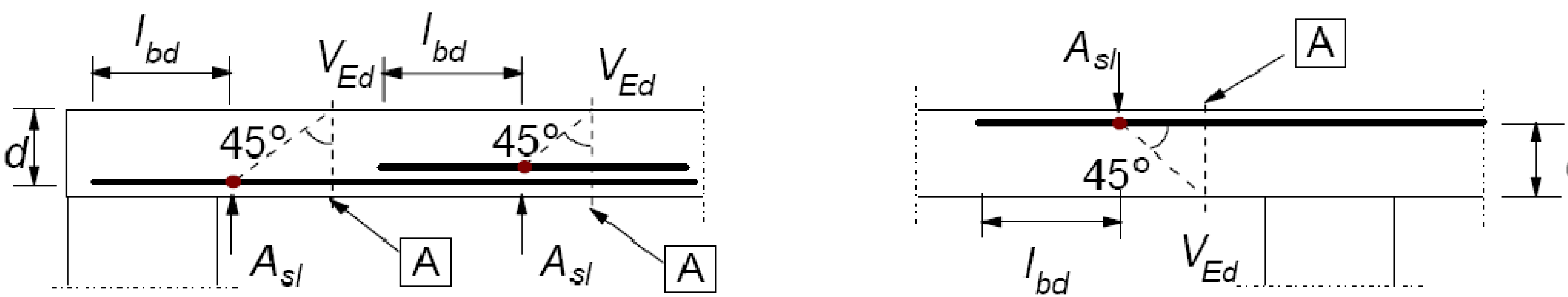
Design shear resistance of the member without shear reinforcement

$$V_{Rd,c} = \max\begin{pmatrix} \left[C_{Rd,c}k(100\rho_l f_{ck})^{1/3} + k_1\sigma_{cp}\right]b_w d \\ (v_{min} + k_1\sigma_{cp})b_w d \end{pmatrix}$$

Unde

$$\rho_l = \frac{A_{sl}}{b_w d} \leq 0.02$$

aria secțiunii armăturilor întinse, prelungite pe o lungime ≥ (l_{bd} + d) dincolo de secțiunea considerată



A - secțiunea considerată

Design for shear force / Calculul la forţă tăietoare

Design shear resistance of the member without shear reinforcement

$$V_{Rd,c} = \max \begin{pmatrix} \left[C_{Rd,c} k (100 \rho_l f_{ck})^{1/3} + k_1 \sigma_{cp}\right] b_w d \\ (v_{min} + k_1 \sigma_{cp}) b_w d \end{pmatrix}$$

By neglecting the effect of the axial force and the contribution of longitudinal reinforcement, a cover value of the shear resistance will be obtained

$$\sigma_{cp} = 0 \qquad \rho_l = 0$$

$$\boldsymbol{V_{Rd,c} = 0,035 \cdot k^{3/2} \cdot f_{ck}^{1/2} \cdot b_w \cdot d}$$

Design for shear force / Calculul la forţă tăietoare

IF

$$V_{Ed} \leq V_{Rd,c}$$

→ NO SHEAR REINFORCEMENT IS NEEDED

IF

$$V_{Ed} > V_{Rd,c}$$

→ NECESSARY TO PROVIDE/DESIGN SHEAR REINFORCEMENT

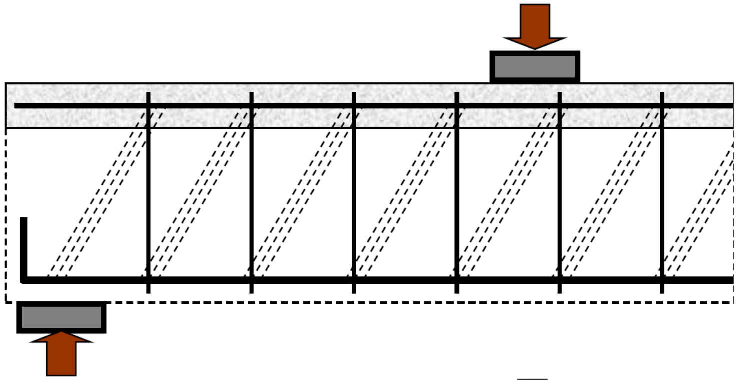
10.4 ELEMENTS REQUIRING SHEAR REINFORCEMENT

Elements requiring shear reinforcement / Elemente care necesită armătură la forţă tăietoare

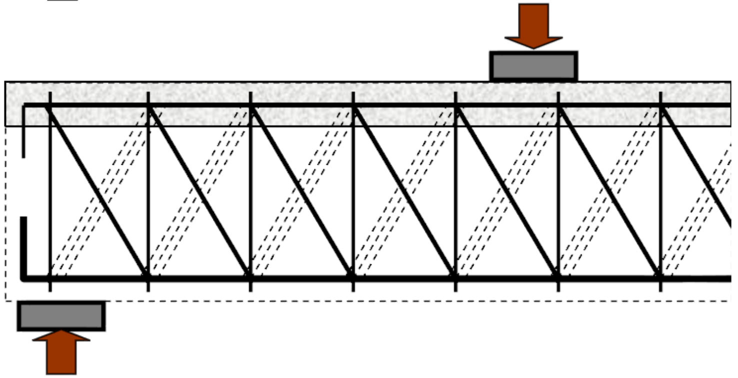
IF

$V_{Ed} > V_{Rd,c}$ → **IS NECESSARY TO PROVIDE SHEAR REINFORCEMENT**

DESIGN SCHEME:



→ with stirrups

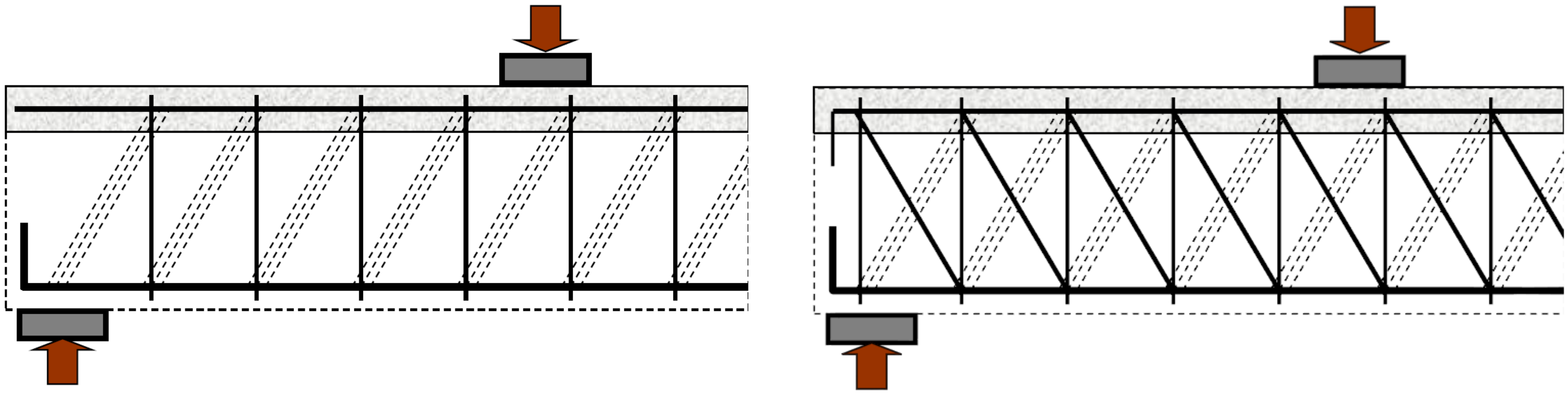


→ with stirrups and inclined reinforcements

(Dr. Kovács I., DE)

Elements requiring shear reinforcement / Elemente care necesită armătură la forţă tăietoare

FAILURE MODES



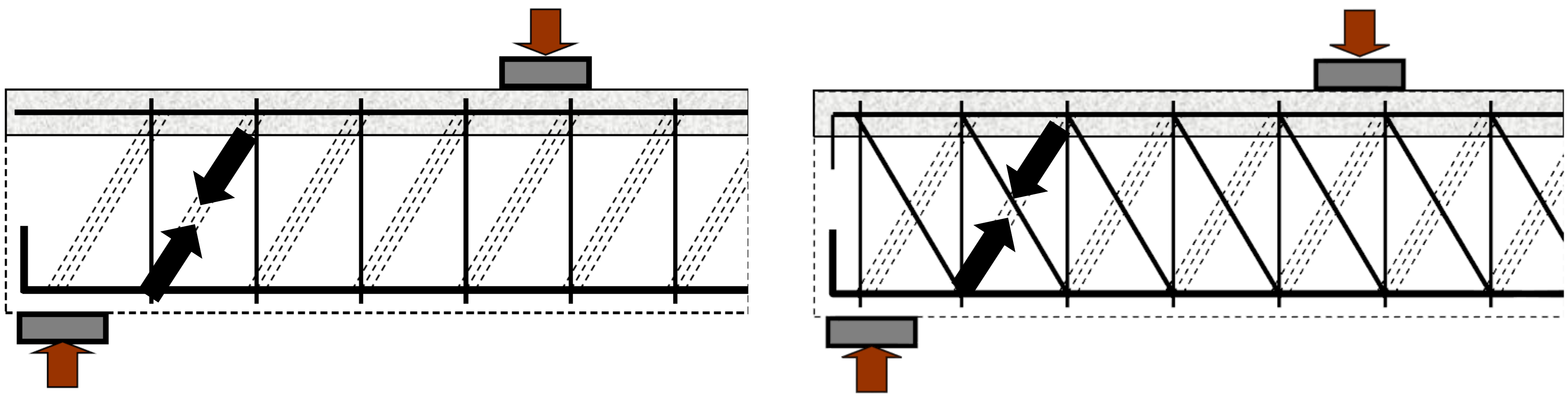
(Dr. Kovács I., DE)

Elements requiring shear reinforcement / Elemente care necesită armătură la forţă tăietoare

FAILURE MODES

1. CRUSHING OF COMPRESSED CHORD (CONCRETE)

$\sigma_{cd} = f_{cd}$ and $\sigma_{sw} < f_{ywd}$ → $V_{Rd} = V_{Rd,max}$



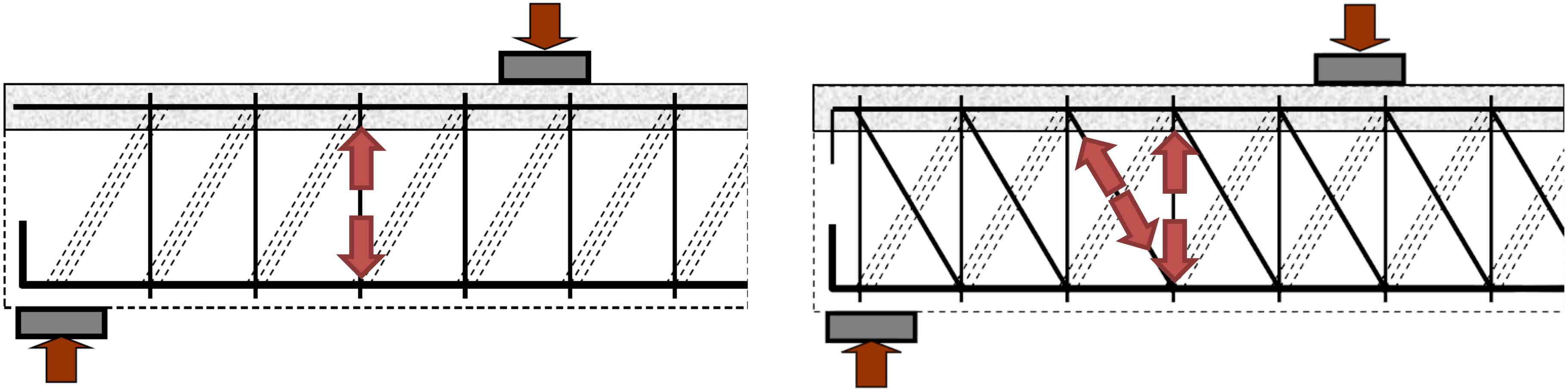
(Dr. Kovács I., DE)

Elements requiring shear reinforcement / Elemente care necesită armătură la forță tăietoare

FAILURE MODES

2. SHEAR REINFORCEMENT YIELDING

$\sigma_{sw} = f_{ywd}$ and $\sigma_{cd} < f_{cd}$ → $V_{Rd} = V_{Rd,s}$



(Dr. Kovács I., DE)

Elements requiring shear reinforcement / Elemente care necesită armătură la forţă tăietoare

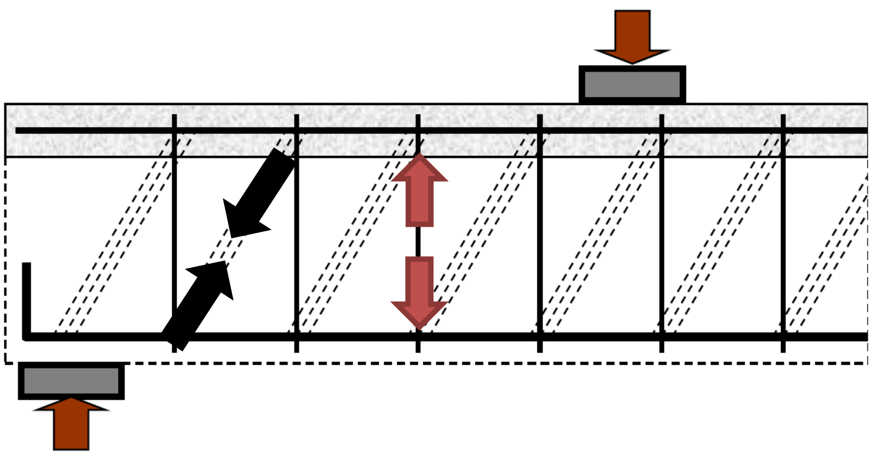
FAILURE MODES

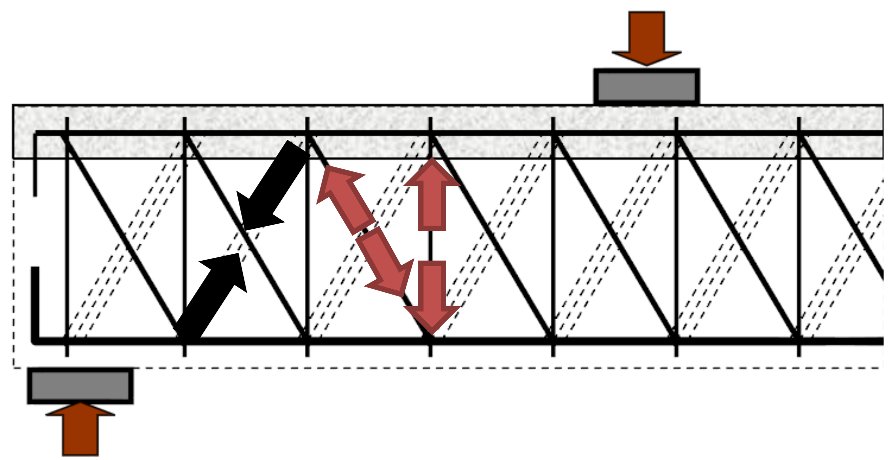
1. CRUSHING OF COMPRESSED CHORD (CONCRETE)

and → $V_{Rd} = V_{Rd,max}$

2. SHEAR REINFORCEMENT YIELDING

$\sigma_{sw} = f_{ywd}$ and $\sigma_{cd} < f_{cd}$ → $V_{Rd} = V_{Rd,s}$





Elements requiring shear reinforcement / Elemente care necesită armătură la forţă tăietoare

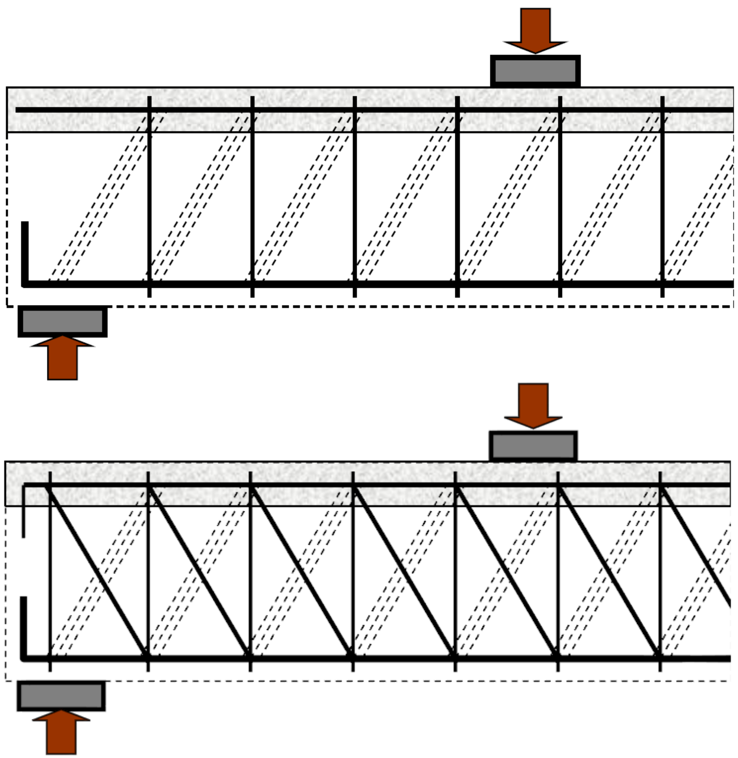
RESISTANCE OF THE CONCRETE AND REINFORCEMENT IS NOT SUMMED!

Must respect the conditions:

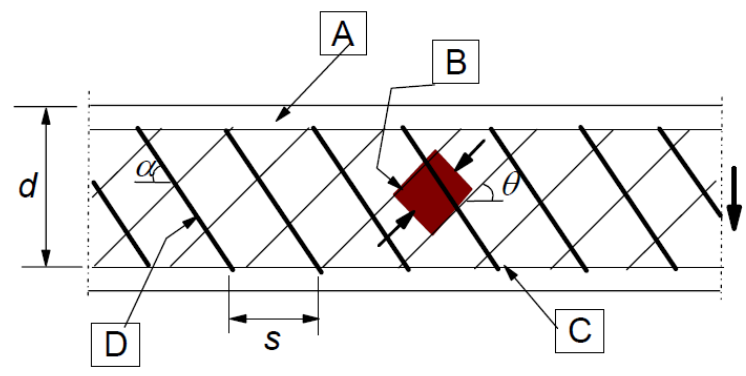
$$V_{Ed} \leq V_{Rd,max}$$

$$V_{Ed} \leq V_{Rd,s}$$

Due to ductility reasons crushing of concrete must be avoided, so as first to reach transversal reinforcement yielding and than concrete crushing

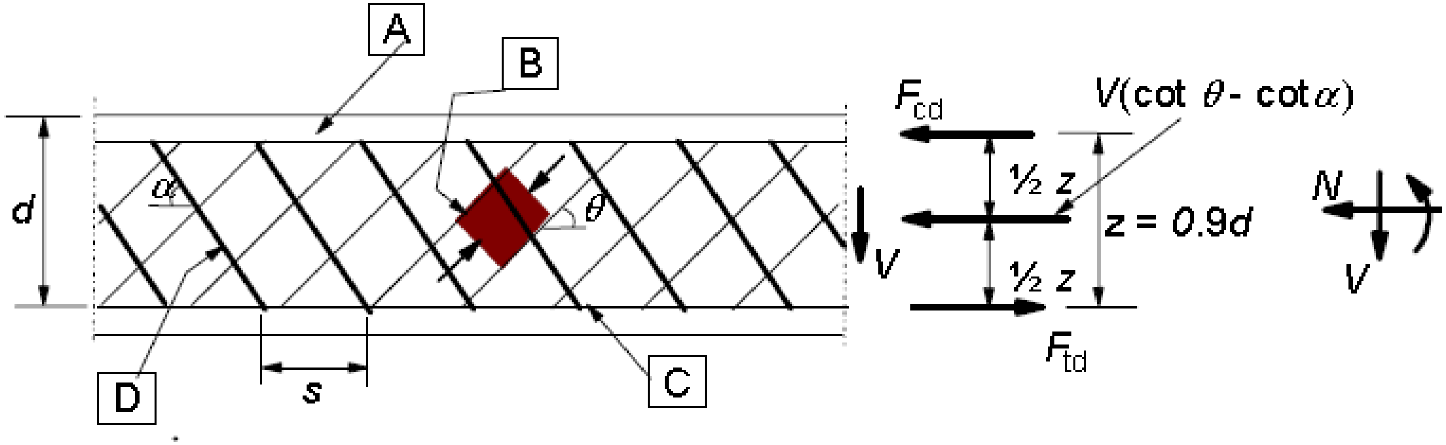


$$V_{Rd} = \min(V_{Rd,s}; V_{Rd,max})$$



Elements requiring shear reinforcement / Elemente care necesită armătură la forţă tăietoare

DESIGN MODEL

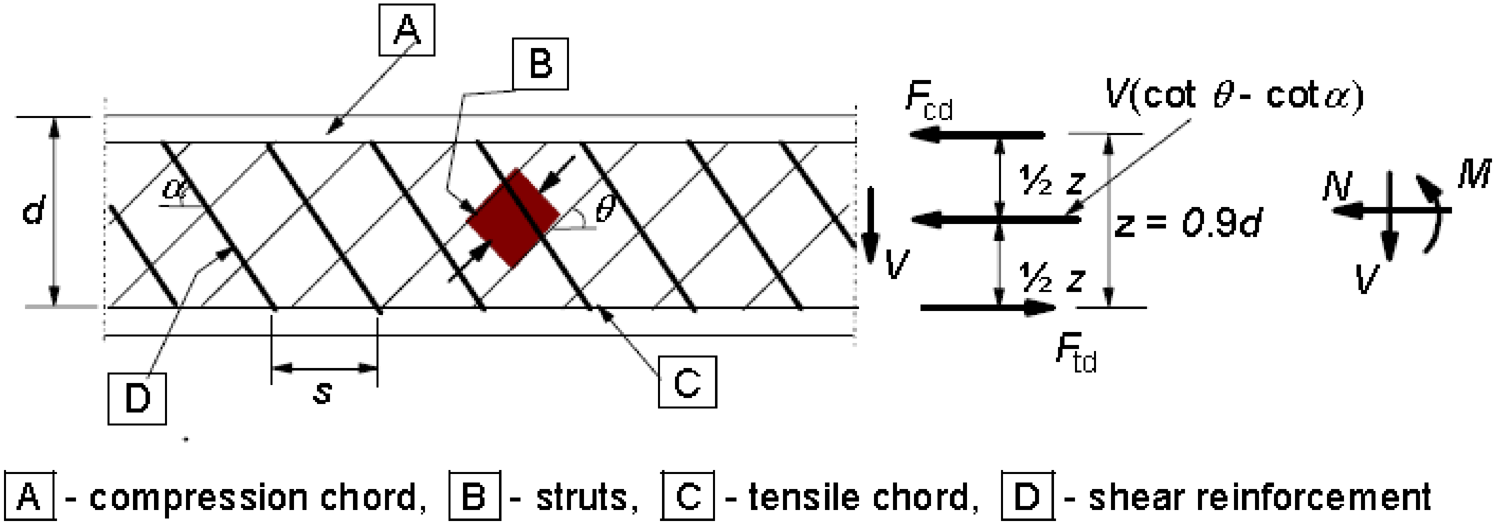


A - compression chord, B - struts, C - tensile chord, D - shear reinforcement

α	is the angle between shear reinforcement and the beam axis perpendicular to the shear force (measured positive as shown in Figure 6.5)
θ	is the angle between the concrete compression strut and the beam axis perpendicular to the shear force
F_{td}	is the design value of the tensile force in the longitudinal reinforcement
F_{cd}	is the design value of the concrete compression force in the direction of the longitudinal member axis.
b_w	is the minimum width between tension and compression chords
z	is the inner lever arm, for a member with constant depth, corresponding to the bending moment in the element under consideration. In the shear analysis of reinforced concrete without axial force, the approximate value $z = 0{,}9d$ may normally be used.

Elements requiring shear reinforcement / Elemente care necesită armătură la forţă tăietoare

DESIGN MODEL

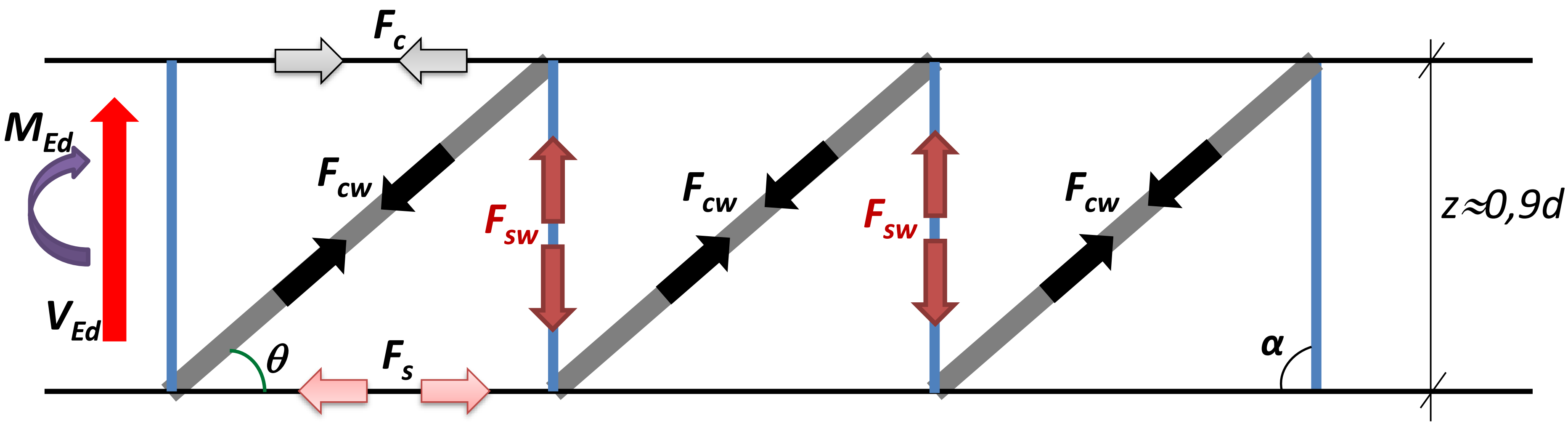


$$0,4 \le ctg\theta \le 2,5 \quad \Leftrightarrow \quad \theta = 21,8° \ldots 68,2°$$

A.N. $$\mathbf{1 \le ctg\theta \le 2,5 \quad \Leftrightarrow \quad \theta = 21,8° \ldots 45°}$$

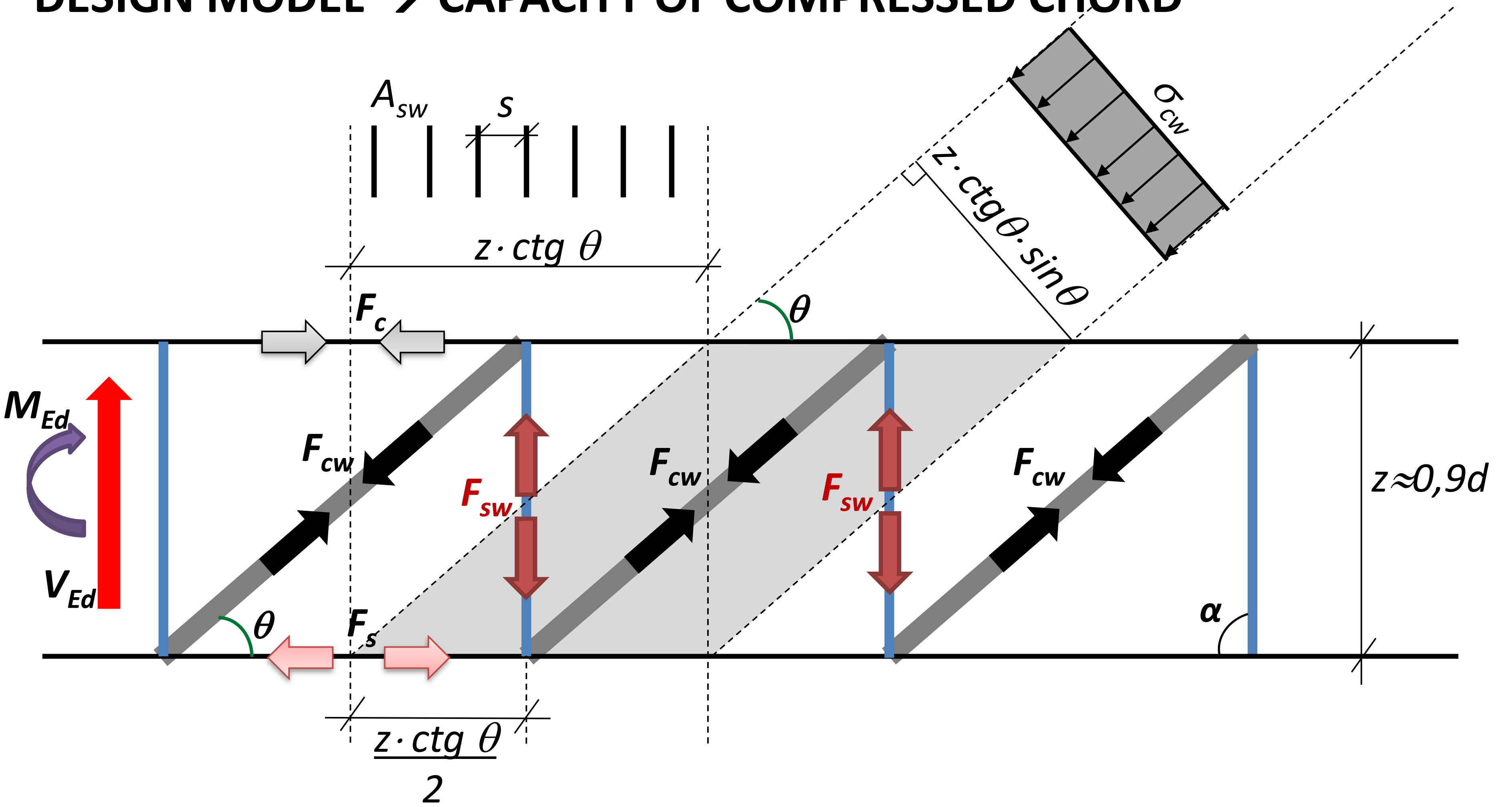
Elements requiring shear reinforcement / Elemente care necesită armătură la forţă tăietoare

DESIGN MODEL → WITH STIRRUPS



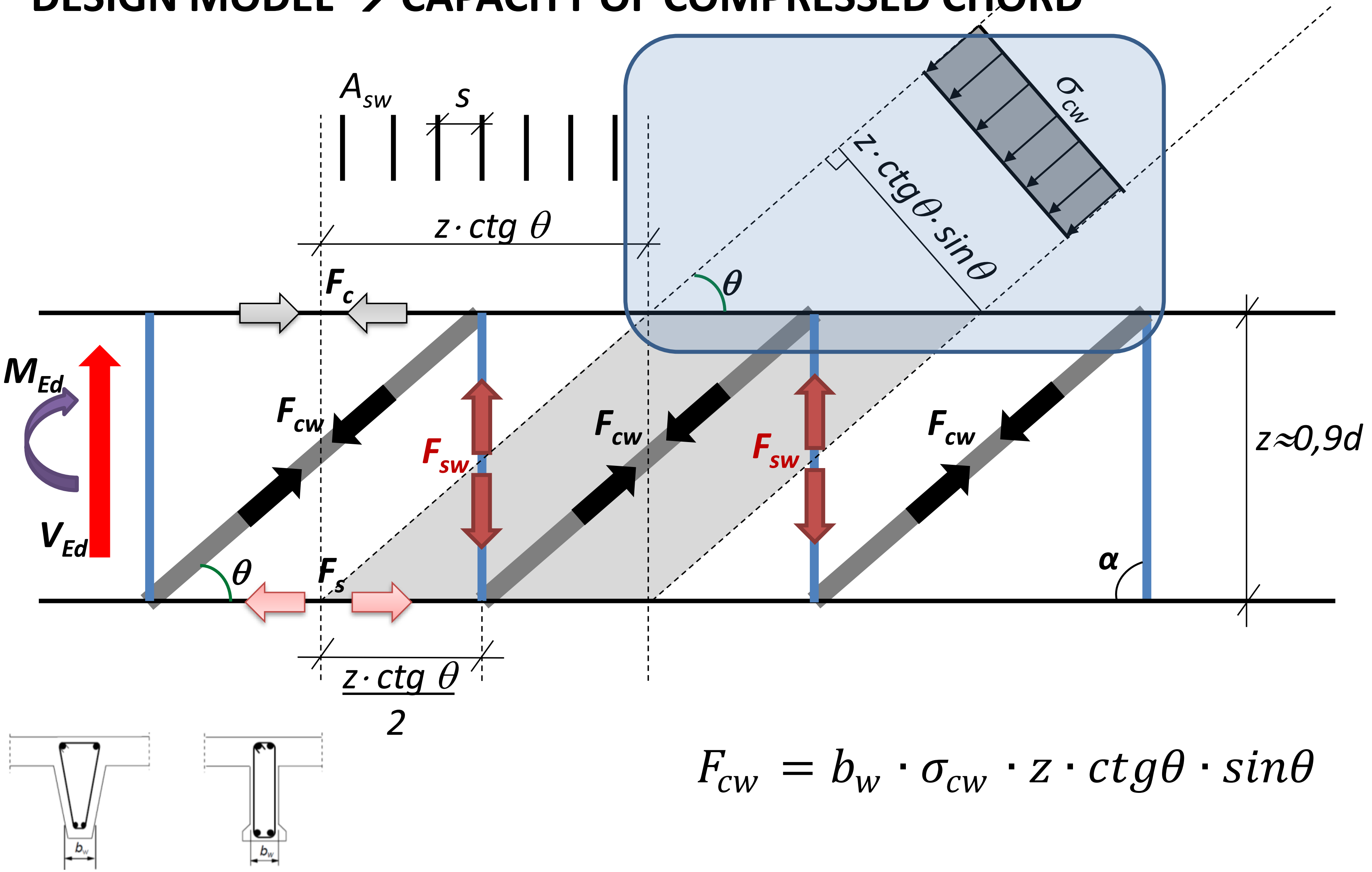
Elements requiring shear reinforcement / Elemente care necesită armătură la forță tăietoare

DESIGN MODEL → CAPACITY OF COMPRESSED CHORD



Elements requiring shear reinforcement / Elemente care necesită armătură la forță tăietoare

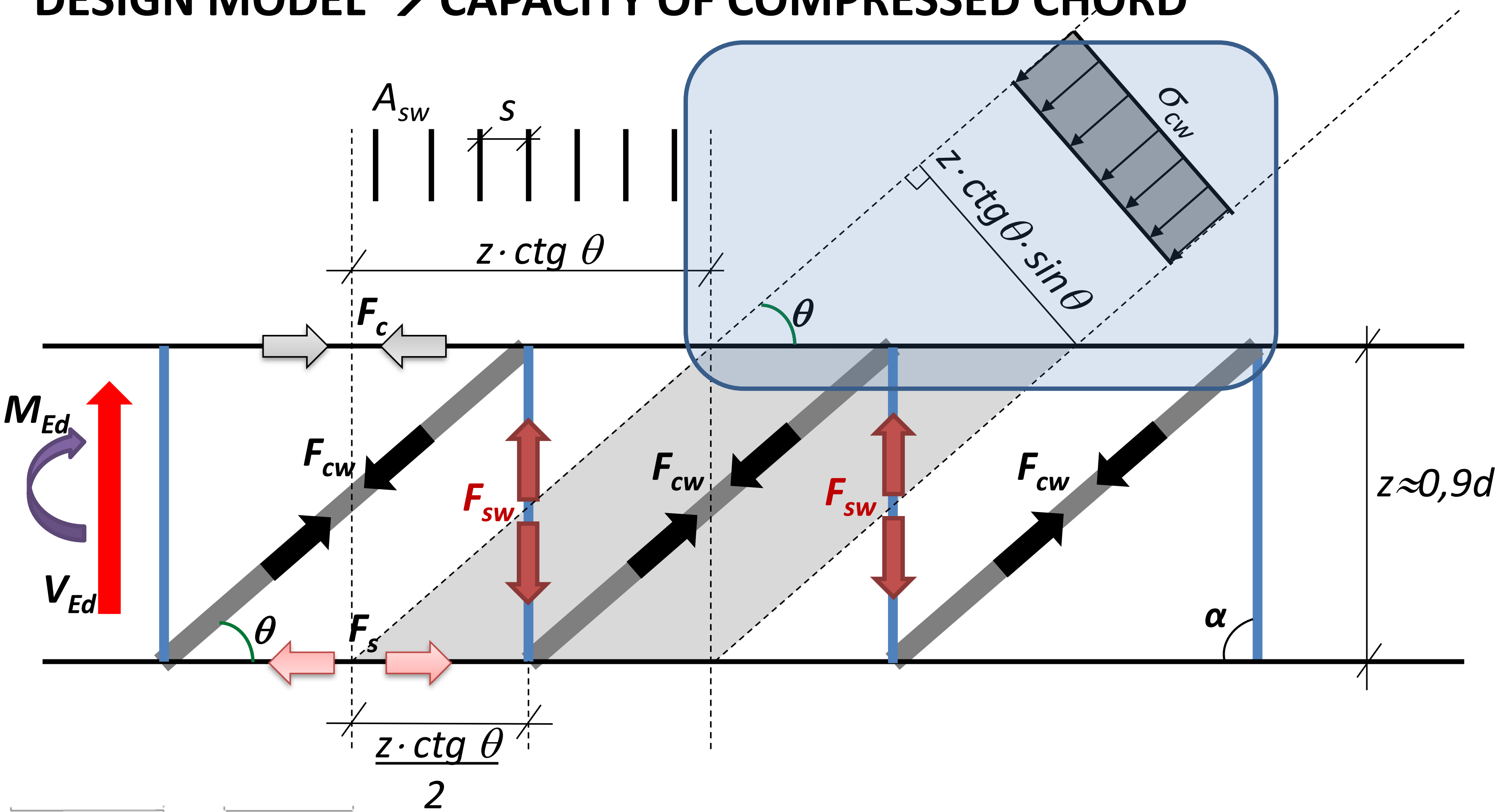
DESIGN MODEL → CAPACITY OF COMPRESSED CHORD

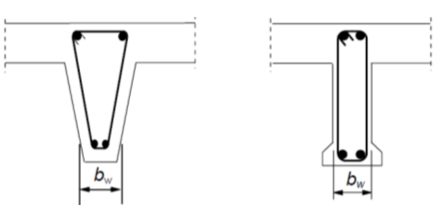


$$F_{cw} = b_w \cdot \sigma_{cw} \cdot z \cdot ctg\theta \cdot \sin\theta$$

Elements requiring shear reinforcement / Elemente care necesită armătură la forță tăietoare

DESIGN MODEL → CAPACITY OF COMPRESSED CHORD

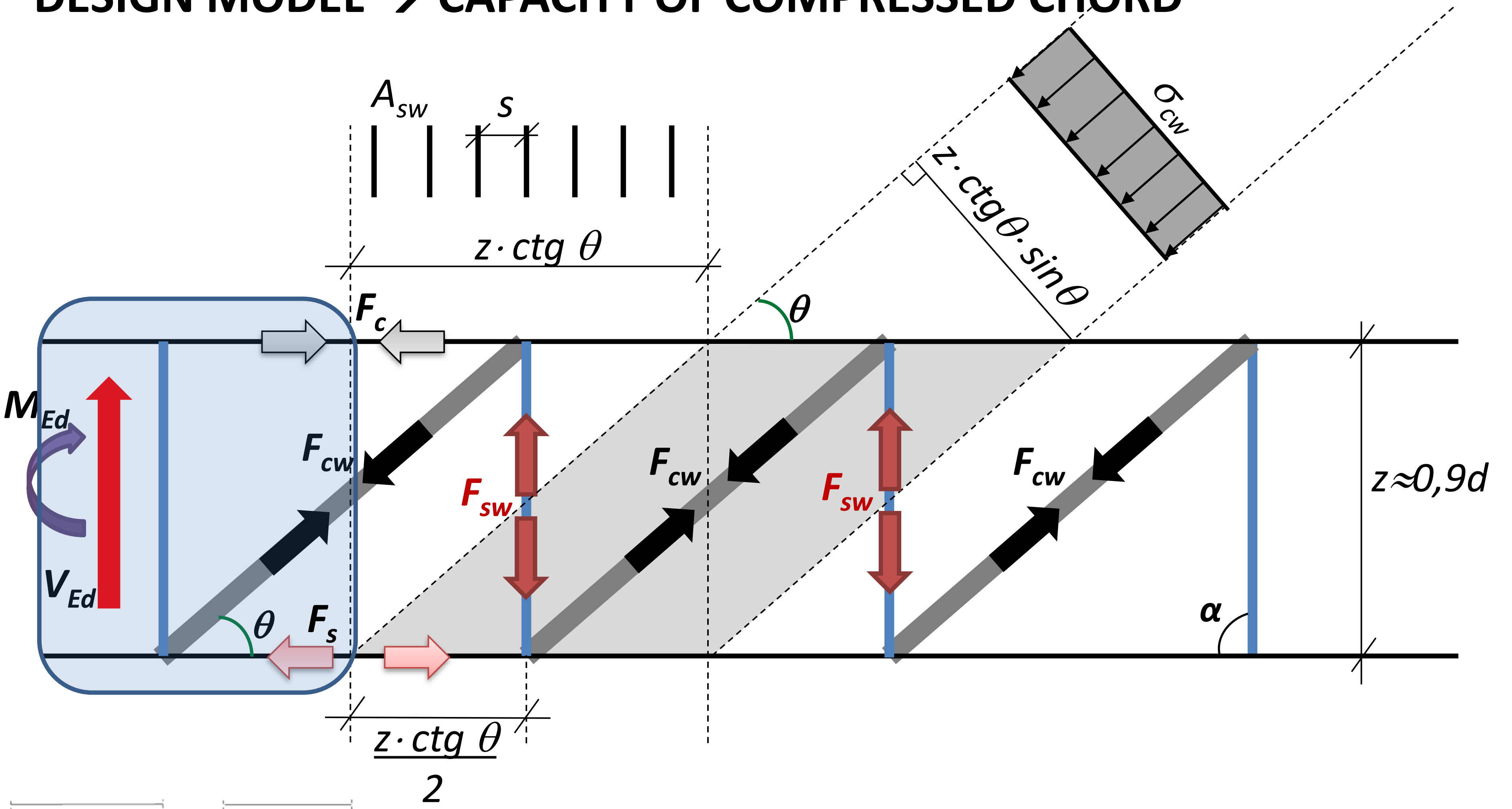


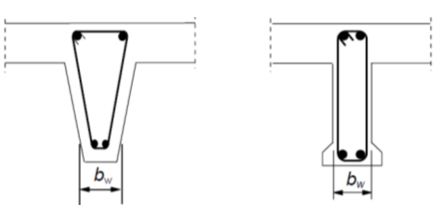


$$F_{cw} = b_w \cdot z \cdot \sigma_{cw} \cdot cos\theta$$

Elements requiring shear reinforcement / Elemente care necesită armătură la forță tăietoare

DESIGN MODEL → CAPACITY OF COMPRESSED CHORD

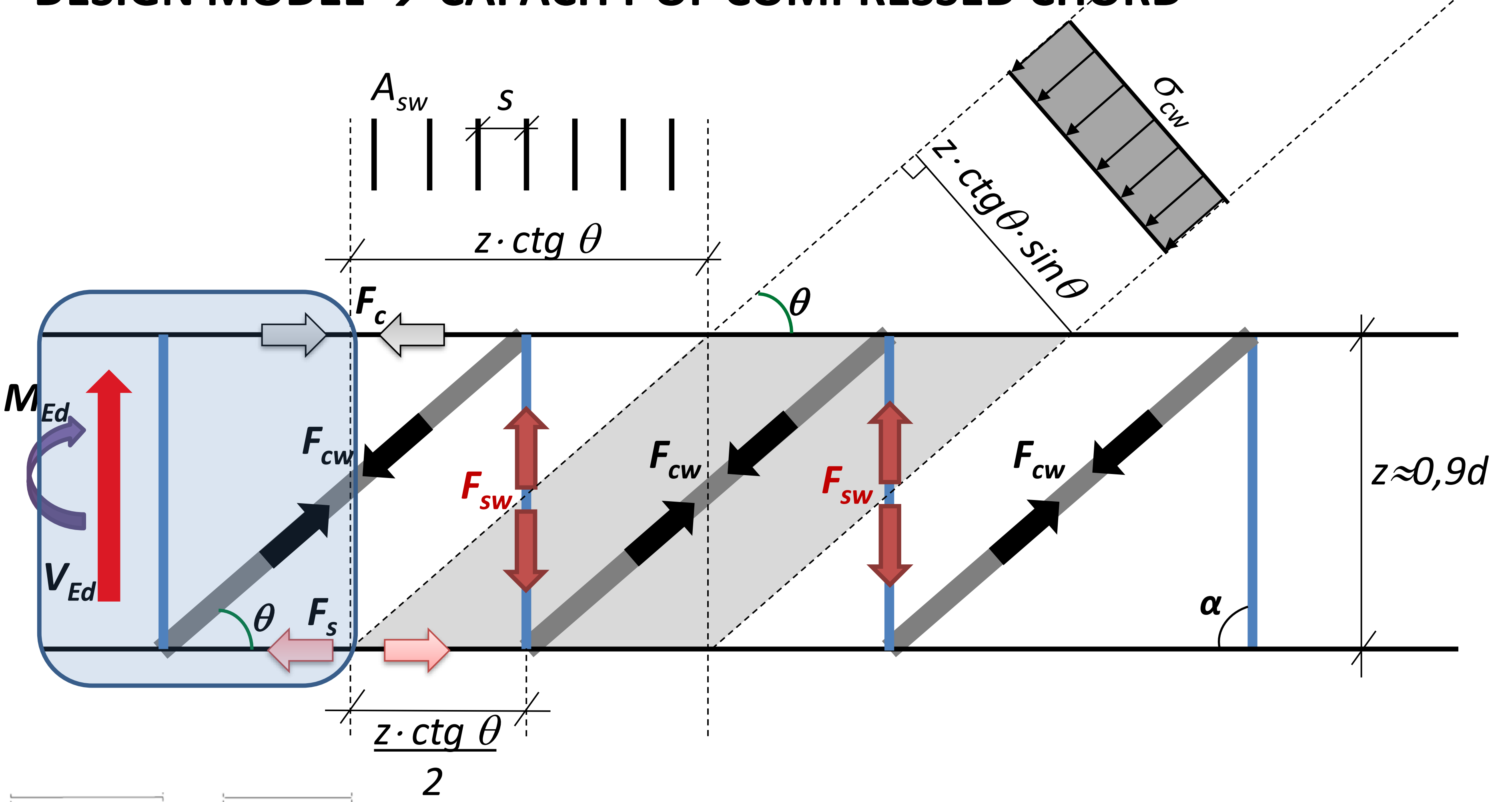


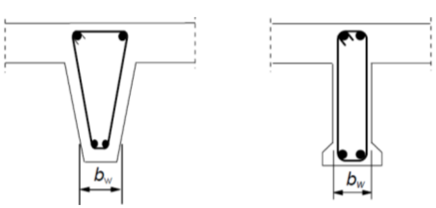


$$V_{Ed} = F_{cw} \cdot sin\theta$$

Elements requiring shear reinforcement / Elemente care necesită armătură la forţă tăietoare

DESIGN MODEL → CAPACITY OF COMPRESSED CHORD





$$V_{Ed} = b_w \cdot z \cdot \sigma_{cw} \cdot \cos\theta \cdot \sin\theta$$

Elements requiring shear reinforcement / Elemente care necesită armătură la forţă tăietoare

THE MAXIMUM CAPACITY OF THE COMPRESSED CHORD ($V_{Rd,max}$)

$$\sigma_{cw} = \alpha_{cw} \nu f_{cd}$$

(reduction of concrete strength)

$$\Rightarrow \quad V_{Rd,max} = \alpha_{cw} b_w \cdot z \cdot \nu_1 \cdot f_{cd} sin\theta cos\theta$$

where

α_{cw} - coefficient taking account of the state of the stress in the compression chord

$\alpha_{cw}=1$ for non-prestressed structures

$\alpha_{cw}>1$ for prestressed structures

ν_1 - is a strength reduction factor for concrete cracked in shear

$$\nu_1 = \nu = 0{,}6\left(1 - \frac{f_{ck}}{250}\right) \qquad \text{(A.N.)}$$

$$sin\theta cos\theta = \frac{1}{tg\theta + ctg\theta}$$

Elements requiring shear reinforcement / Elemente care necesită armătură la forță tăietoare

THE MAXIMUM CAPACITY OF THE COMPRESSED CHORD ($V_{Rd,max}$)

$$\sigma_{cw} = \alpha_{cw} \nu f_{cd}$$

(reduction of concrete strength)

$$\Rightarrow \quad V_{Rd,max} = \alpha_{cw} b_w \cdot z \cdot \nu_1 \cdot f_{cd} \sin\theta\cos\theta$$

where

α_{cw} - coefficient taking account of the state of the stress in the compression chord

α_{cw}=1 for non-prestressed structures

α_{cw}>1 for prestressed structures

ν_1 - is a strength reduction factor for concrete cracked in shear

$$\nu_1 = \nu = 0{,}6\left(1 - \frac{f_{ck}}{250}\right) \quad \text{(A.N.)}$$

$$\sin\theta\cos\theta = \frac{1}{tg\theta + ctg\theta}$$

Elements requiring shear reinforcement / Elemente care necesită armătură la forță tăietoare

THE MAXIMUM CAPACITY OF THE COMPRESSED CHORD ($V_{Rd,max}$)

$$\sigma_{cw} = f_{cd}$$

$$\Rightarrow \qquad \boldsymbol{V_{Rd,max} = \alpha_{cw} b_w \cdot z \cdot \nu_1 \cdot f_{cd} / (tg\theta + ctg\theta)}$$

where

α_{cw} - coefficient taking account of the state of the stress in the compression chord

- $\alpha_{cw}=1$ for non-prestressed structures
- $\alpha_{cw}>1$ for prestressed structures

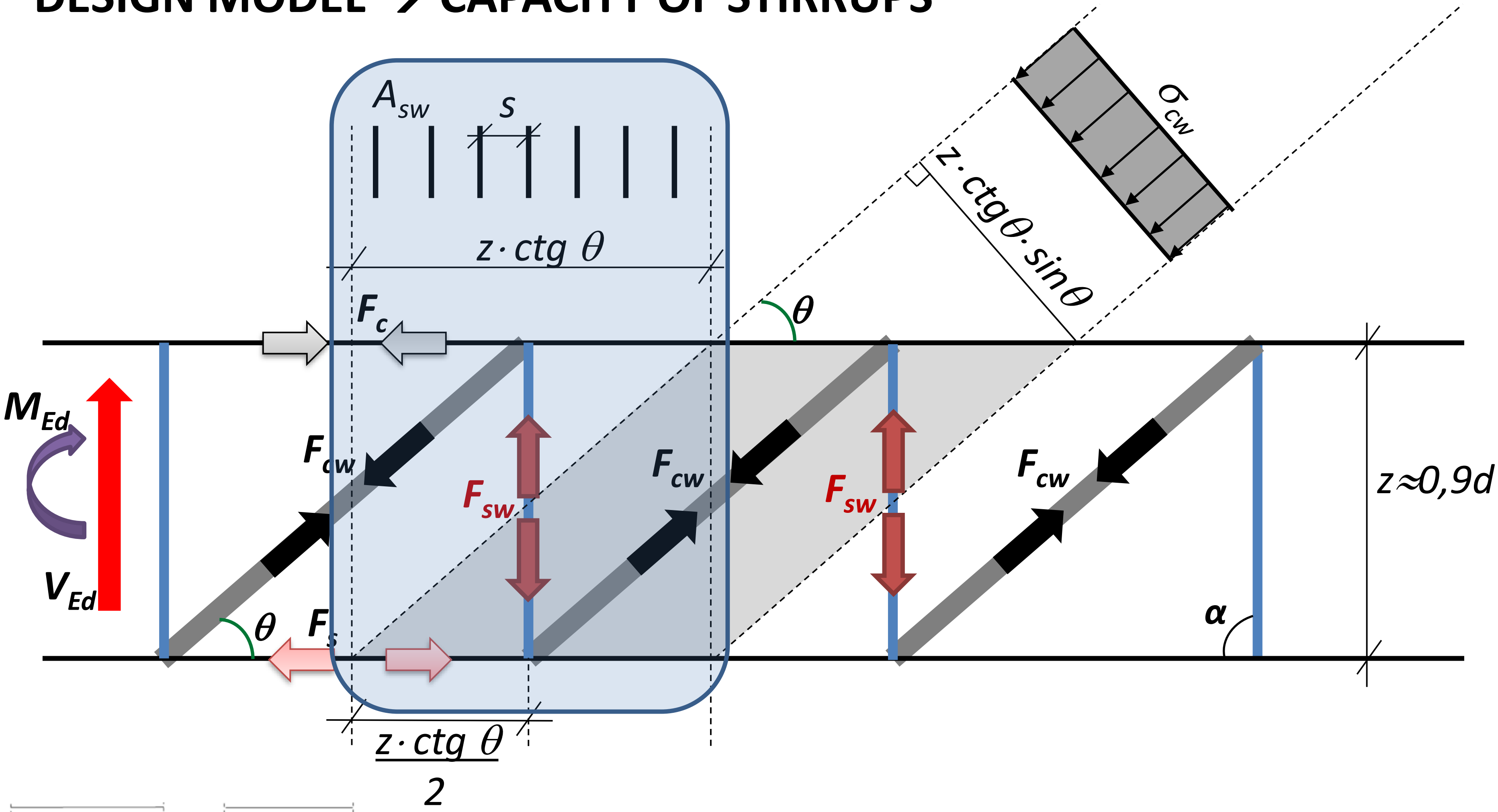
ν_1 - is a strength reduction factor for concrete cracked in shear

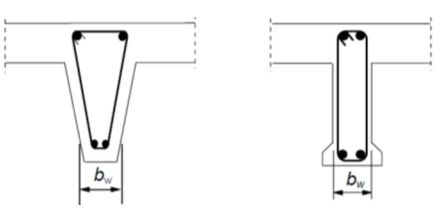
$$\nu_1 = \nu = 0{,}6\left(1 - \frac{f_{ck}}{250}\right) \qquad \text{(A.N.)}$$

$$sin\theta cos\theta = \frac{1}{tg\theta + ctg\theta}$$

Elements requiring shear reinforcement / Elemente care necesită armătură la forţă tăietoare

DESIGN MODEL → CAPACITY OF STIRRUPS

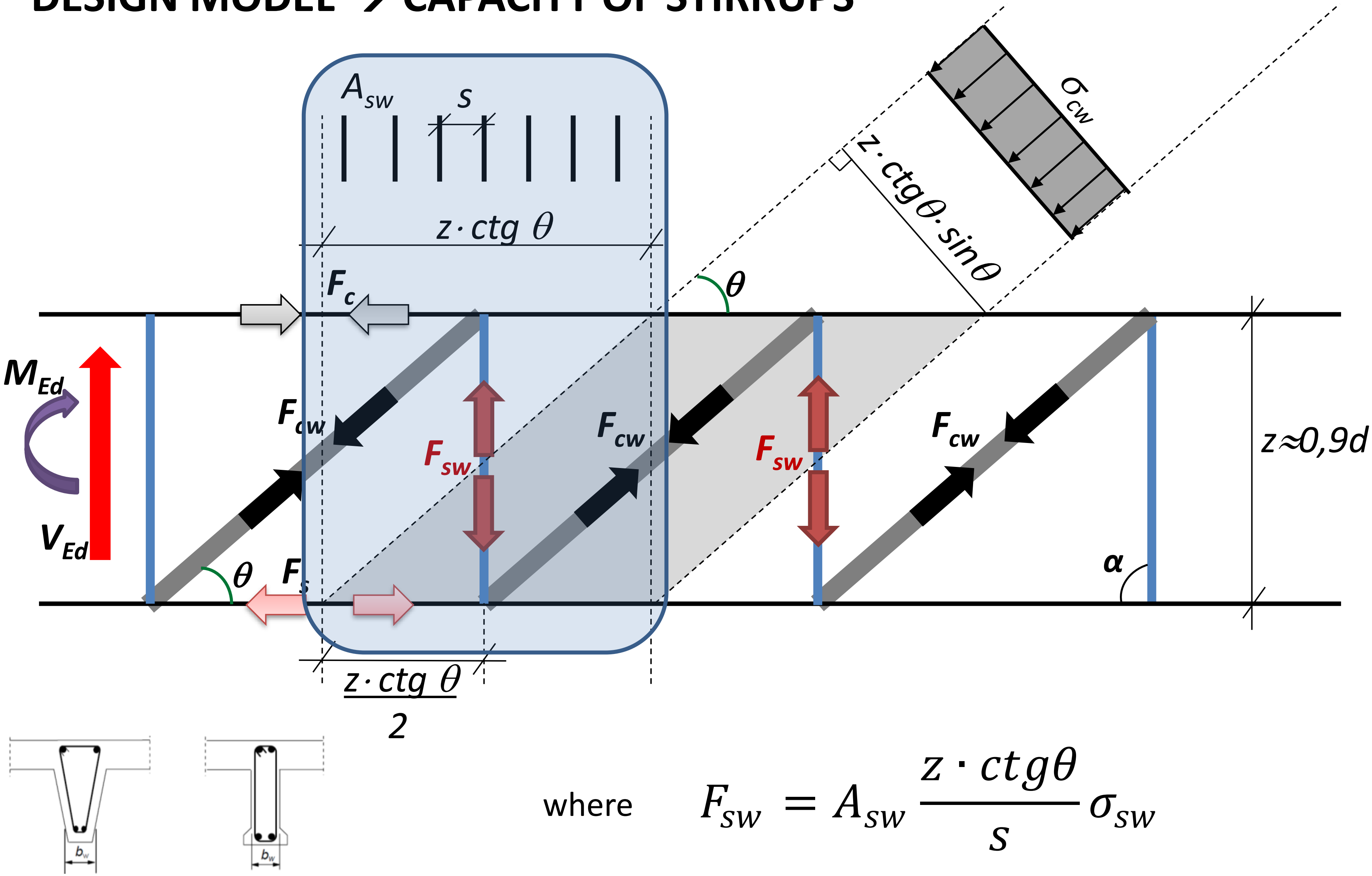




$$V_{Ed} = F_{sw}$$

Elements requiring shear reinforcement / Elemente care necesită armătură la forţă tăietoare

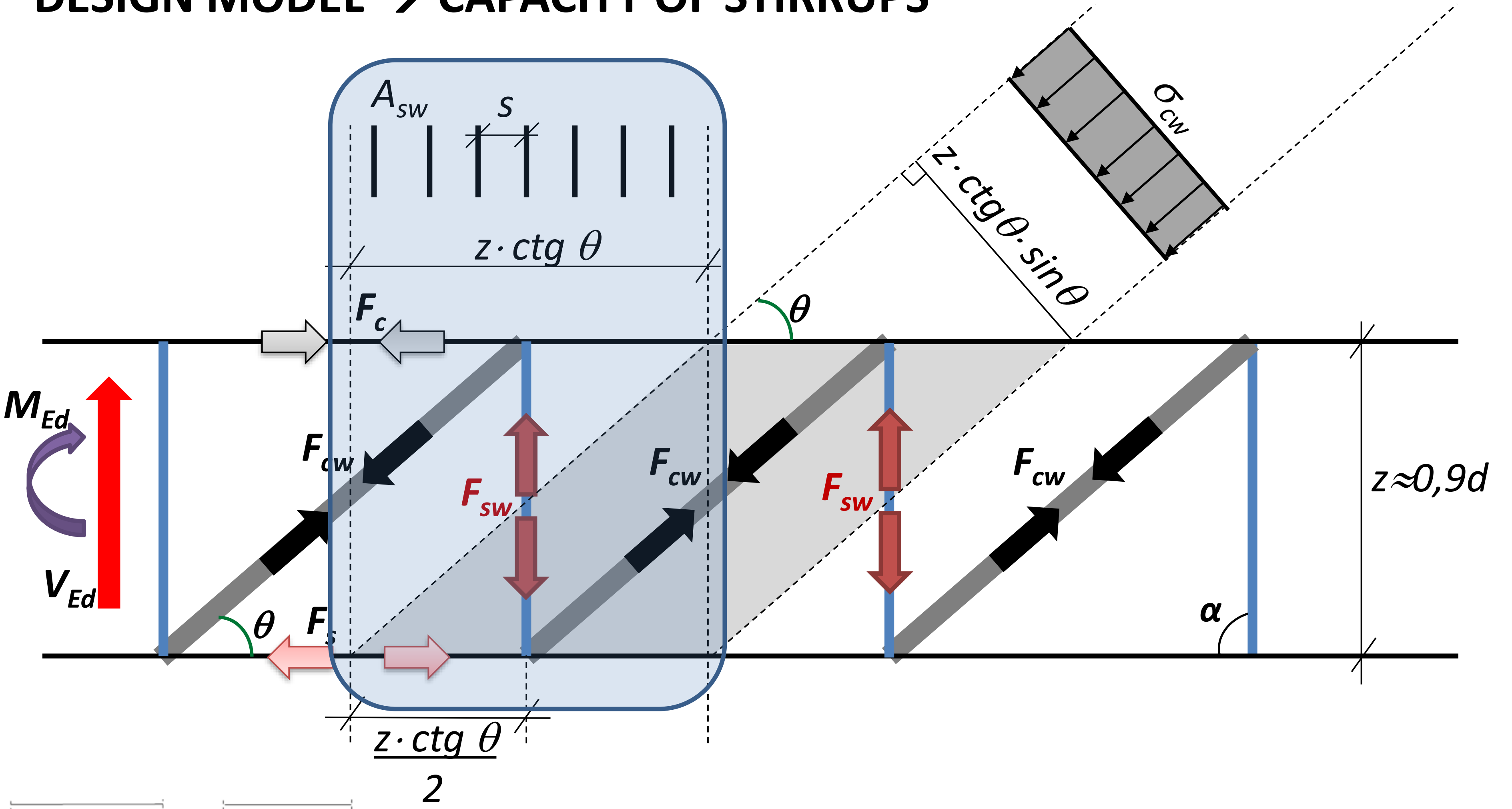
DESIGN MODEL → CAPACITY OF STIRRUPS

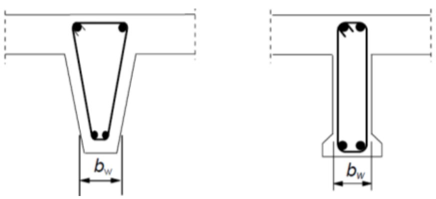


where $F_{sw} = A_{sw} \dfrac{z \cdot ctg\theta}{s} \sigma_{sw}$

Elements requiring shear reinforcement / Elemente care necesită armătură la forță tăietoare

DESIGN MODEL → CAPACITY OF STIRRUPS





$$\Rightarrow \qquad V_{Ed} = A_{sw} \frac{z \cdot ctg\theta}{s} \sigma_{sw}$$

Elements requiring shear reinforcement / Elemente care necesită armătură la forţă tăietoare

SHEAR RESITANCE OF STIRRUPS ($V_{Rd,s}$)

$$\sigma_{sw} = f_{yw\,d}$$

$$\Rightarrow \quad V_{Rd,s} = \frac{A_{sw}}{s} \cdot z \cdot f_{ywd} \cdot ctg\theta$$

where

A_{sw} - cross-sectional area of the shear reinforcement

s - spacing of the stirrups

f_{ywd} - design yield strength of the shear reinforcement

DUCTILITY CONDITION IN CASE OF STIRRUPS

$$\Rightarrow \quad \boldsymbol{V_{Rd,s} \leq V_{Rd,max}}$$

$$\Rightarrow \quad \frac{A_{sw}}{s} \cdot z \cdot f_{ywd} \cdot ctg\theta \leq \alpha_{cw} b_w \cdot z \cdot \nu_1 \cdot f_{cd} / (tg\theta + ctg\theta)$$

$$\frac{A_{sw}}{s} \cdot f_{ywd} \leq b_w \cdot \nu_1 \cdot f_{cd} \cdot \frac{1}{1+ctg^2\theta}$$

→ Condiția limitează cantitatea de etrieri din condiții de ductilitate

For $\theta = 45° \rightarrow ctg\theta = 1$

$$\Rightarrow \quad \frac{A_{sw} \cdot f_{ywd}}{b_w \cdot s} \leq 0{,}5\nu_1 \cdot f_{cd}$$

Elements requiring shear reinforcement / Elemente care necesită armătură la forţă tăietoare

DIRECT DESIGN OF STIRRUPS

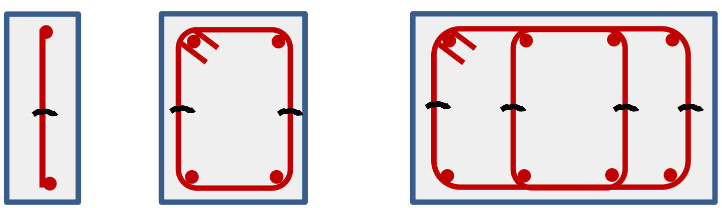
$$V_{Rd,s} = \frac{A_{sw}}{s} \cdot z \cdot f_{ywd} \cdot ctg\theta$$

the condition of rational use of stirrups $V_{Rd,s} = V_{Ed}$

$$\Rightarrow V_{Ed} = \frac{A_{sw}}{s} \cdot z \cdot f_{ywd} \cdot ctg\theta \qquad \Rightarrow \qquad \frac{A_{sw}}{s} = \frac{V_{Ed}}{z \cdot f_{ywd} \cdot ctg\theta}$$

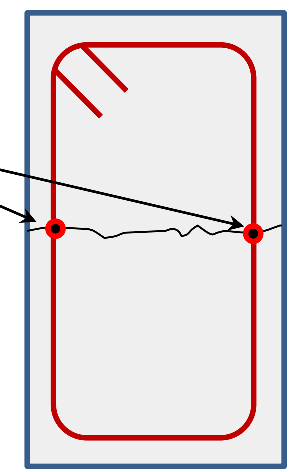
V1. Diameter of stirrups (ϕ_w) imposed $\Rightarrow$ ***A_{sw}=nA_s***

(n= no of branches!!!)



n=1 *n=2* *n=4*

$\Rightarrow$ **s** *(spacing)*

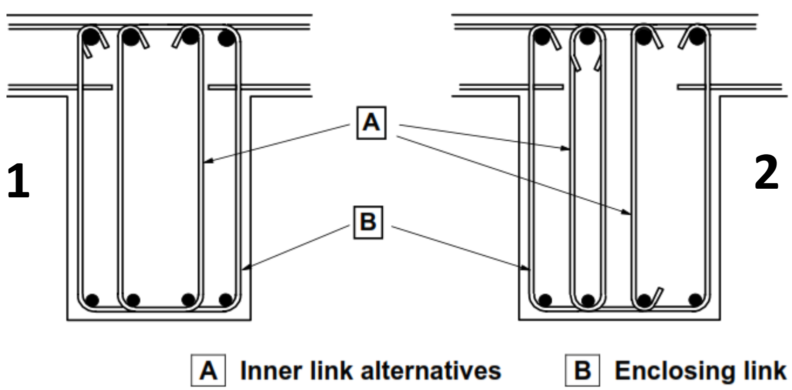


V2. Spacing of stirrups (s) imposed $\Rightarrow A_{sw}$ → used in seismic design, when in the plastic zones the maximum spacing is limited

Elements requiring shear reinforcement / Elemente care necesită armătură la forţă tăietoare

STIRRUPS

- OPEN (1, 2, 3) OR CLOSED (4, 5)
- 2 BRANCHES (3, 4) OR MORE BRANCHES (1, 2, 5)



Bar diameter: - ϕ

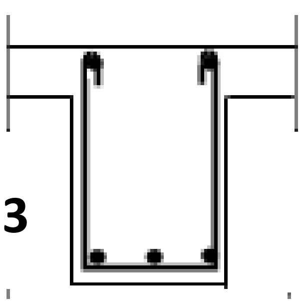
Bar cross section area: $A_\phi = \pi\phi^2/4$

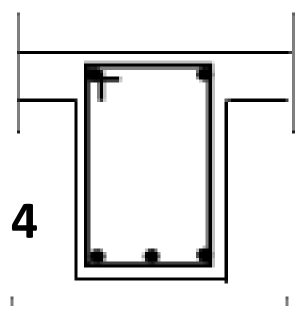
Number of the branches: n_{br}

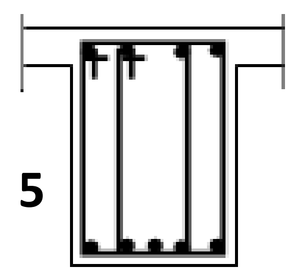
Area of shear reinforcement: $A_{sw} = n_{br}A_\phi$

Ratio of shear reinforcement: $\rho_w = \dfrac{A_{sw}}{s b_w} \geq \rho_{w,\min}$

$$\rho_{w,\min} = \frac{0{,}08\sqrt{f_{ck}}}{f_{yk}}$$







Elements requiring shear reinforcement / Elemente care necesită armătură la forţă tăietoare

SHEAR REZISTANCE OF ELEMENTS WITH INCLINED BARS

It is a minimum between

$$V_{Rd,s} = \frac{A_{sw}}{s} \cdot z \cdot f_{ywd}(ctg\theta + ctg\alpha)sin\alpha$$

and

$$V_{Rd,max} = \alpha_{cw} b_w \cdot z \cdot \nu_1 \cdot f_{cd} \frac{(ctg\theta + ctg\alpha)}{1 + ctg^2\theta}$$

And It must be met the limiting condition of the shear reinforcement ($ctg\theta = 1$):

$$\frac{A_{sw} \cdot f_{ywd}}{b_w \cdot s} \leq 0{,}5 \frac{\nu_1 \cdot f_{cd}}{sin\alpha}$$

Elements requiring shear reinforcement / Elemente care necesită armătură la forţă tăietoare

CHOOSING THE ANGLE θ

Assuming that $V_{Rd,max} = V_{Ed}$

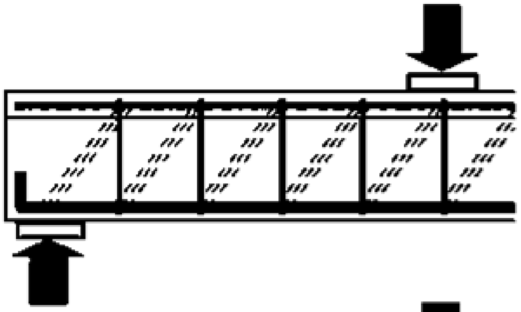
$$\Rightarrow \qquad \theta = 0{,}5 arcsin\left[\frac{v_{Ed}}{0{,}2\left(1-\frac{f_{ck}}{250}\right)f_{ck}}\right]$$

where $$v_{Ed} = \frac{V_{Ed}}{b_w z}$$

Elements requiring shear reinforcement / Elemente care necesită armătură la forţă tăietoare

SHEAR REZISTANCE OF ELEMENTS WITH STIRRUPS AND INCLINED BARS

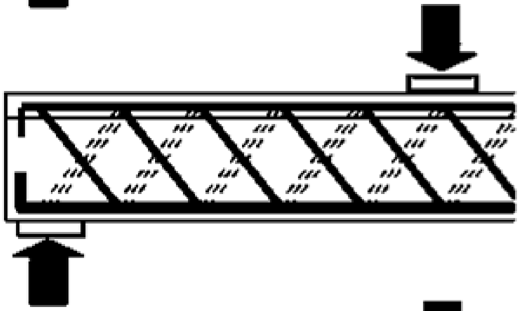
PARTICULAR CASES:



$\theta = 45^0$

$\alpha = 90^0$

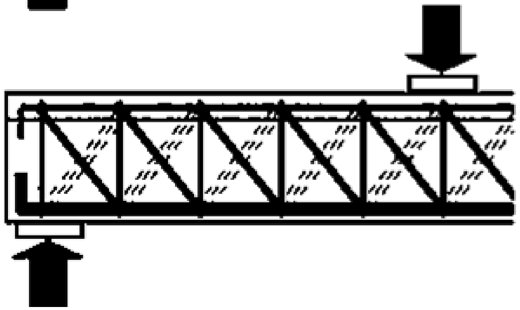
$$V_{Rd,s}^{s} = 0{,}9 \cdot d \cdot \frac{A_{sw} \cdot f_{ywd}}{s_s}$$



$\theta = 45^0$

$\alpha = 45^0$

$$V_{Rd,s}^{b} = 0{,}9 \cdot d \cdot \frac{A_{sw} \cdot f_{ywd}}{s_s} \cdot \sqrt{2}$$



$\theta = 45^0$

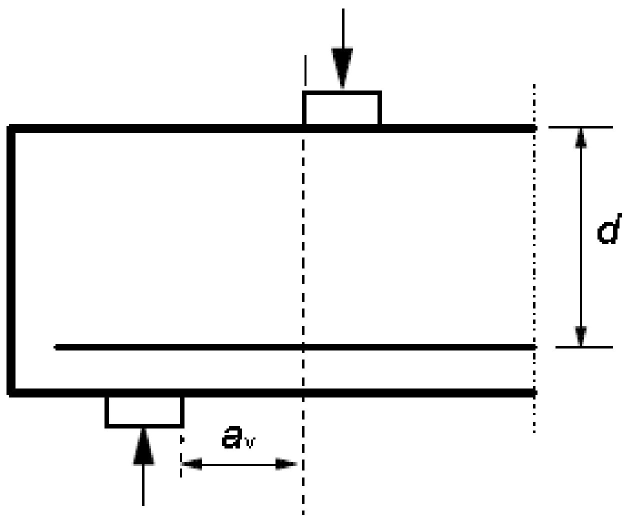
$$V_{Rd,s} = V_{Rd,s}^{s} + V_{Rd,s}^{b}$$

(Dr. Kovács I., DE)

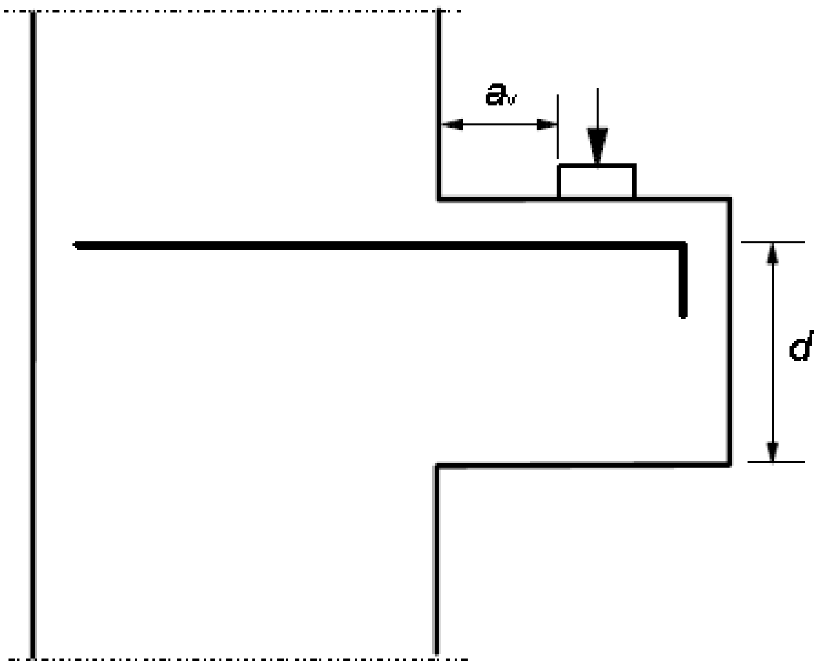
10.5 SPECIAL CASES IN SHEAR

Special cases of shear / Cazuri speciale la forţă tăietoare

LOADS NEAR SUPPORTS



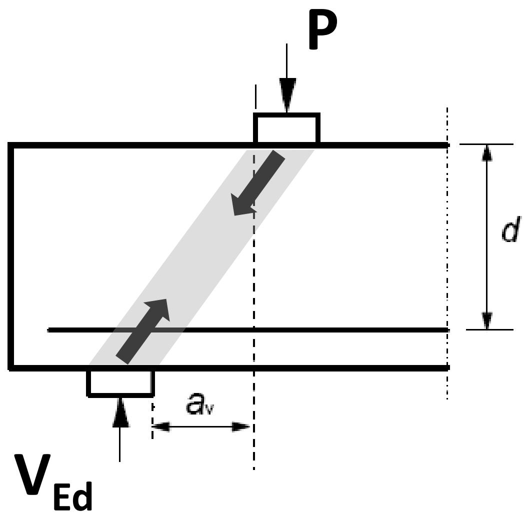
(a) Beam with direct support

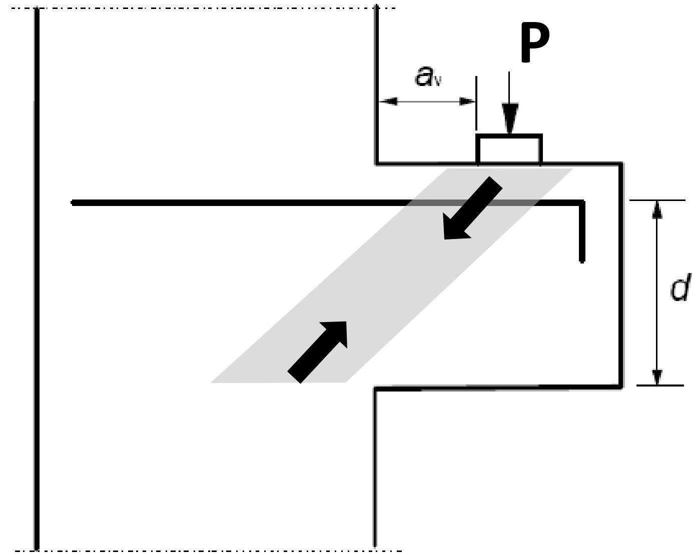


(b) Corbel

Special cases of shear / Cazuri speciale la forţă tăietoare

LOADS NEAR SUPPORTS





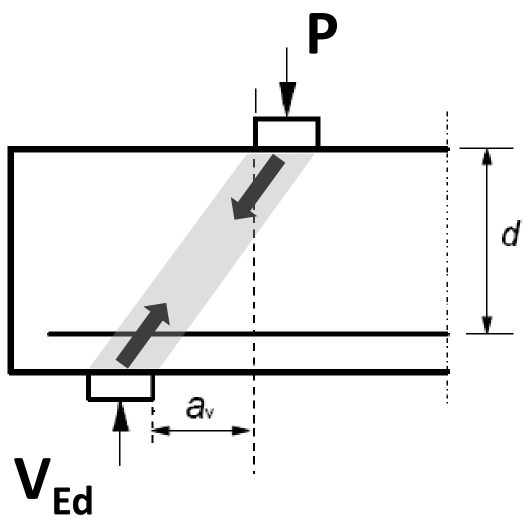
In the distance of $\boldsymbol{0{,}5d \le a_v \le 2d}$ force $\boldsymbol{V_{Ed}}$ could be reduced with $\boldsymbol{\beta = a_v / 2d}$

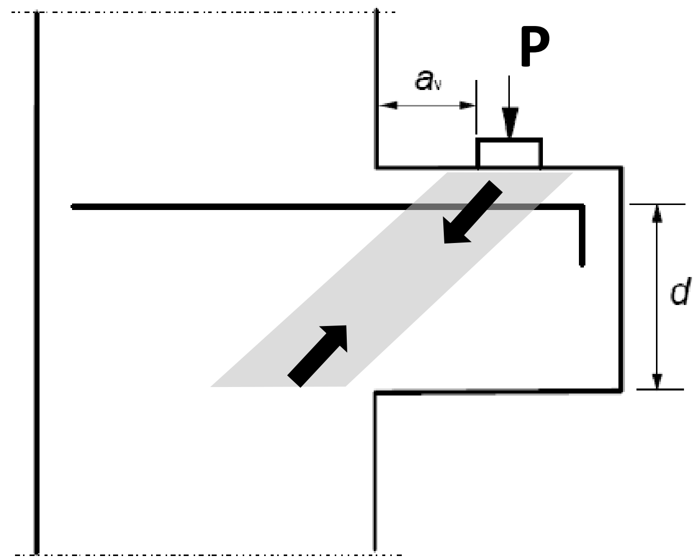
$\rightarrow \boldsymbol{V_{Ed} = \beta \cdot P}$

If $a_v \le 0{,}5d$ $\rightarrow a_v = 0{,}5d$

Special cases of shear / Cazuri speciale la forţă tăietoare

LOADS NEAR SUPPORTS





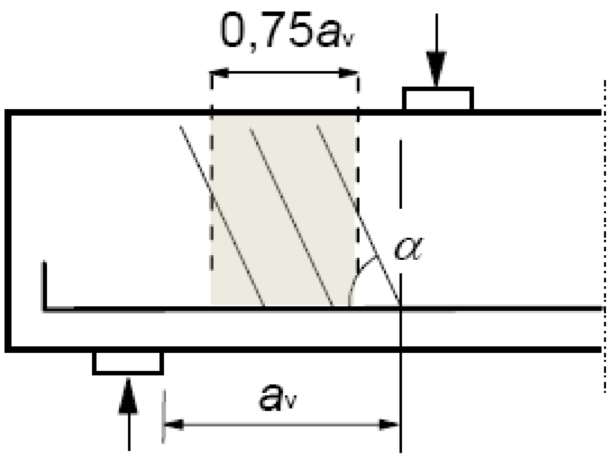
The shear force V_{Ed}, calculated without reduction by β, should however always satisfy the condition

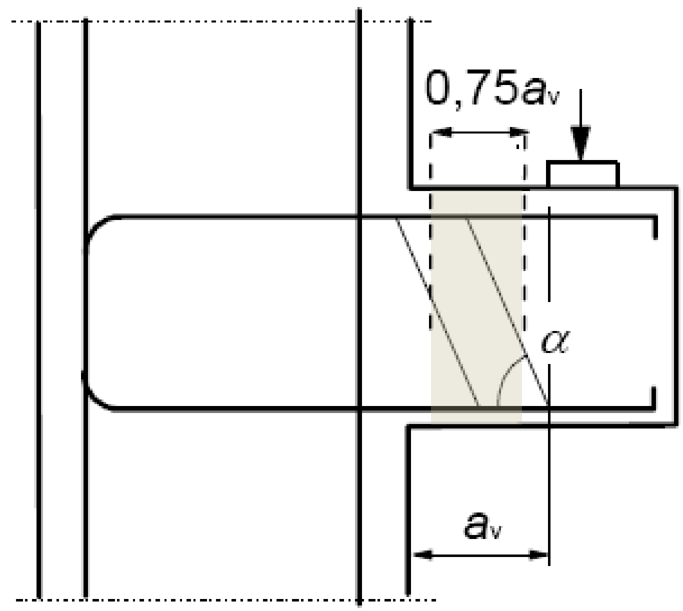
$$V_{Ed} \leq 0{,}5\, b_w\, d\, \nu\, f_{cd}$$

$$\nu = 0{,}6\left(1 - \frac{f_{ck}}{250}\right)$$

Special cases of shear / Cazuri speciale la forţă tăietoare

LOADS NEAR SUPPORTS





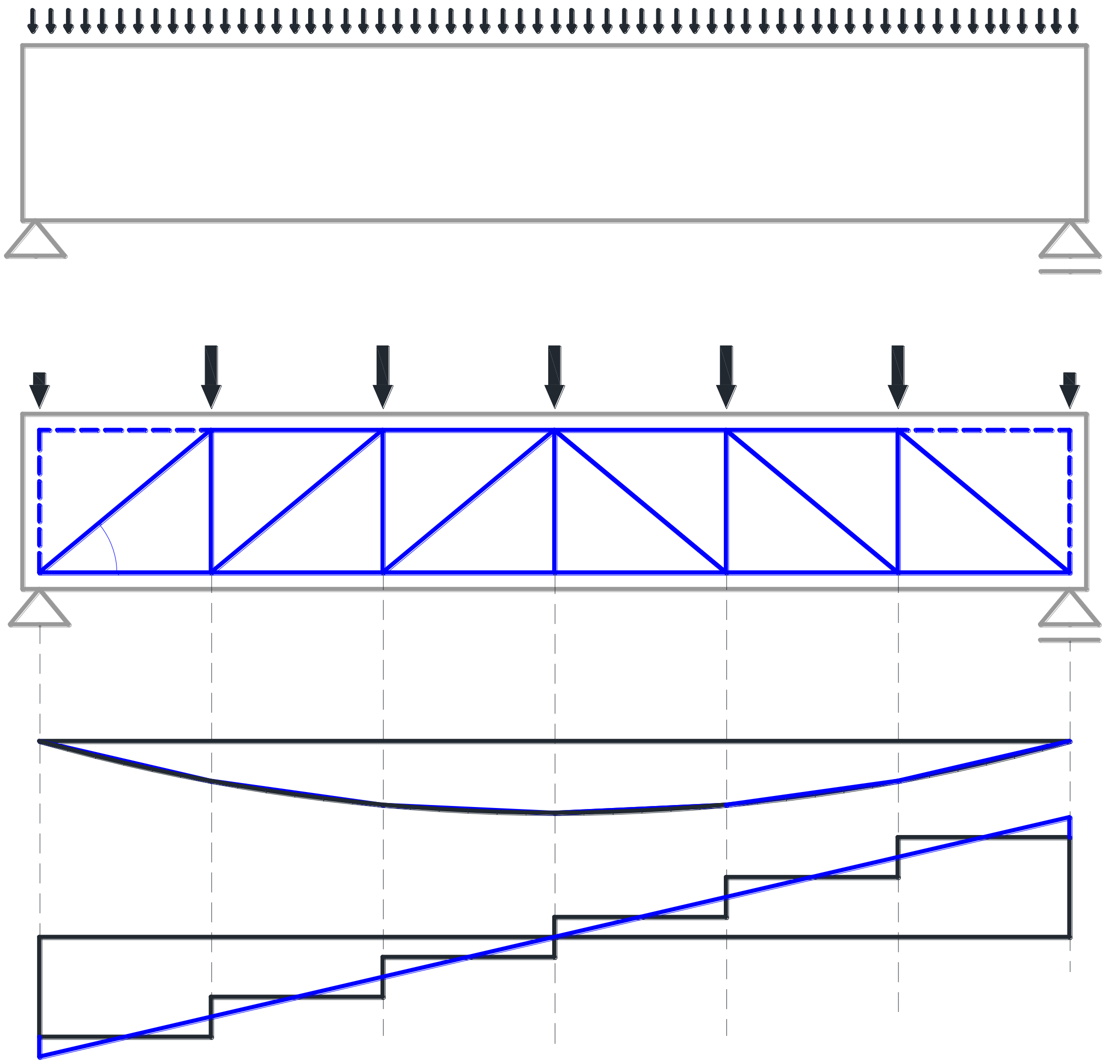
The shear force V_{Ed} calculated without reduction by β, should satisfy the condition

$$V_{Ed} \leq A_{sw} \ f_{ywd} \sin\alpha$$

$A_{sw} \ f_{ywd}$ is the resistance of the shear reinforcement crossing the inclined shear crack between the loaded areas. Only the shear reinforcement within the central 0,75 a_v should be taken into account.

Special cases of shear / Cazuri speciale la forţă tăietoare

ADDITIONAL SHEAR FORCE IN LONGITUDINAL REINFORCEMENTS

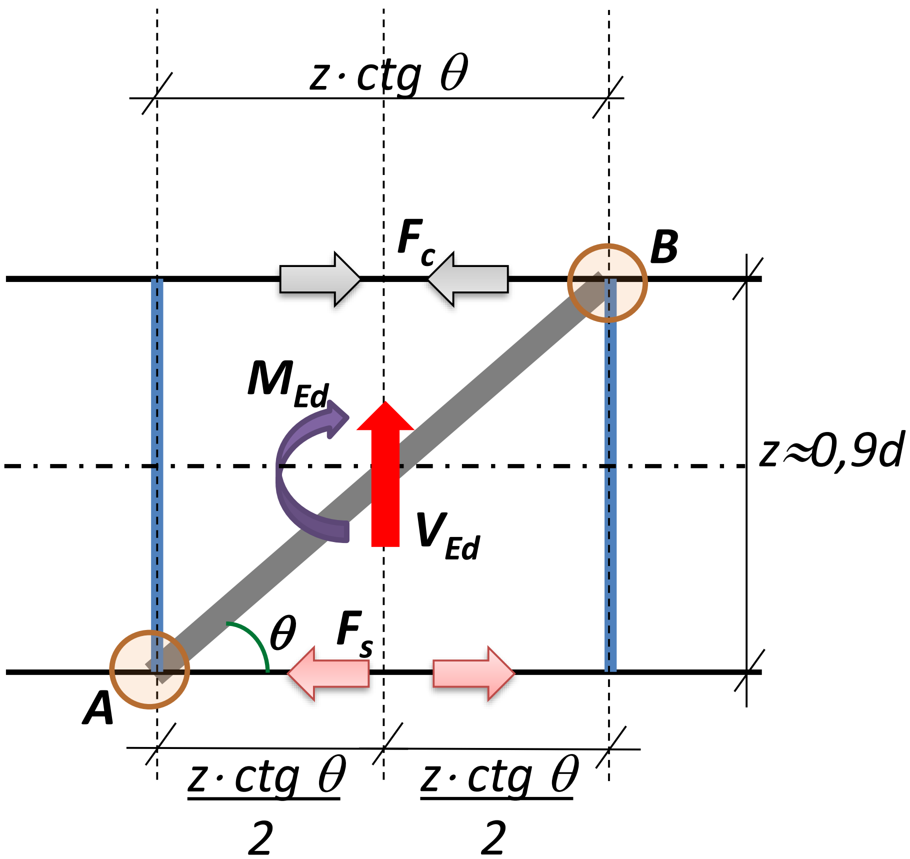


$M_{S\&T} \leq M_{Ed}$

$V_{S\&T} \leq V_{Ed}$

Special cases of shear / Cazuri speciale la forţă tăietoare

ADDITIONAL SHEAR FORCE IN LONGITUDINAL REINFORCEMENTS



$$(\Sigma M)_A: M_{Ed} - V_{Ed} \cdot z \cdot \frac{ctg\theta}{2} = F_c \cdot z$$

$$(\Sigma M)_B: M_{Ed} + V_{Ed} \cdot z \cdot \frac{ctg\theta}{2} = F_s \cdot z$$

$$F_c = \frac{M_{Ed}}{z} - 0{,}5V_{Ed} \cdot ctg\theta$$

Compression decreasing due to V_{Ed}

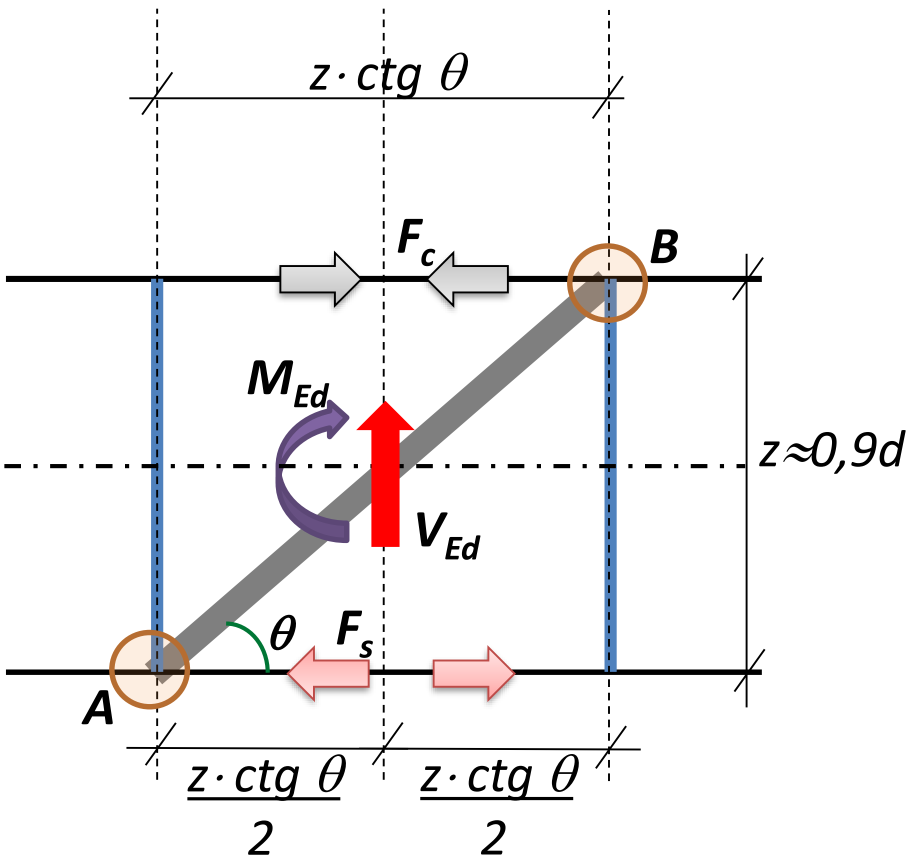
$$F_s = \frac{M_{Ed}}{z} + 0{,}5V_{Ed} \cdot ctg\theta$$

Tension increasing due to V_{Ed}

ADDITIONAL SHEAR FORCE IN LONGITUDINAL REINFORCEMENTS

Could be computed

$$\Delta F_{td} = 0,5V_{Ed}(ctg\theta - ctg\alpha)$$



where is recommended that

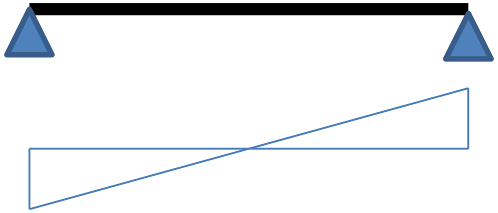
$$M_{Ed}/z + \Delta F_{td} \leq M_{Ed,max}/z$$

A_s

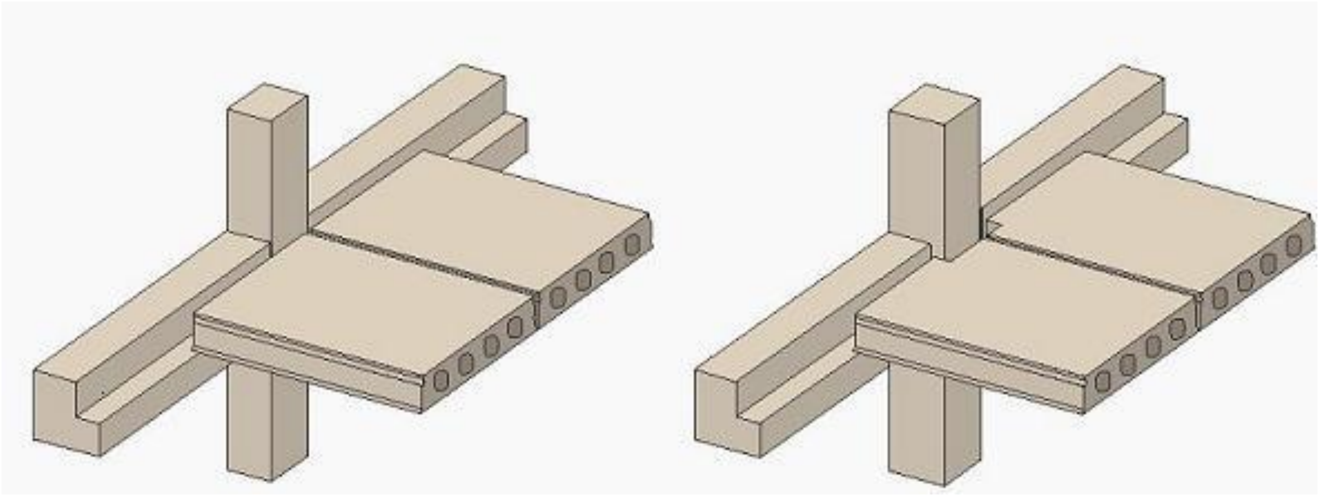
$M_{Ed,max}$ being the maximum moment on the beam

Special cases of shear / Cazuri speciale la forţă tăietoare

FORCE APPLIED ON THE BOTTOM PART

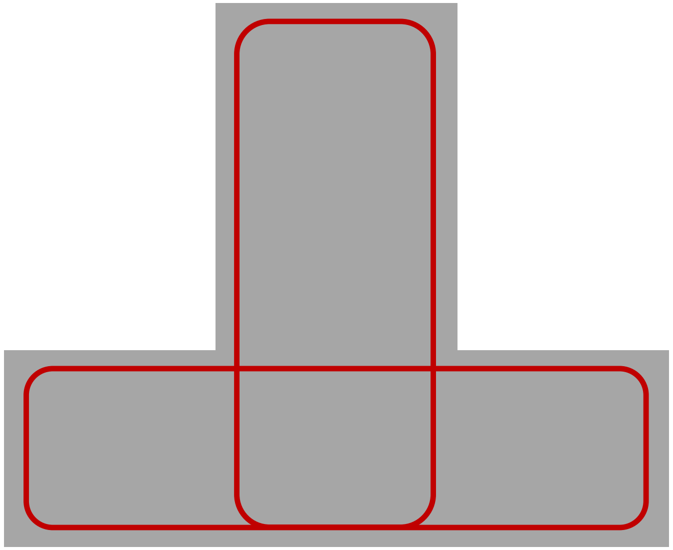


$$V_{Ed1} = V_{Ed2}$$



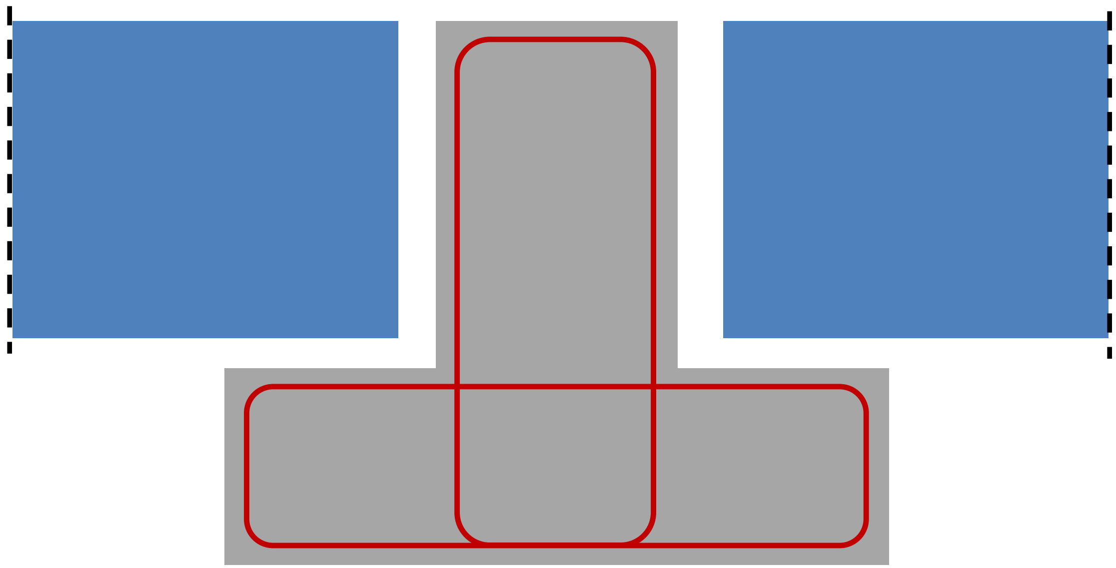
Special cases of shear / Cazuri speciale la forţă tăietoare

FORCE APPLIED ON THE BOTTOM PART



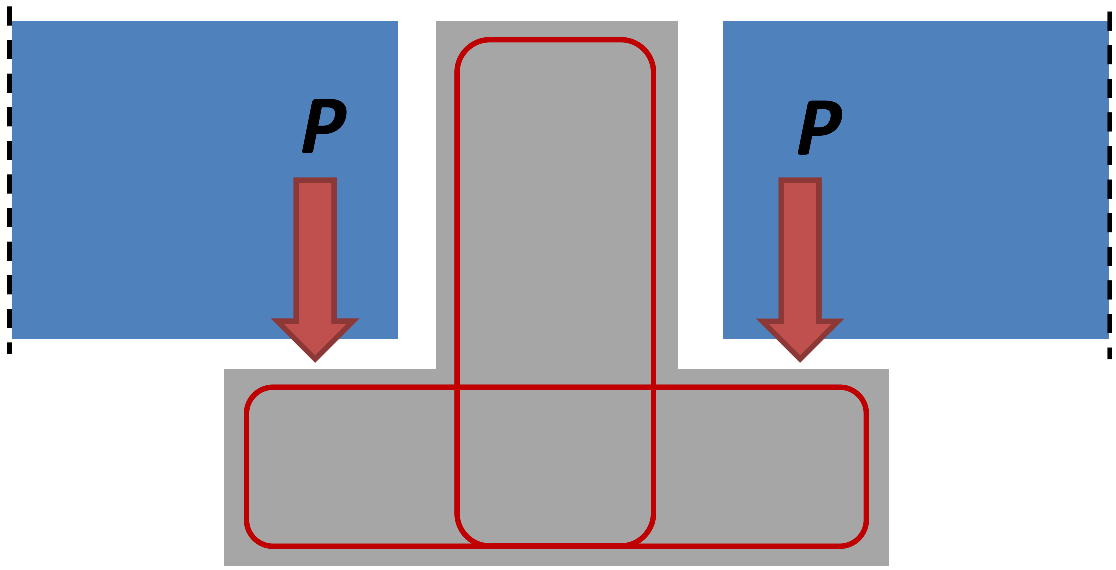
Special cases of shear / Cazuri speciale la forţă tăietoare

FORCE APPLIED ON THE BOTTOM PART



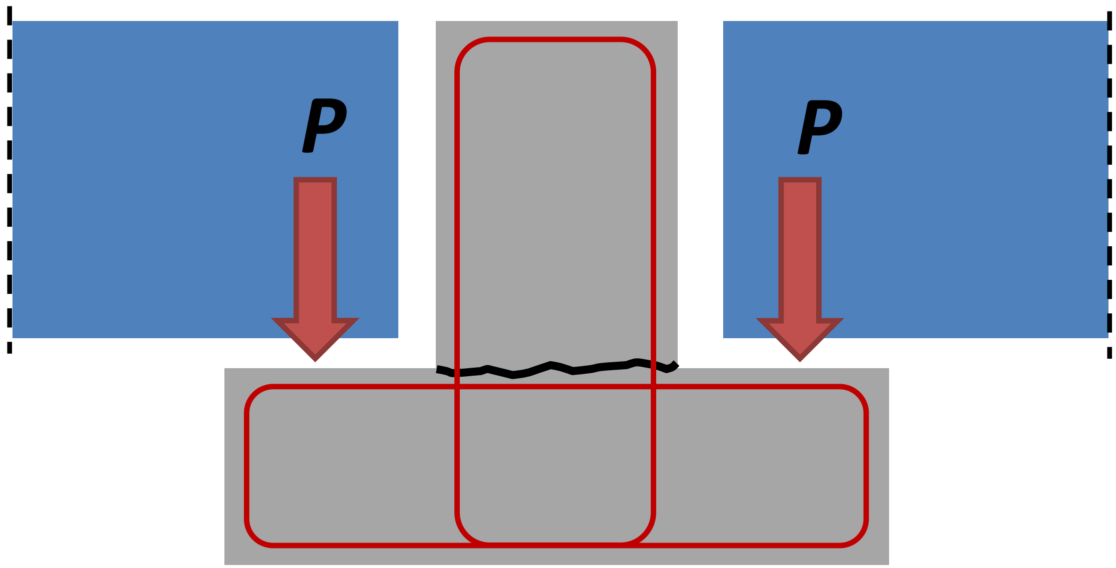
Special cases of shear / Cazuri speciale la forţă tăietoare

FORCE APPLIED ON THE BOTTOM PART



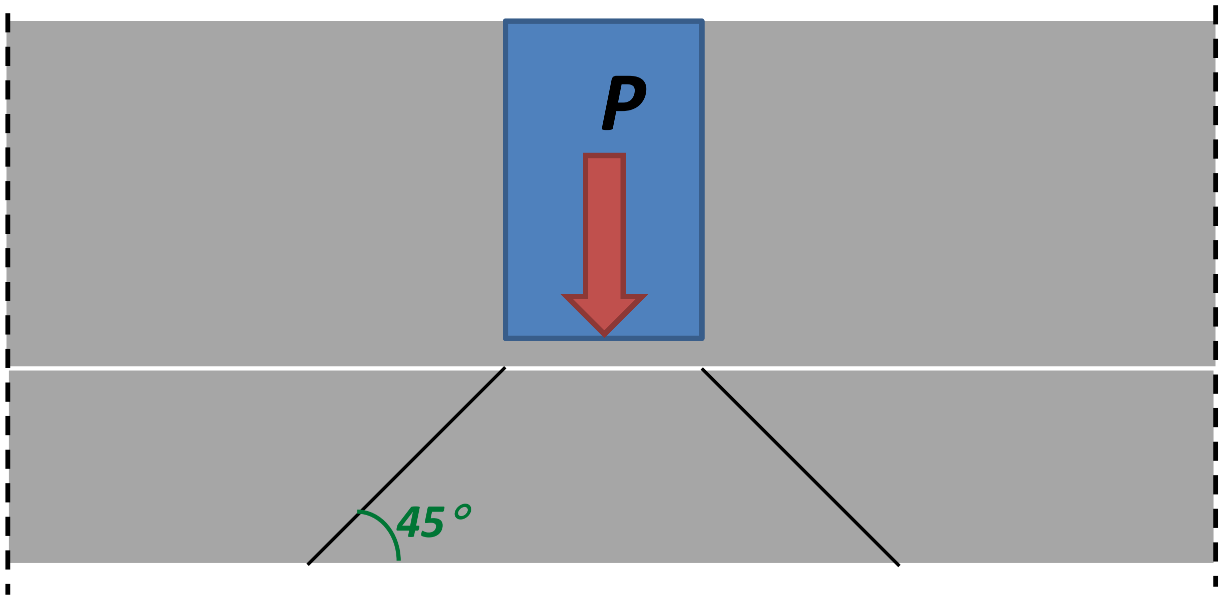
Special cases of shear / Cazuri speciale la forţă tăietoare

FORCE APPLIED ON THE BOTTOM PART



Special cases of shear / Cazuri speciale la forţă tăietoare

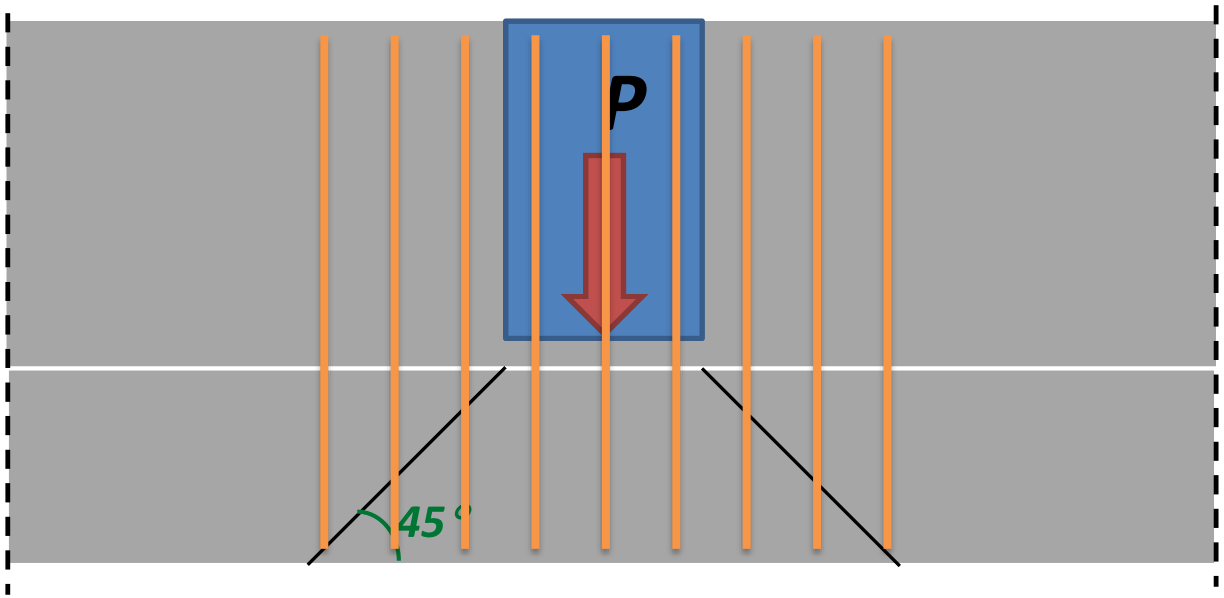
FORCE APPLIED ON THE BOTTOM PART



Special cases of shear / Cazuri speciale la forţă tăietoare

FORCE APPLIED ON THE BOTTOM PART

→ IT IS NECESSARY SUSPENDED REINFORCEMENT



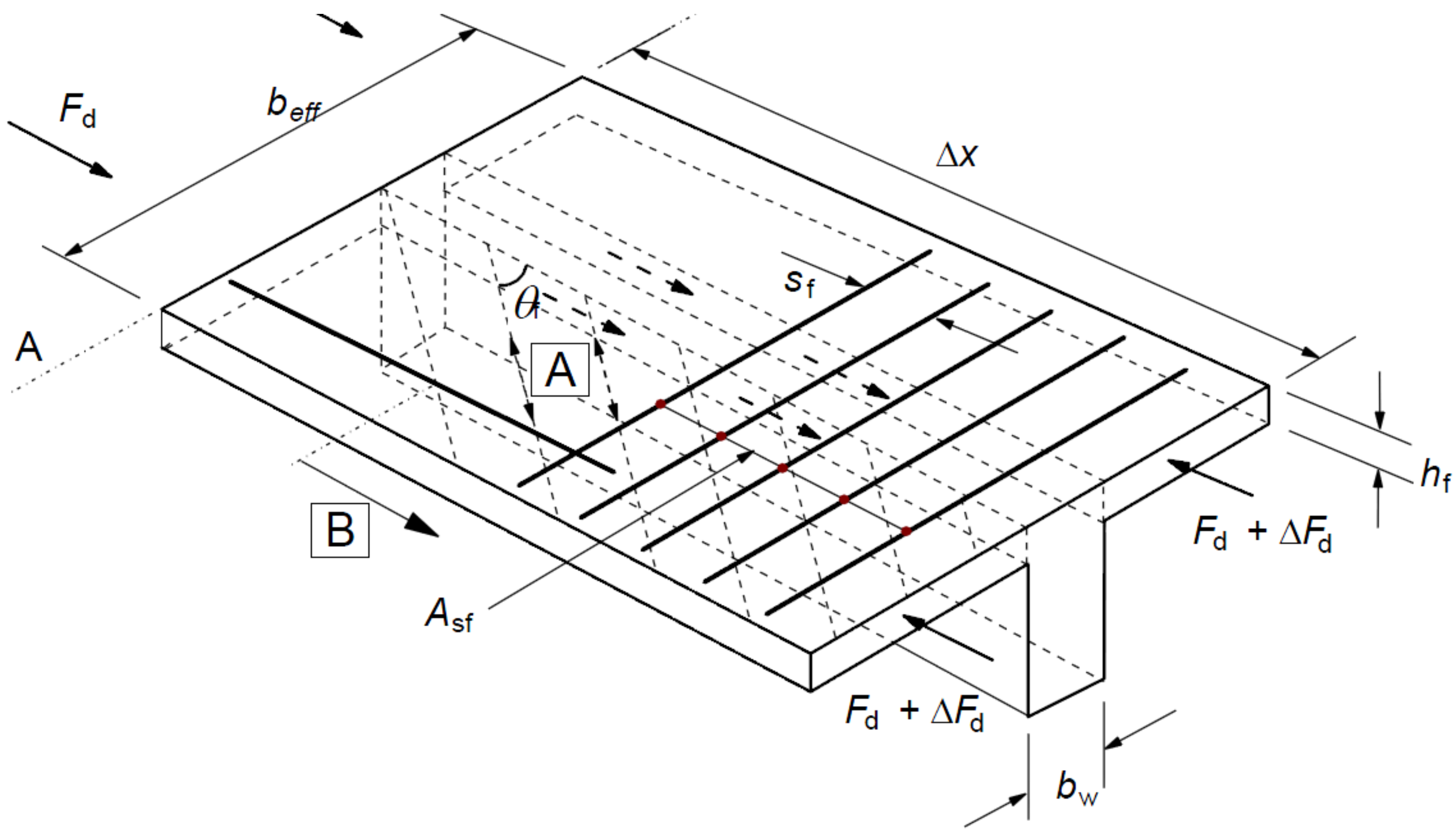
$$\Sigma A_{sw} = \frac{P}{f_{ywd}}$$

10.6. SHEAR BETWEEN WEB AND FLANGES OF T-SECTIONS

Shear between web and flanges/ Forfecarea dintre inimă și talpă

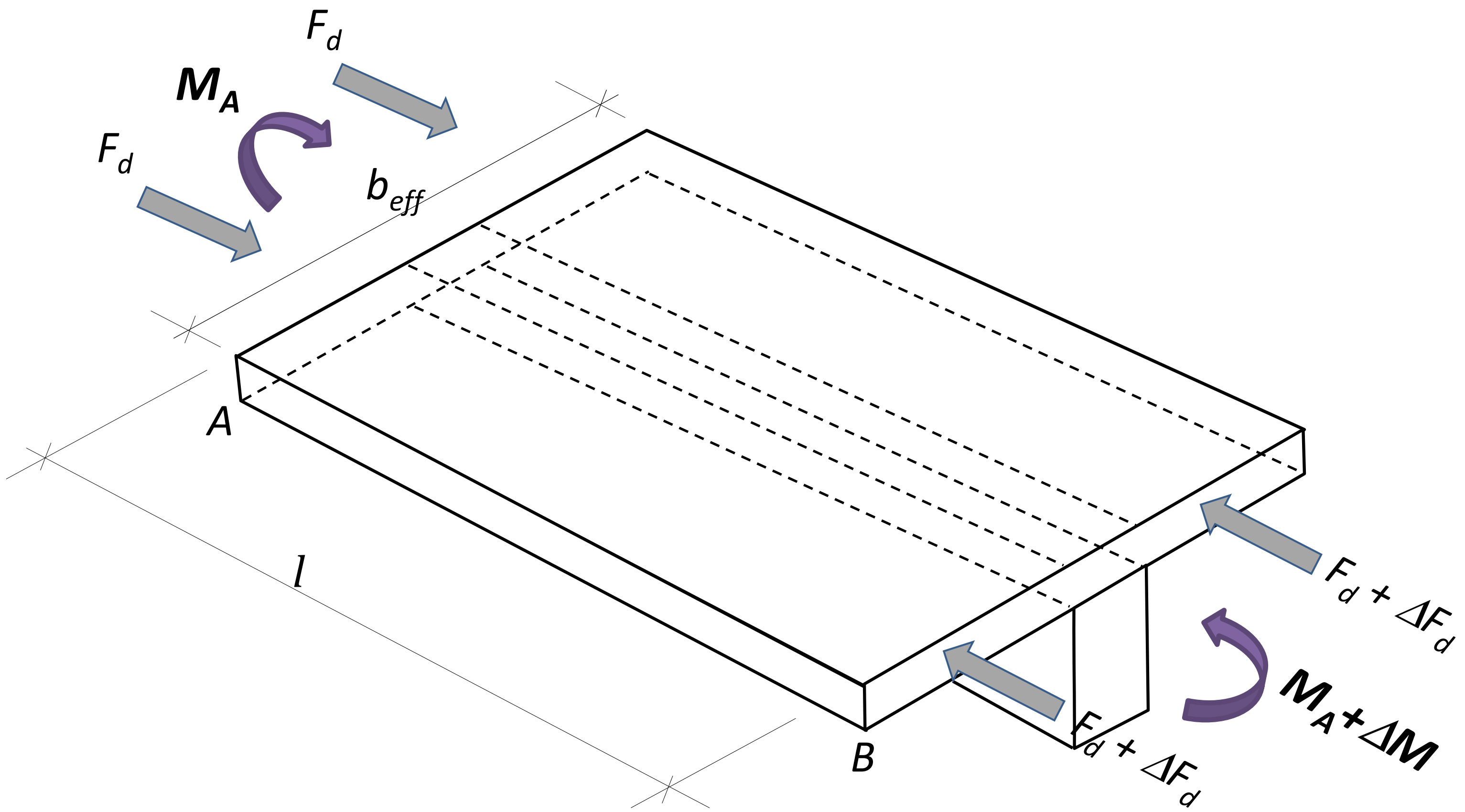
Shear occurs due to the increase of compressive forces in the flanges

A – compressive struts



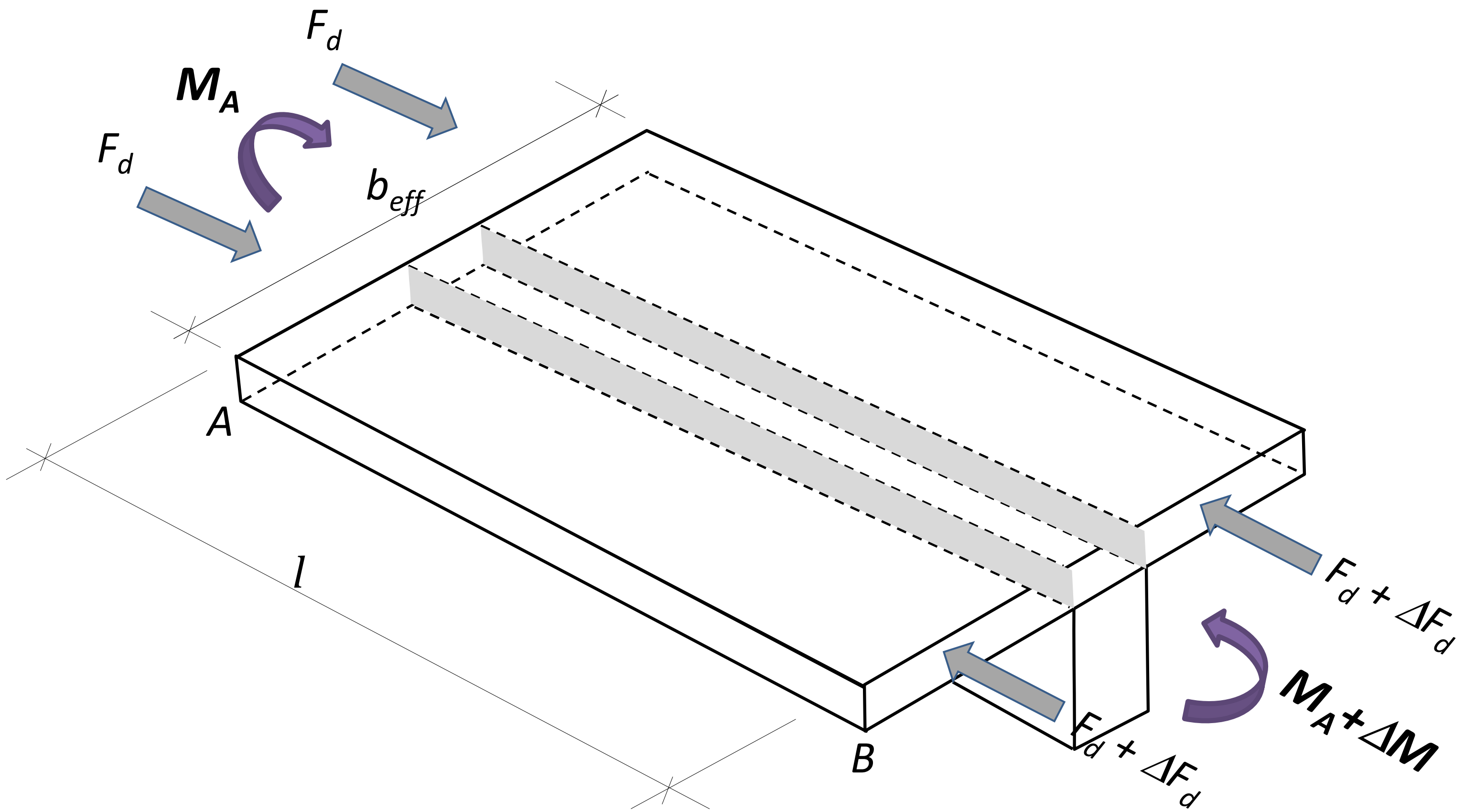
Shear between web and flanges/ Forfecarea dintre inimă și talpă

Shear occurs due to the increase of compressive forces in the flanges



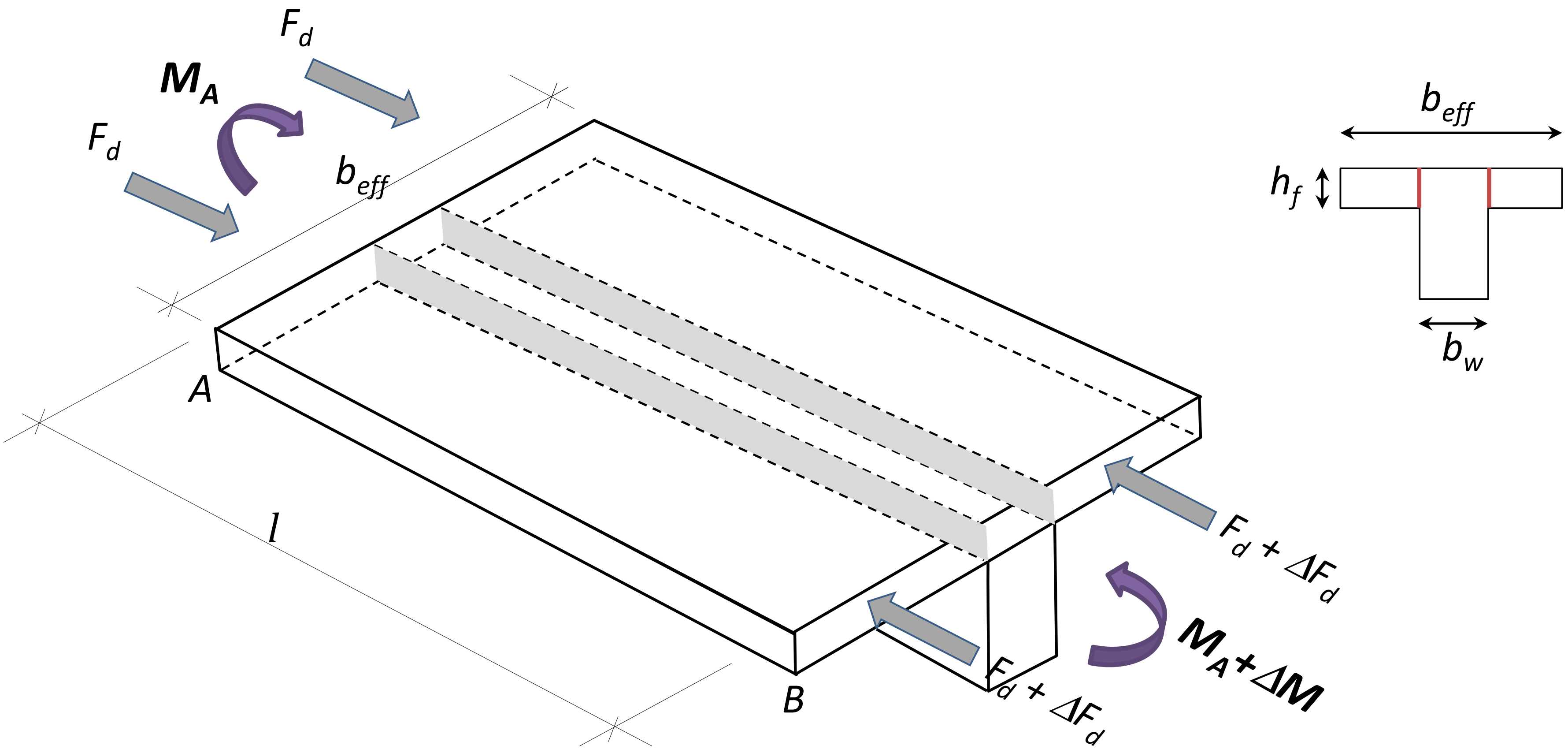
Shear between web and flanges/ Forfecarea dintre inimă și talpă

Shear occurs due to the increase of compressive forces in the flanges



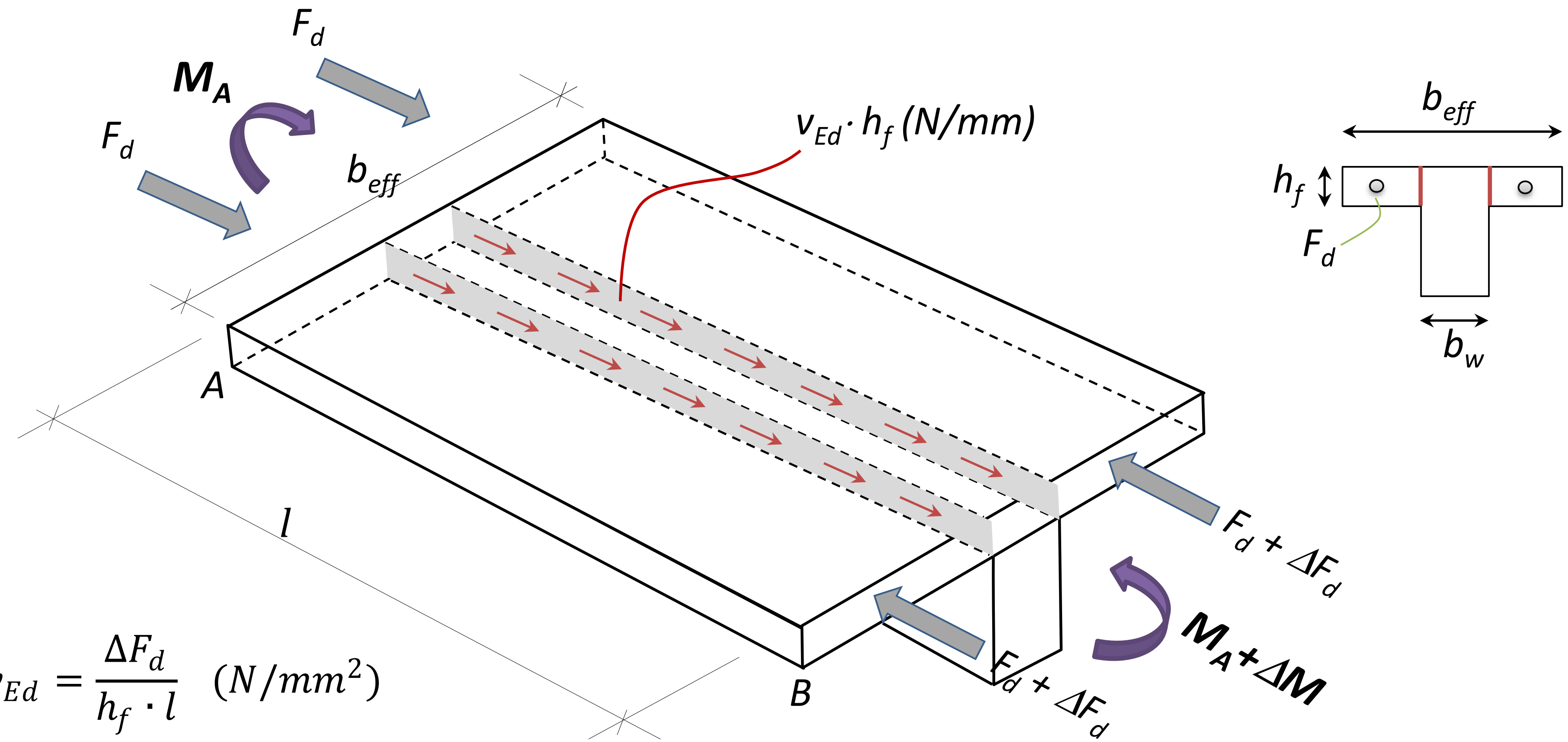
Shear between web and flanges/ Forfecarea dintre inimă şi talpă

Shear occurs due to the increase of compressive forces in the flanges



Shear between web and flanges/ Forfecarea dintre inimă și talpă

Shear occurs due to the increase of compressive forces in the flanges



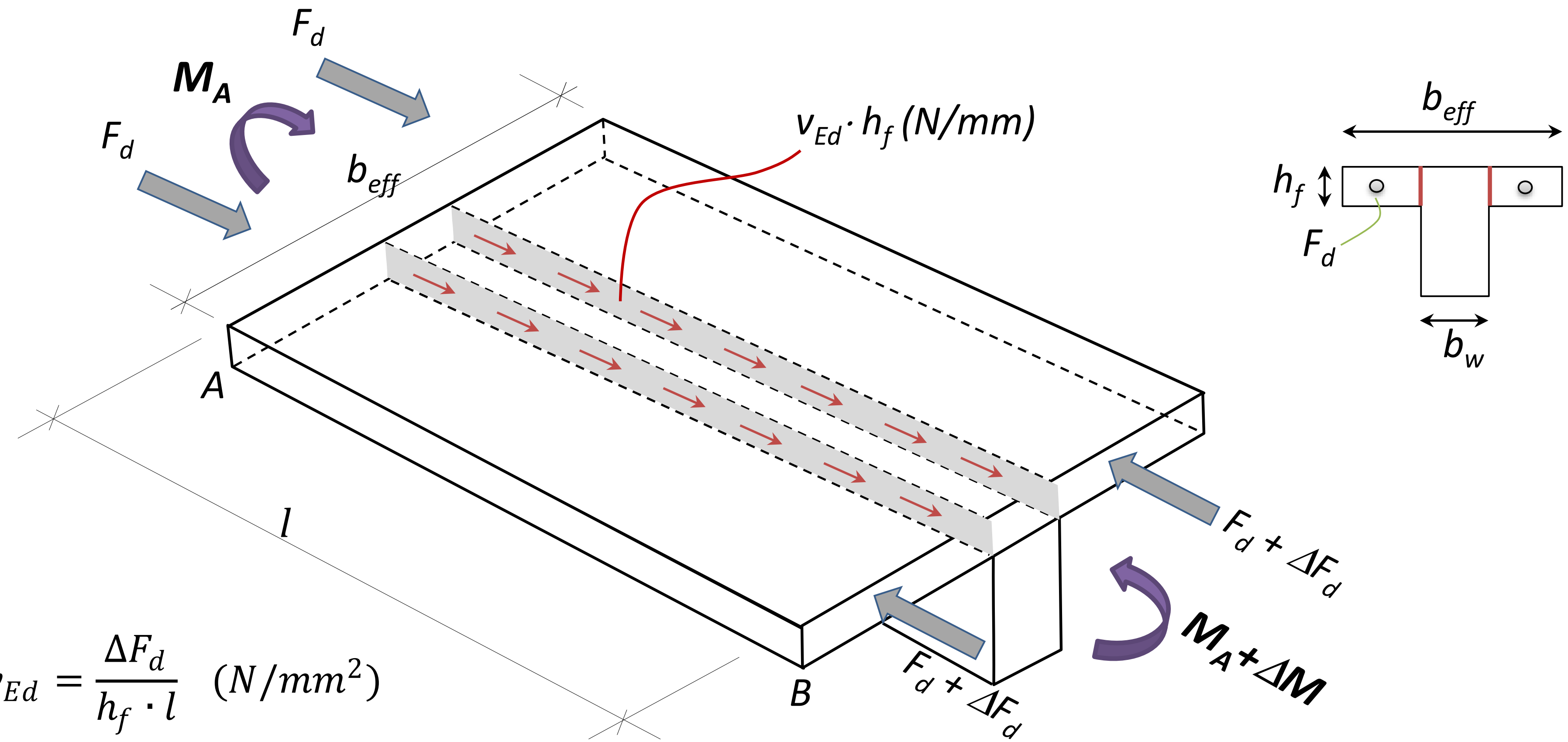
$$v_{Ed} = \frac{\Delta F_d}{h_f \cdot l} \quad (N/mm^2)$$

(Efort de forfecare longitudinal)

ΔF – variația forței axiale din placă pe lungimea l (notat cu Δx în EC2)
l – se alege conform schiței

Shear between web and flanges/ Forfecarea dintre inimă și talpă

Shear occurs due to the increase of compressive forces in the flanges



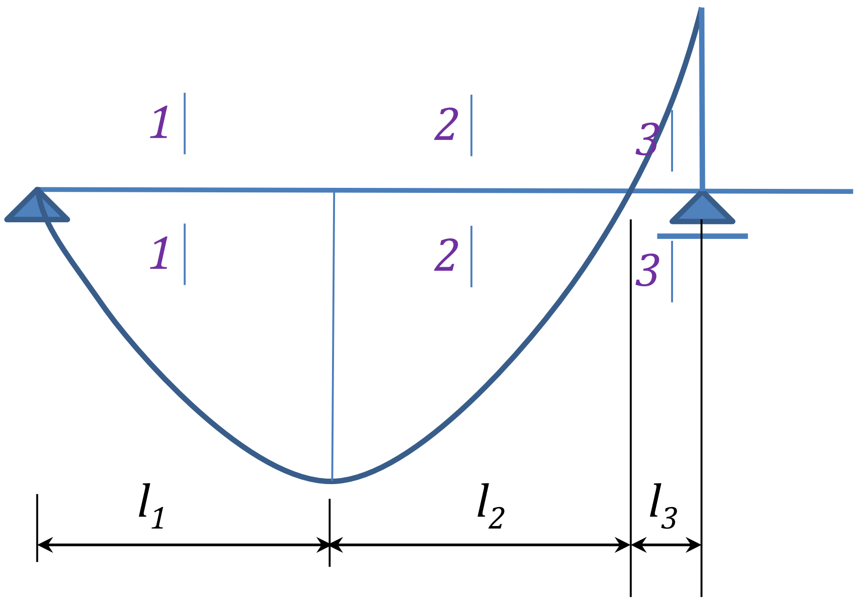
$$v_{Ed} = \frac{\Delta F_d}{h_f \cdot l} \quad (N/mm^2)$$

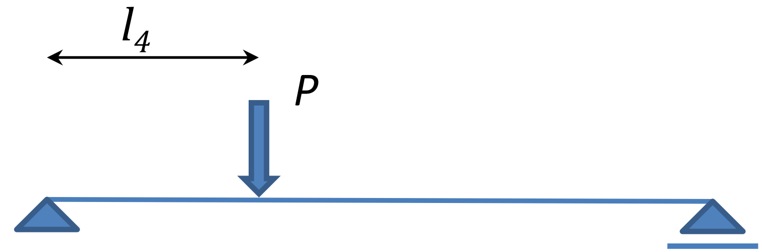
$$\Delta F_d = \frac{1}{2}\frac{\Delta M_{Ed}}{z}\left(\frac{b_{eff} - b_w}{b_{eff}}\right)$$

ΔM_{Ed} – variația momentului pe distanța l (între A-B)

Shear between web and flanges/ Forfecarea dintre inimă și talpă

Shear occurs due to the increase of compressive forces in the flanges

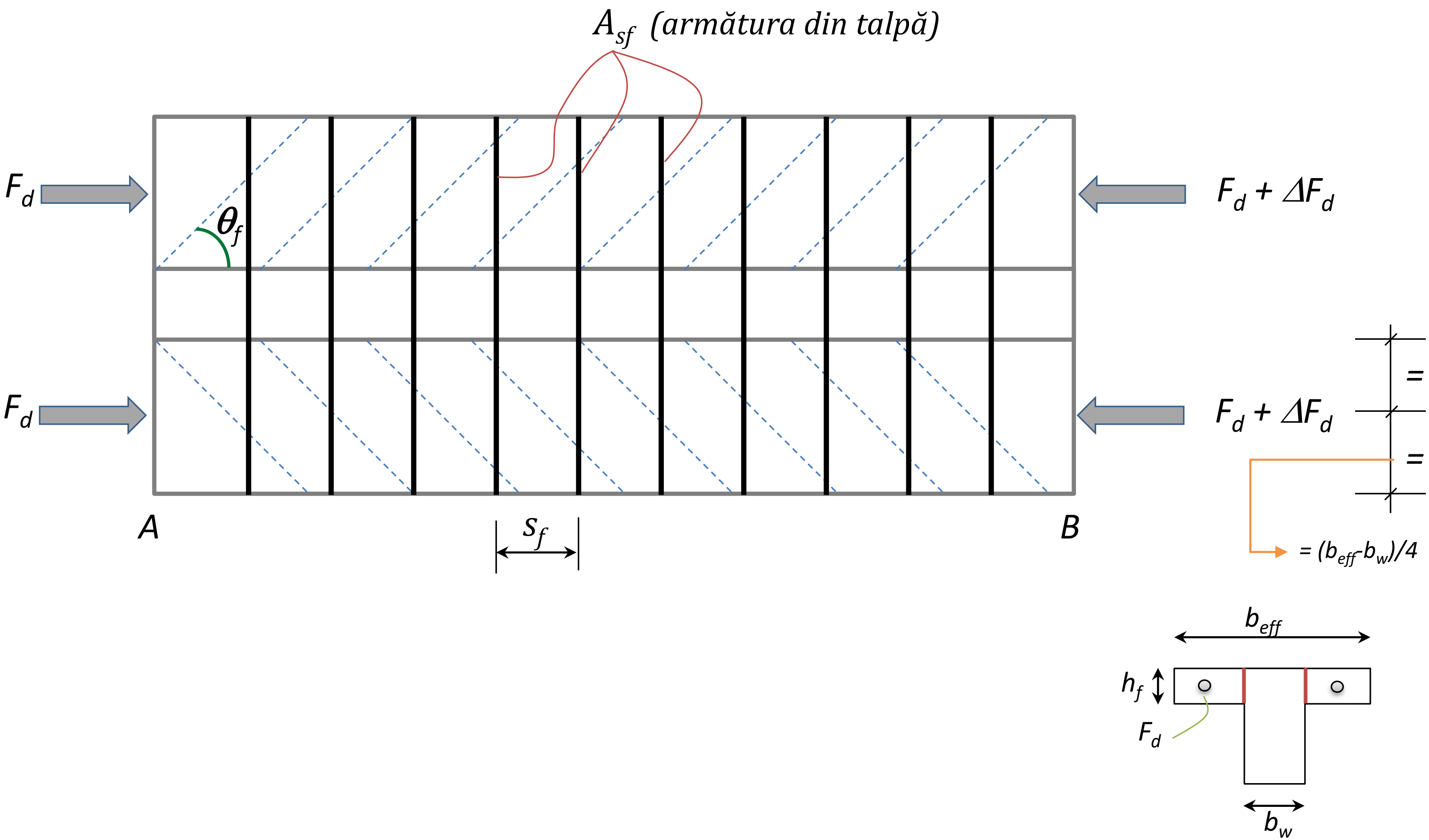




$l = max\ (l_1\ ;\ l_2\ ;\ l_3\ ;\ l_4)$

Shear between web and flanges/ Forfecarea dintre inimă și talpă

Shear occurs due to the increase of compressive forces in the flanges



Shear between web and flanges/ Forfecarea dintre inimă și talpă

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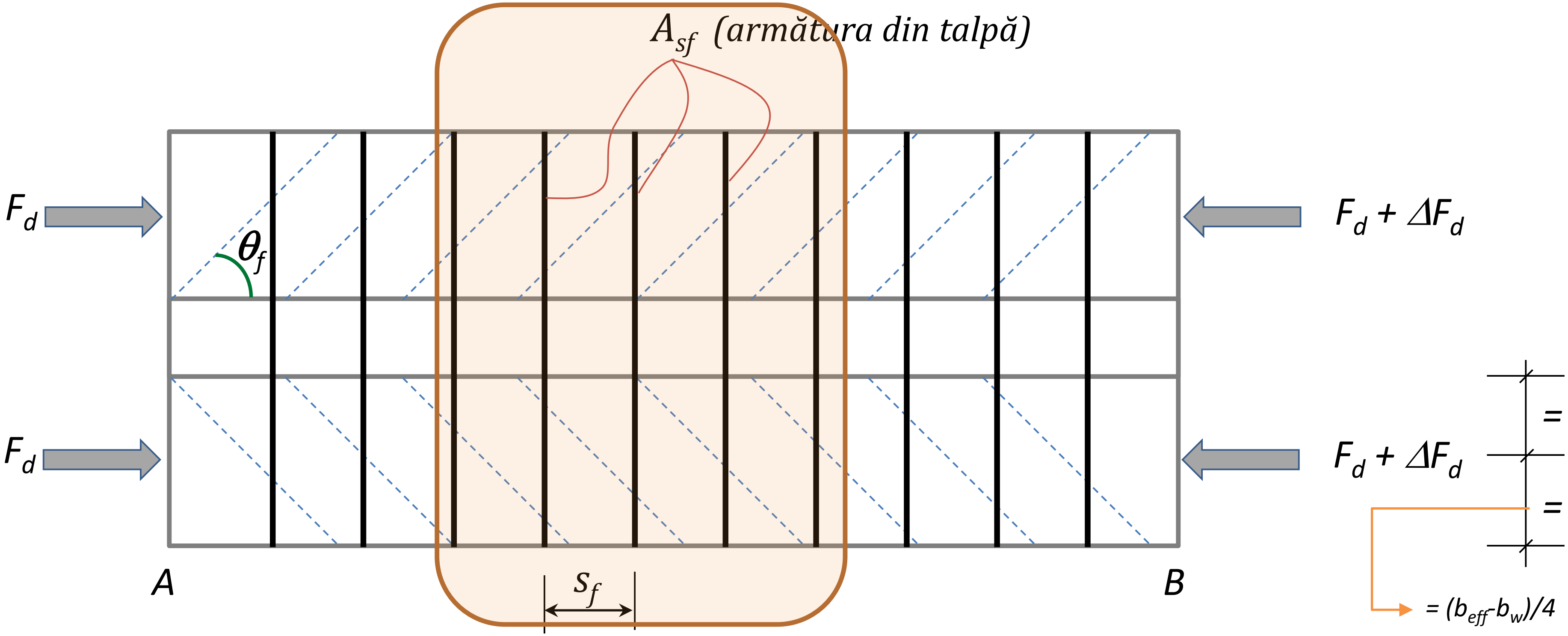
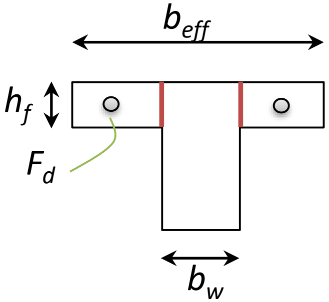


$$\frac{A_{sf}}{s_f} f_{ywd}$$



Shear between web and flanges/ Forfecarea dintre inimă și talpă

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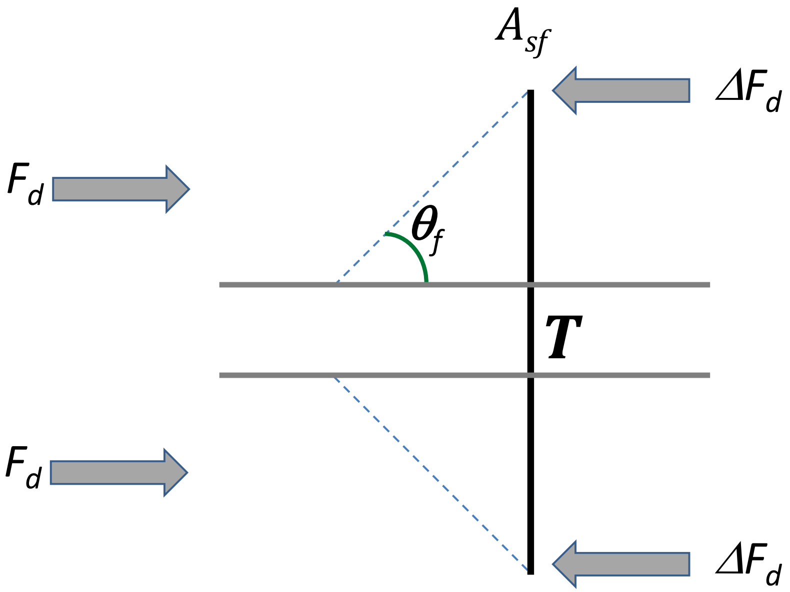
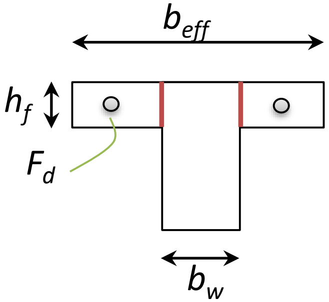


$$tg\theta_f = \frac{T}{\Delta F_d} \quad \Rightarrow \quad T = \Delta F_d tg\theta_f$$

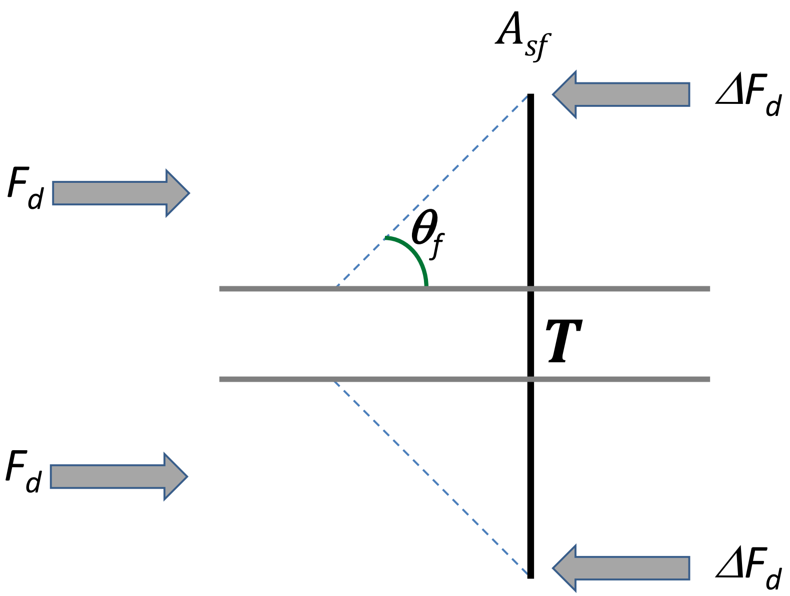
$$\frac{A_{sf}}{s} f_{ywd} \geq T = \Delta F_d tg\theta_f$$

$$v_{Ed} = \frac{\Delta F_d}{h_f \cdot l} \quad (N/mm^2)$$



Shear between web and flanges/ Forfecarea dintre inimă și talpă

Shear occurs due to the increase of compressive forces in the flanges



$$1 \le ctg\theta_f \le 2$$ ⇒ *Pt plăci comprimate*

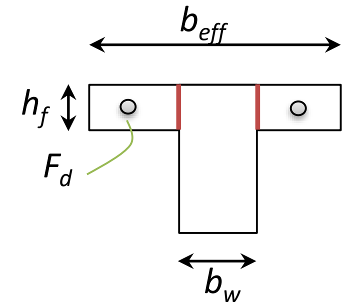
$$1 \le ctg\theta_f \le 1{,}25$$ ⇒ *Pt plăci întinse*

Pentru $v_{Ed} \le 0{,}4 f_{ctd}$

nu este necesară o armare în plus

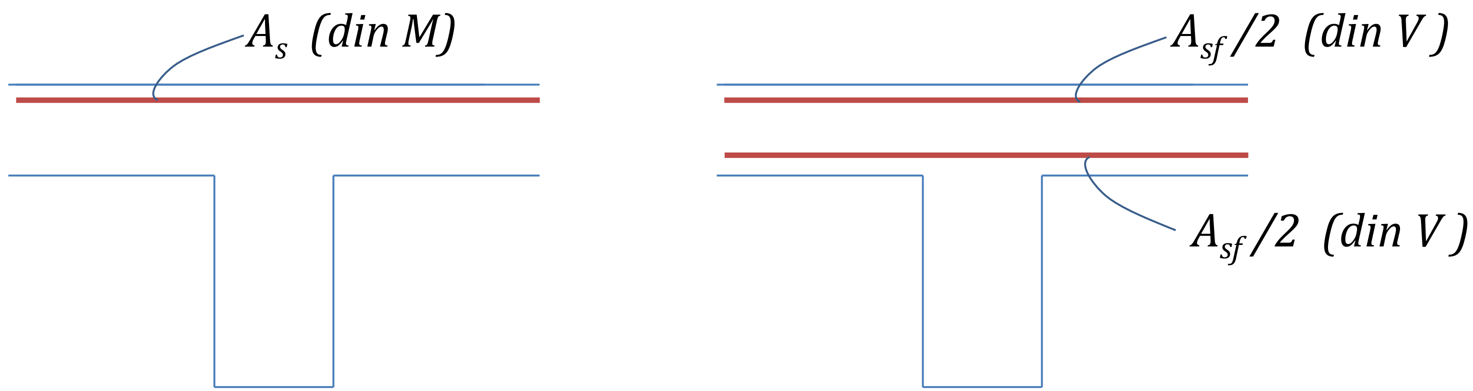
$$\Rightarrow \quad \frac{A_{sf}}{s} f_{ywd} \ge v_{Ed} h_f tg\theta_f$$

unde $v_{Ed} \le \nu f_{cd} sin\theta_f cos\theta_f$

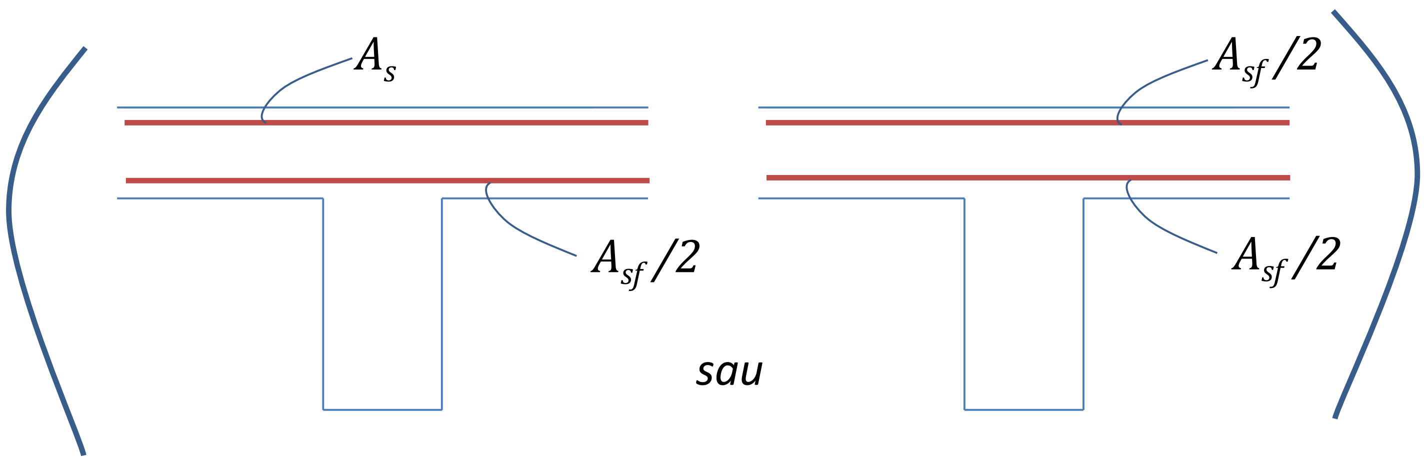


Shear between web and flanges/ Forfecarea dintre inimă și talpă

Shear reinforcement should be combined with slab reinforcement



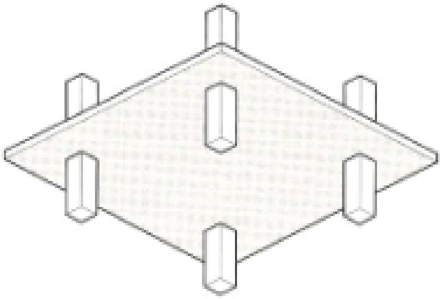
$\Rightarrow$ *Se va alege max din*



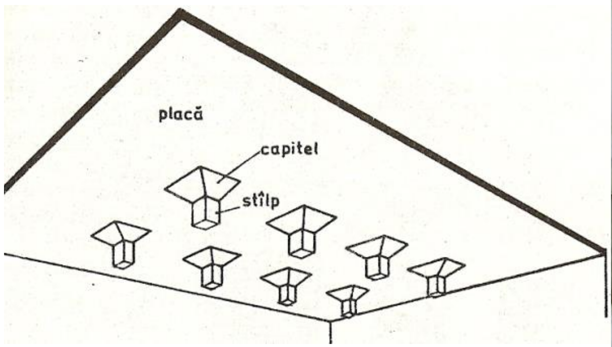
10.7. PUNCHING

Punching / Străpungere

Punching shear can result from a concentrated load or reaction acting on a relatively small area, called the loaded area A_{load} of a slab or a foundation

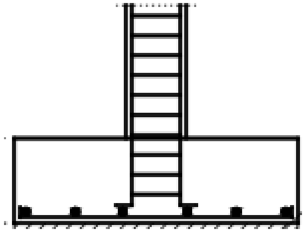


FLAT SLAB

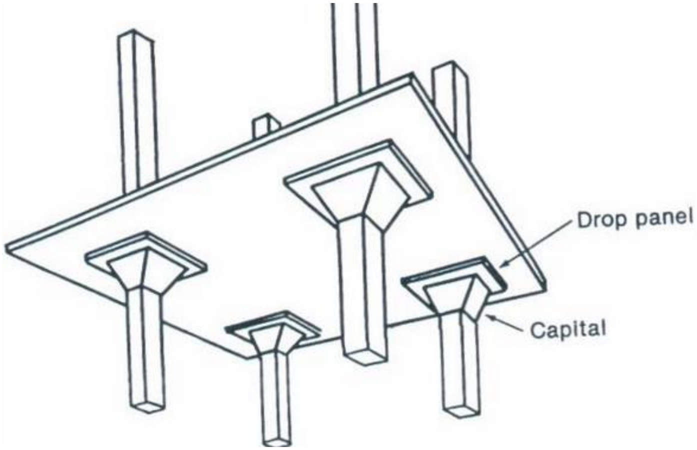


FLARED HEAD
ENLARGED HEAD

DROPHEAD

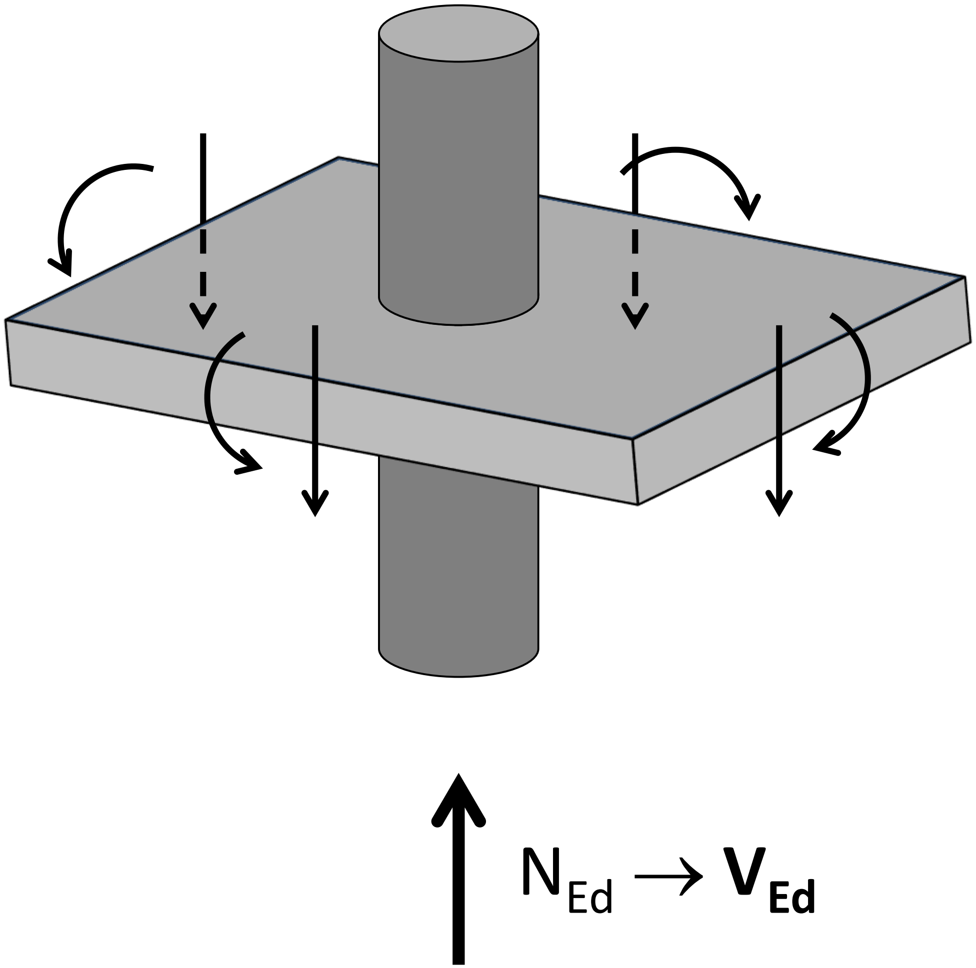


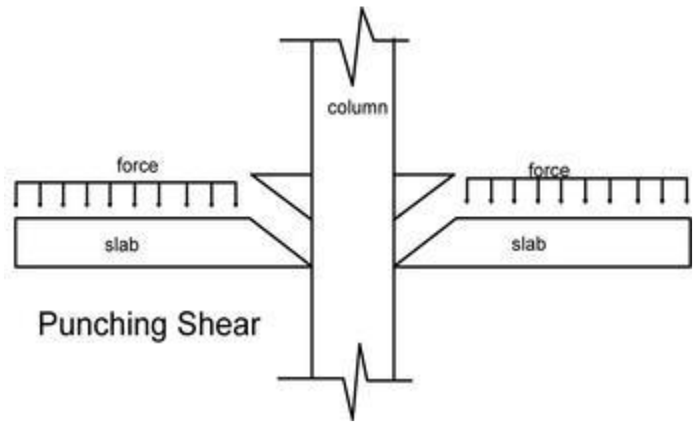
PAD FOUNDATION



Punching / Străpungere

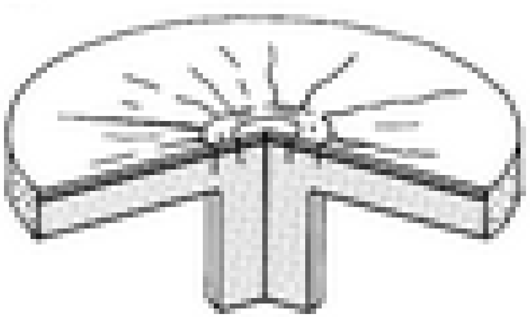
Punching shear can result from a concentrated load or reaction acting on a relatively small area, called the loaded area A_{load} of a slab or a foundation



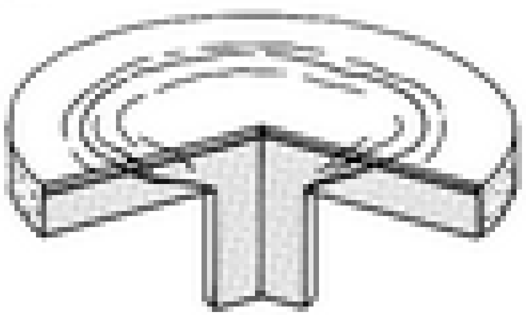


Punching / Străpungere

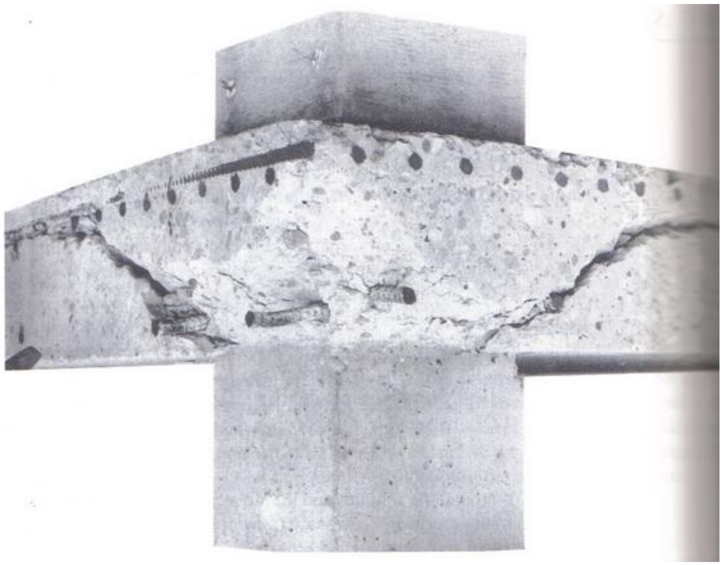
WAYS OF FAILURE



Cracks due to bending



Cracks due to punching

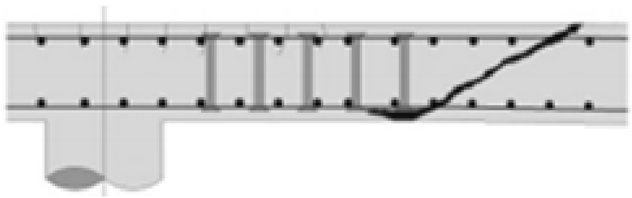


Tested slab

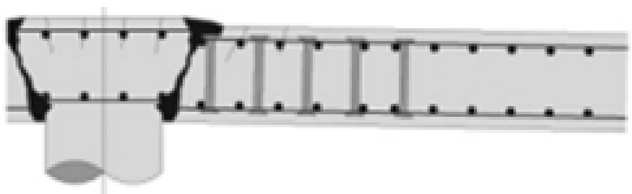
Punching / Străpungere

WAYS OF FAILURE

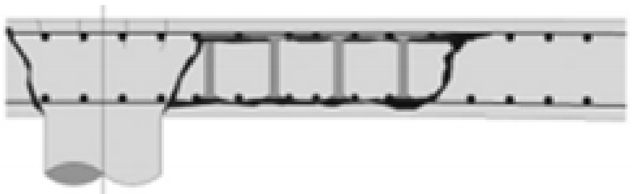
Failure within shear-reinforced area



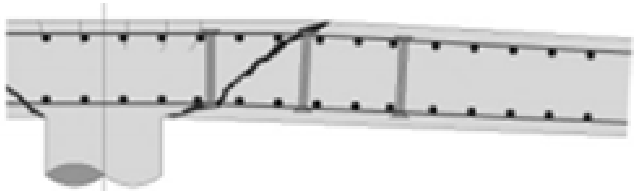
Failure outside shear- reinforced area



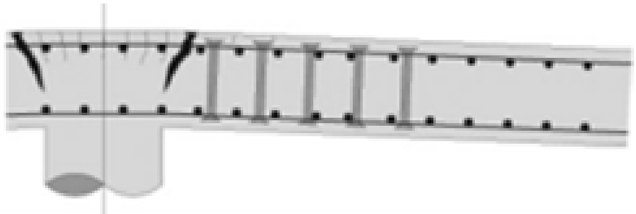
Failure closed to column by crushing of concrete



Delamination of concrete core

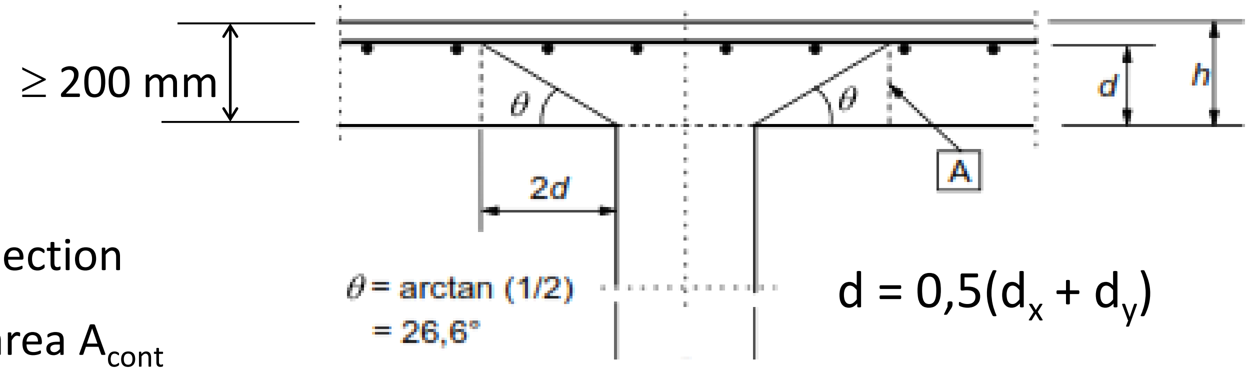


Failure between transverse reinforcement



Flexural failure

LOAD DISTRIBUTION AND BASIC CONTROL PERIMETER



$d = 0{,}5(d_x + d_y)$

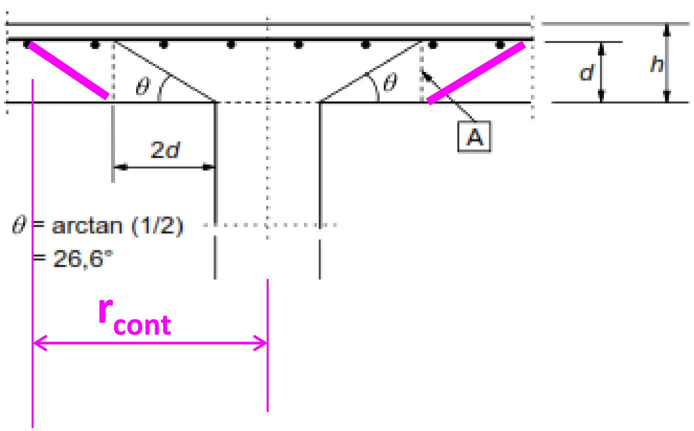
A - basic control section

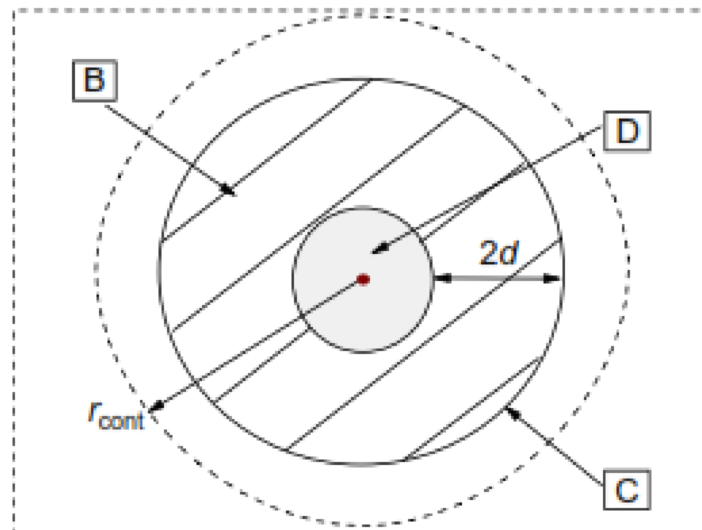
B - basic control area A_{cont}

C - basic control perimeter, u_1

D – loaded area A_{load}

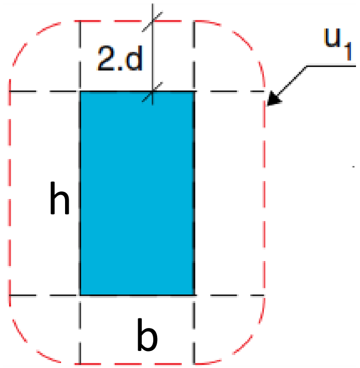
r_{cont} - further control perimeter





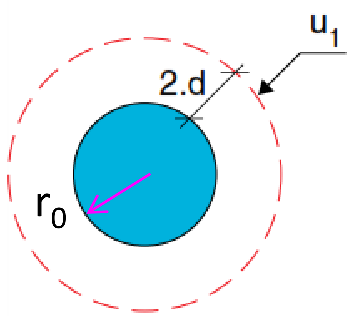
Punching / Străpungere

LOAD DISTRIBUTION AND BASIC CONTROL PERIMETER

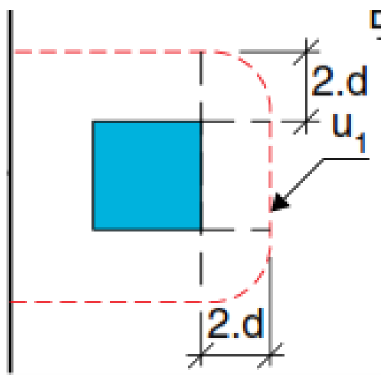


$u_1 = 2(b + h) + 2\pi(2d) = u_0 + 4\,\pi d$

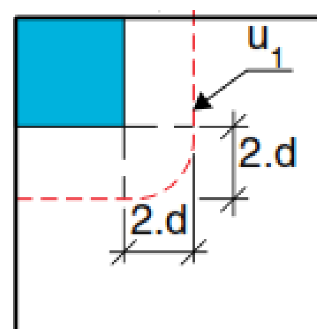
$u_0 = 2(b + h)$ - perimeter



$u_1 = 2\pi(r_0 + 2d)$



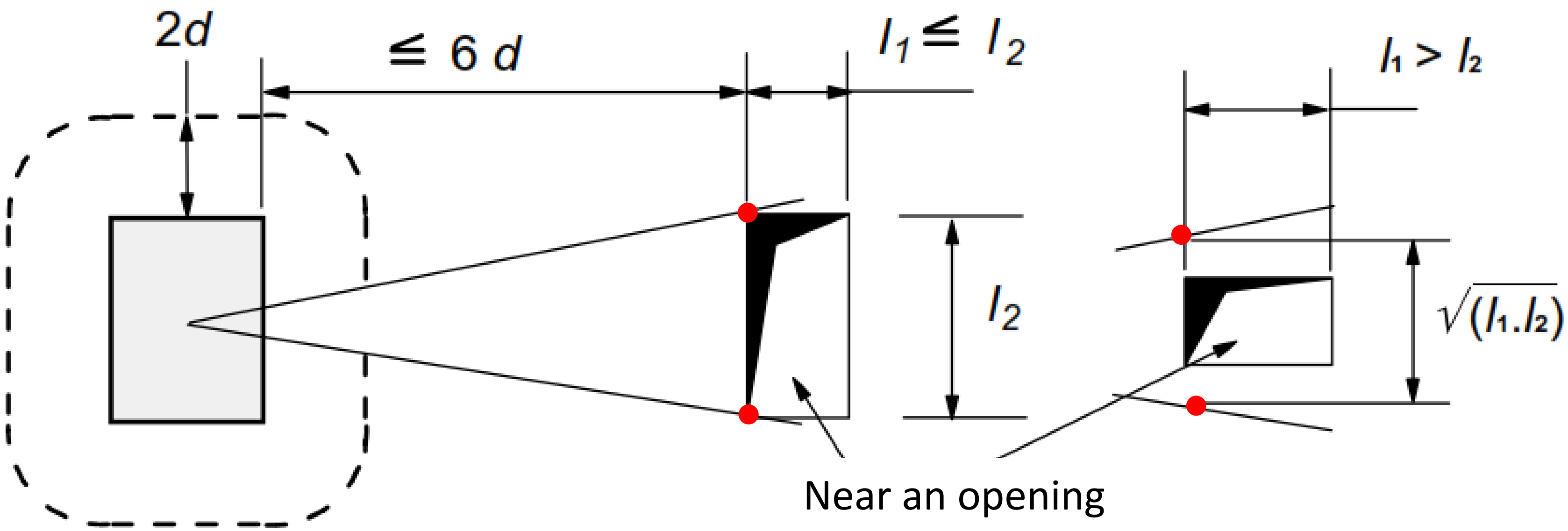
Near edge



Corner

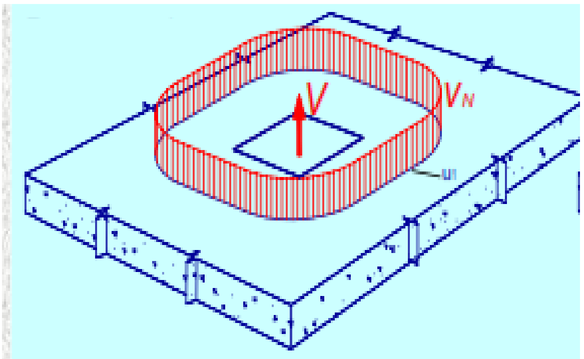
Punching / Străpungere

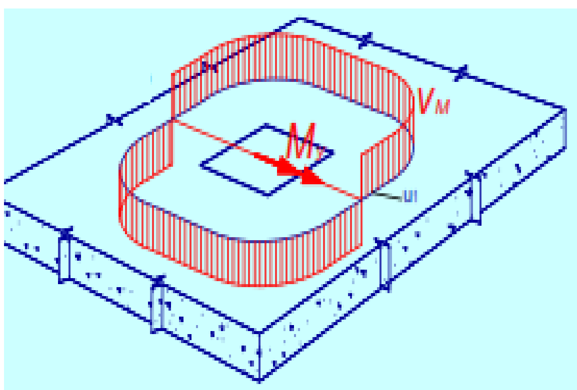
LOAD DISTRIBUTION AND BASIC CONTROL PERIMETER



PUNCHING SHEAR CALCULATION

Shear stress depends on:



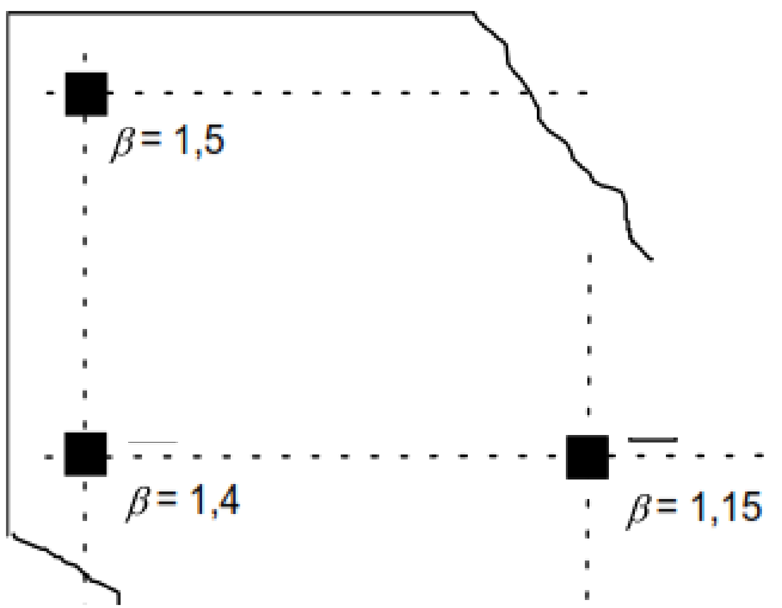


M_{Ed}

u_i - length of the perimeter being considered:

- basic control perimeter u_1
- column perimeter u_0

$$v_{Ed} = \beta \frac{V_{Ed}}{u_i d}$$

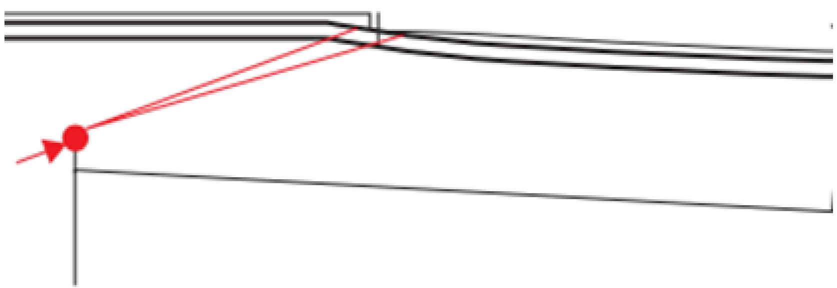


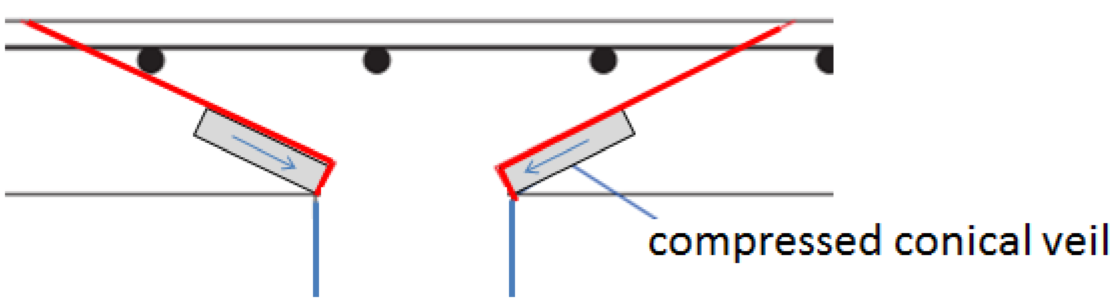
Punching / Străpungere

PUNCHING SHEAR CALCULATION

$$v_{Ed} = \beta \frac{V_{Ed}}{u_0 d} \leq v_{Rd,max} = 0{,}5\nu f_{cd}$$

u_0	for an interior column	u_0 = length of column periphery [mm]
	for an edge column	$u_0 = c_2 + 3d \leq c_2 + 2c_1$ [mm]
	for a corner column	$u_0 = 3d \leq c_1 + c_2$ [mm]





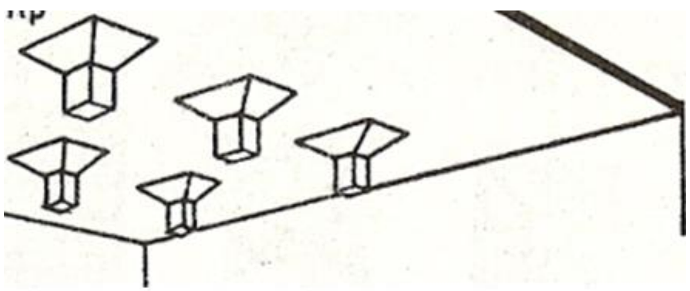
Punching / Străpungere

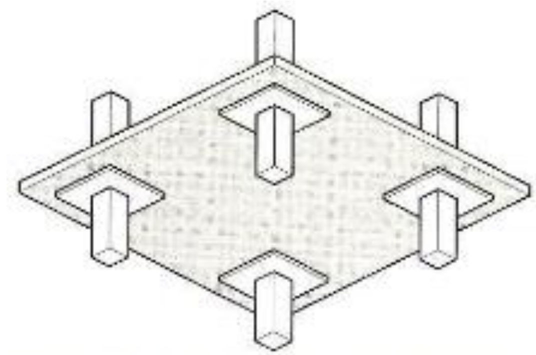
PUNCHING SHEAR CALCULATION

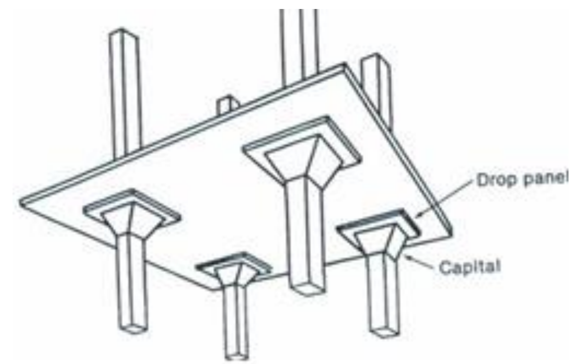
$$v_{Ed} = \beta \frac{V_{Ed}}{u_0 d} > v_{Rd,max} = 0{,}5\nu f_{cd} \quad ?$$

What to do ?

- locally, increased slab thickness



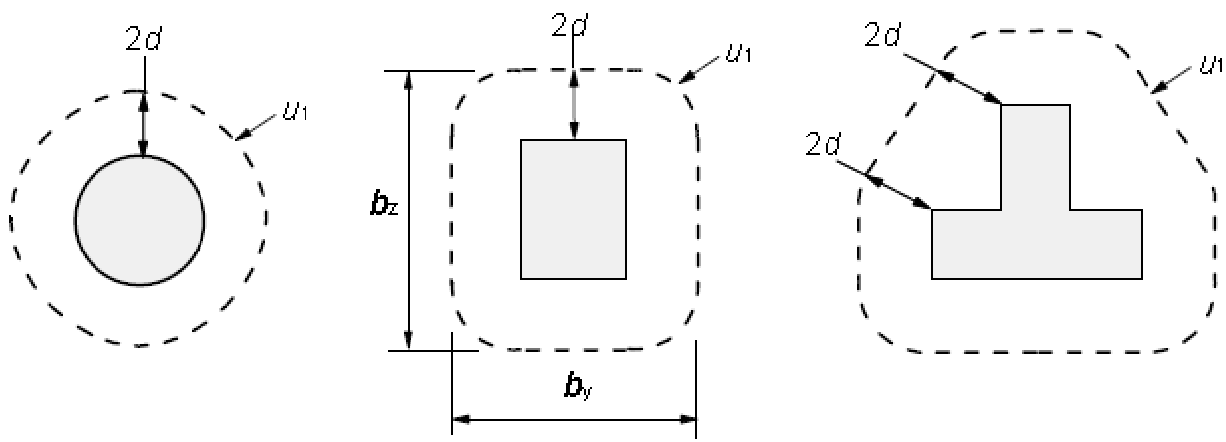


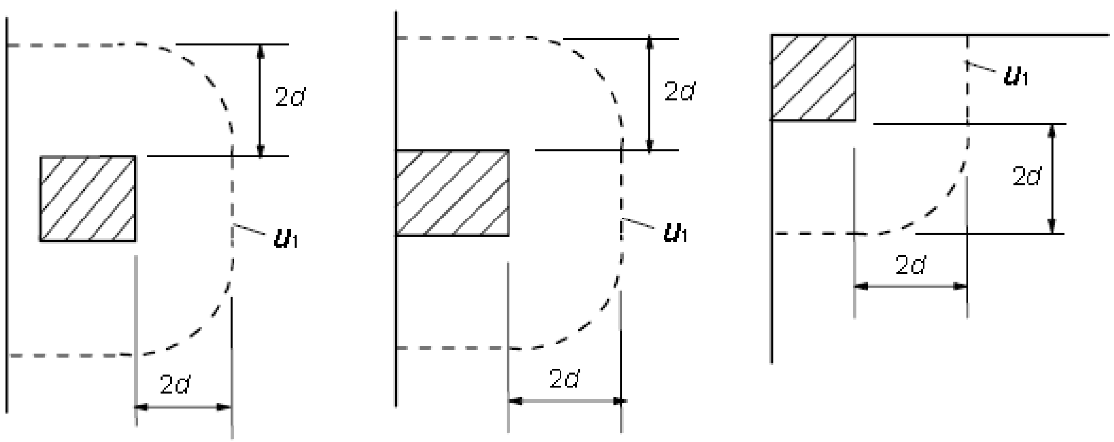


- increased dimensions of column
- higher quality concrete

CHECK AT THE BASIC CONTROL PERIMETER

Typical basic control perimeters around loaded areas





Control perimeters for loaded areas close to or at edge or corner

CHECK AT THE BASIC CONTROL PERIMETER

Slabs without shear reinforcement

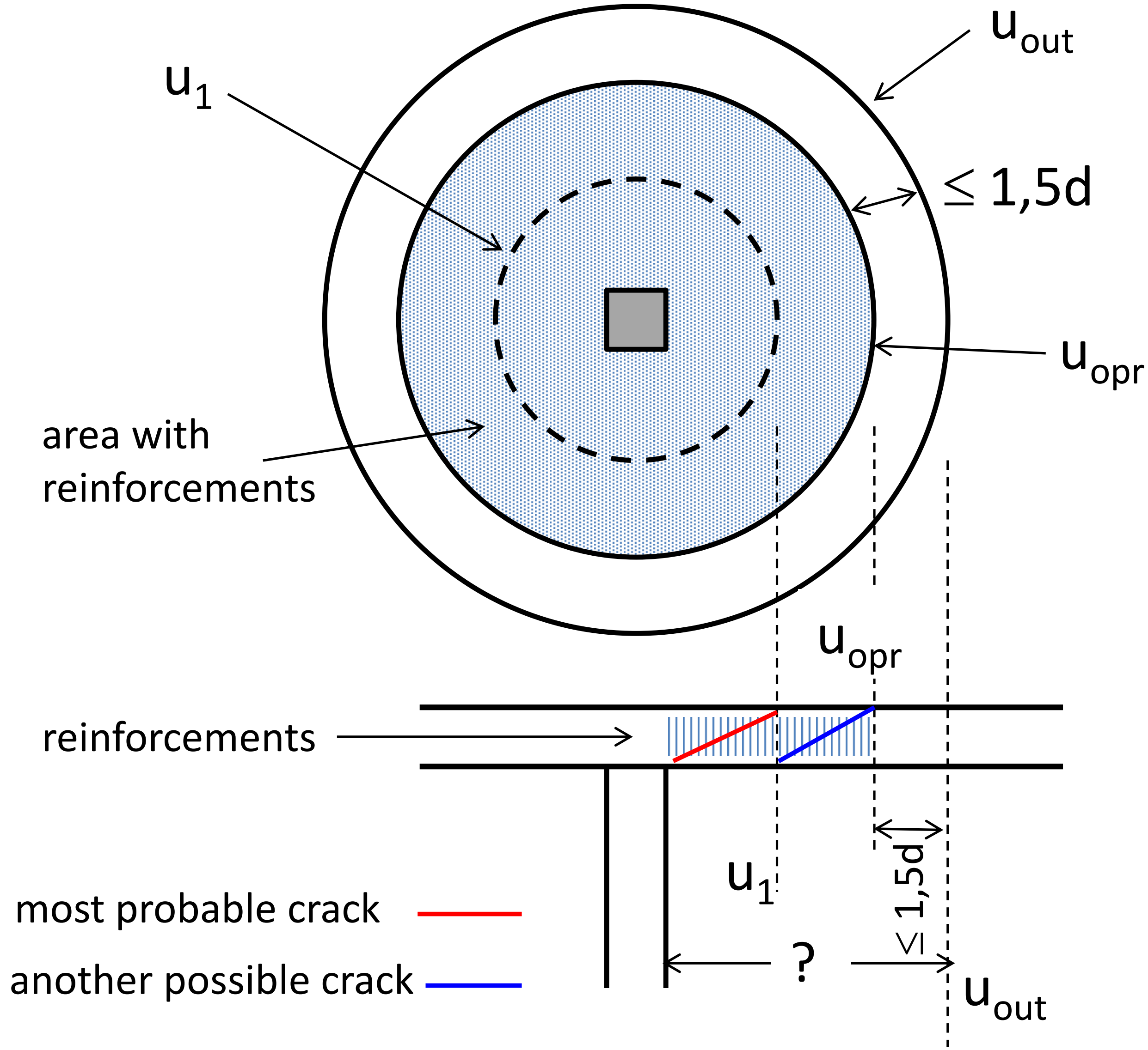
If $v_{Ed} = \beta \frac{V_{Ed}}{u_1 d} \leq v_{Rd,c}$ no calculation for punching reinforcement

CHECK AT THE BASIC CONTROL PERIMETER

Slabs with shear reinforcement

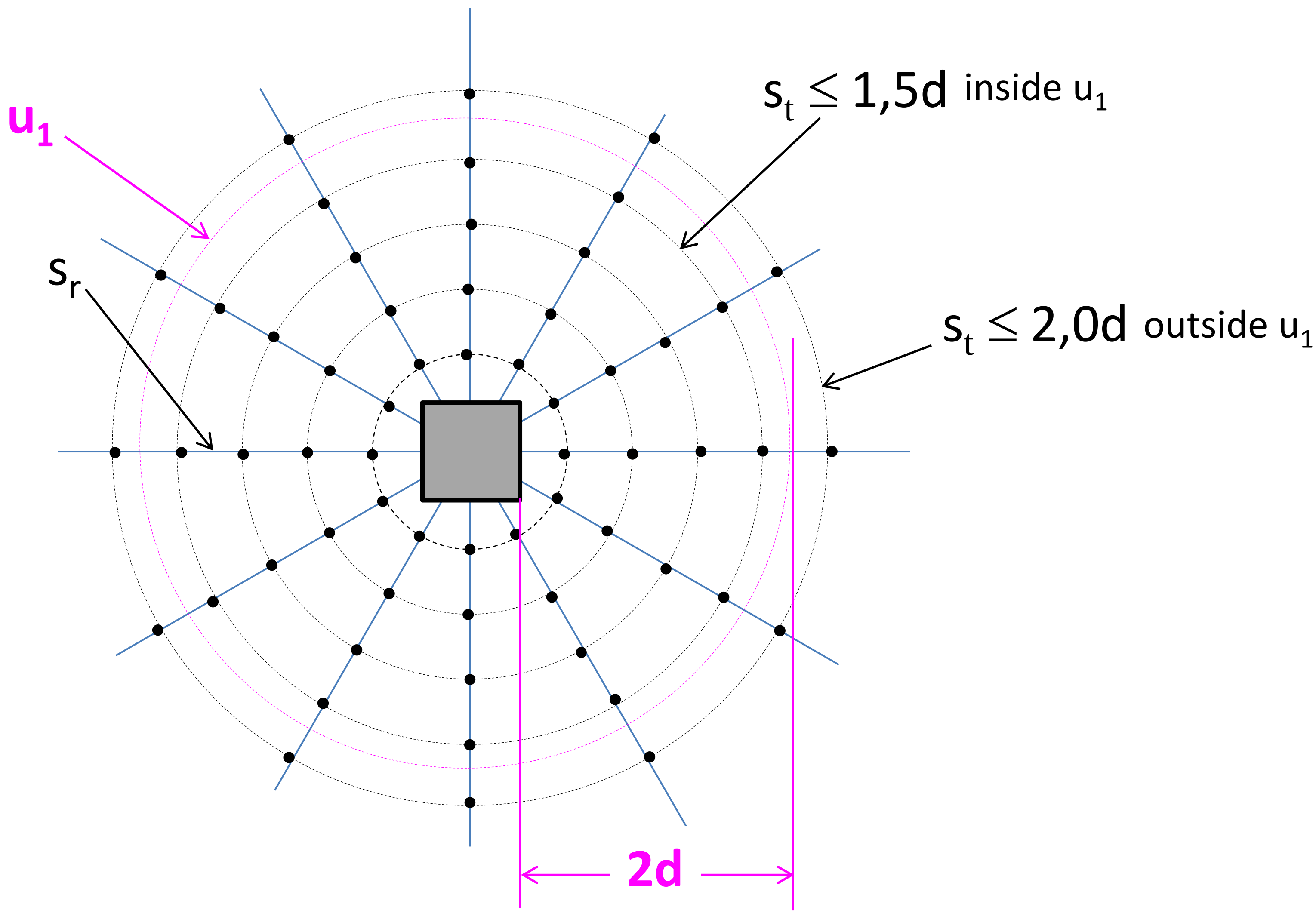
If $v_{Ed} = \beta \frac{V_{Ed}}{u_1 d} > v_{Rd,c}$ punching reinforcement is required

CHECK AT THE BASIC CONTROL PERIMETER



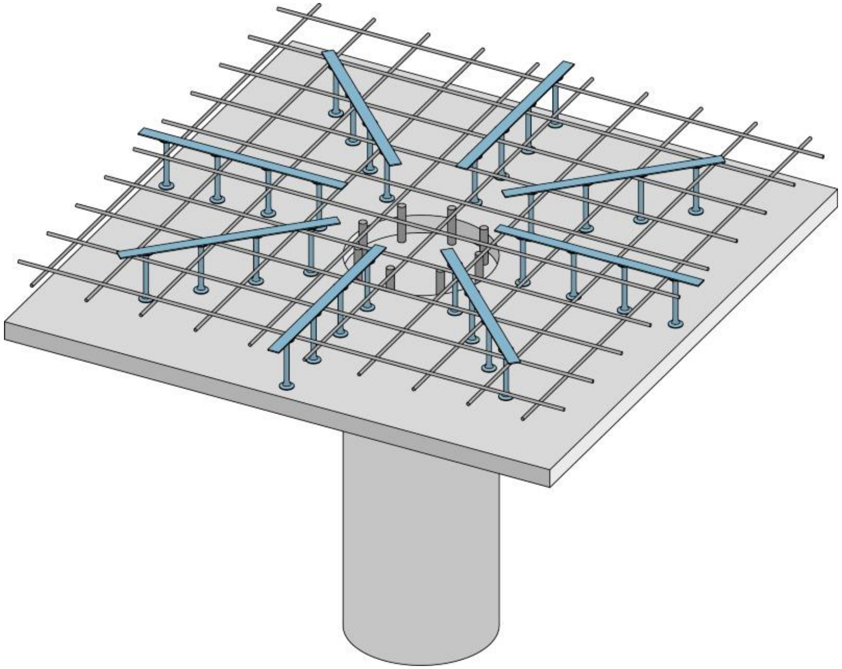
Punching / Străpungere

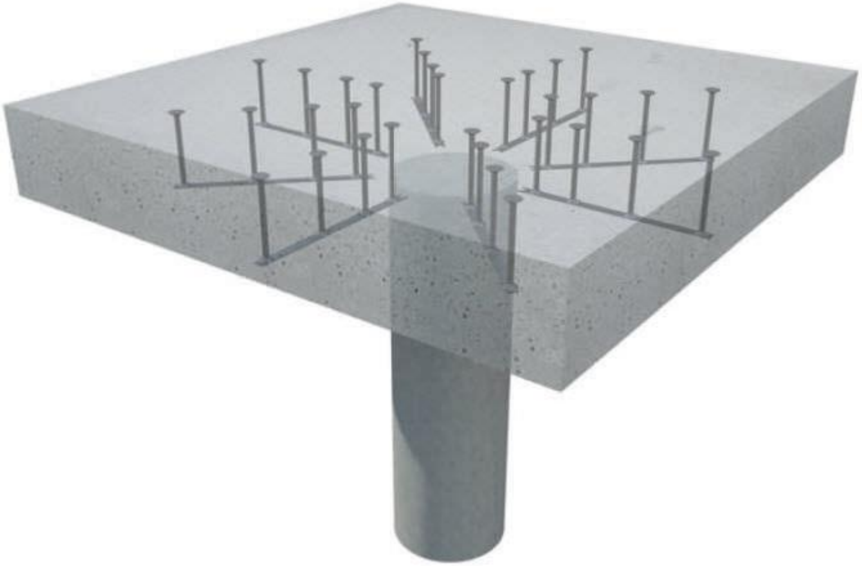
CHECK AT THE BASIC CONTROL PERIMETER

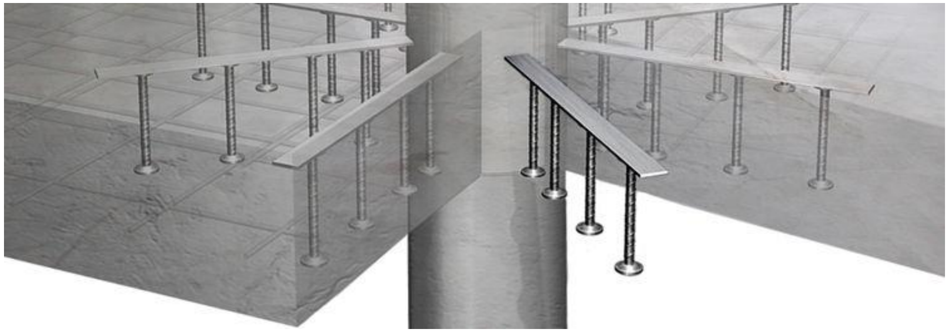


Punching / Străpungere

PUNCHING SHEAR REINFORCEMENTS







Punching / Străpungere

PUNCHING SHEAR REINFORCEMENTS

Punching / Străpungere

PUNCHING SHEAR REINFORCEMENTS

Punching / Străpungere

PUNCHING SHEAR REINFORCEMENTS

THANK YOU FOR YOUR ATTENTION!