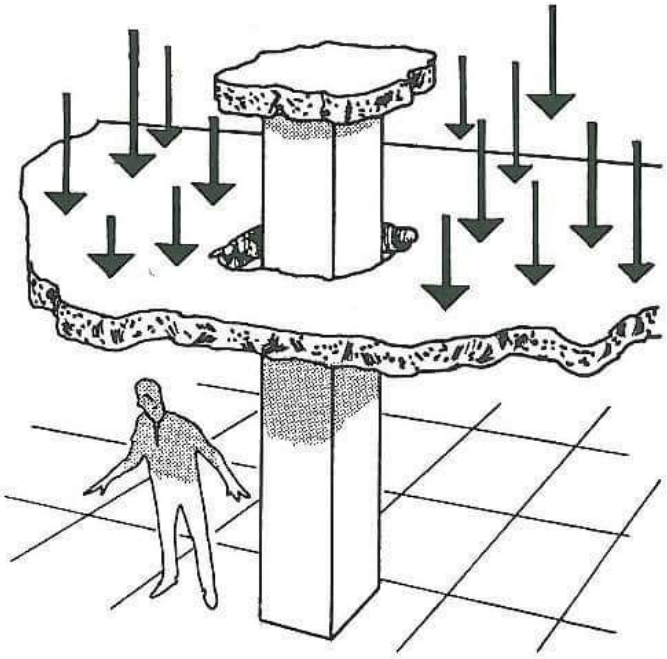

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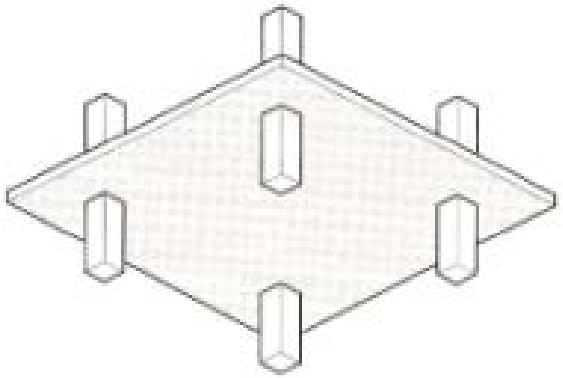
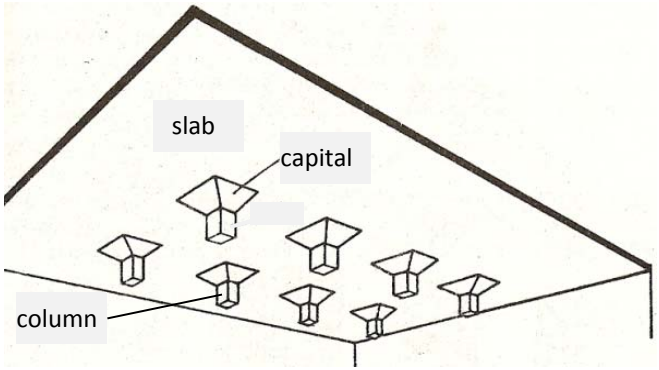
Punching shear can result from a concentrated load or reaction acting on a relatively small area, called the loaded area A_{load} of a slab or a foundation

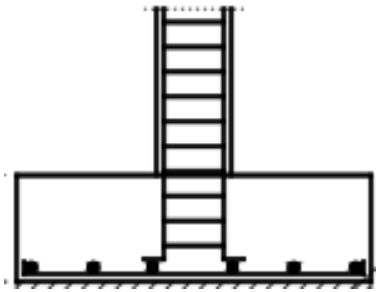


FLAT SLAB

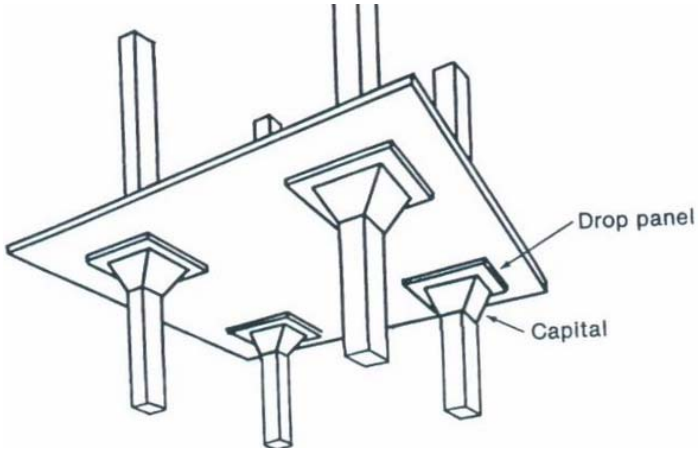


FLARED HEAD
ENLARGED HEAD

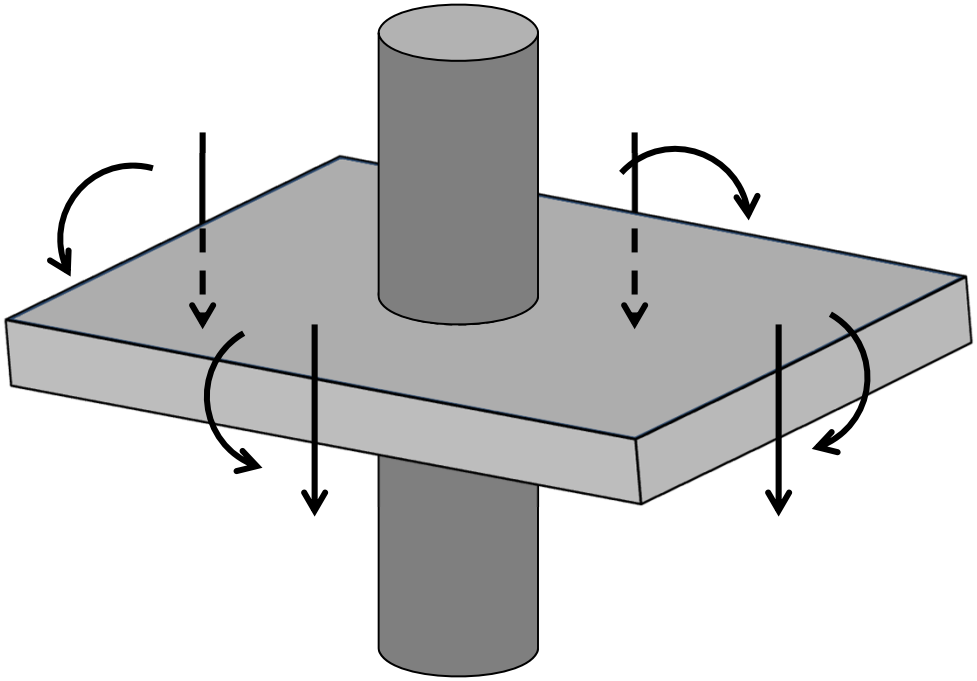
DROPHEAD

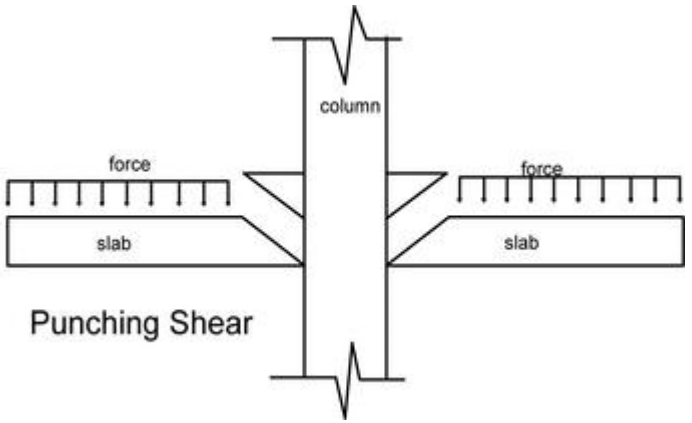


PAD FOUNDATION



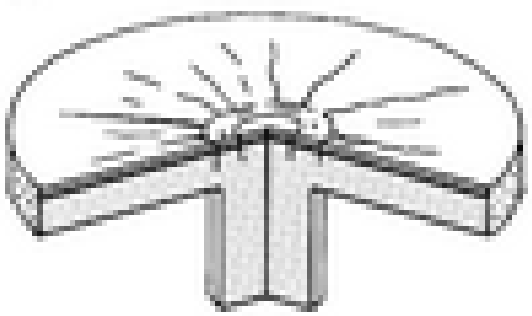
Punching shear can result from a concentrated load or reaction acting on a relatively small area, called the loaded area A_{load} of a slab or a foundation



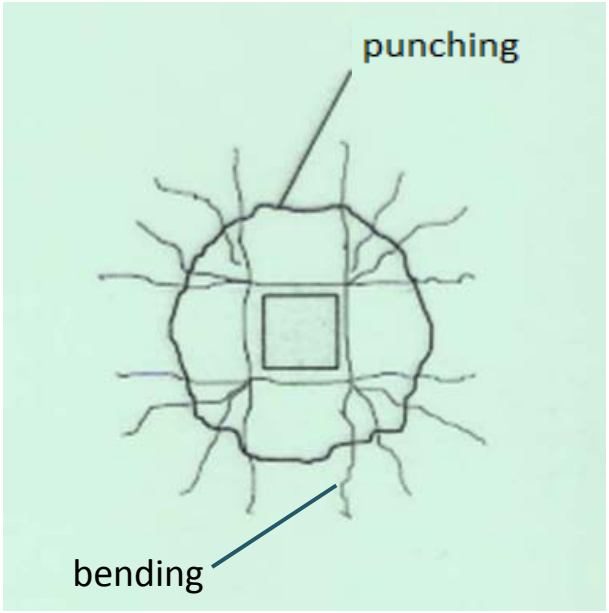


$N_{Ed} \rightarrow \mathbf{V_{Ed}}$

Ways of failure

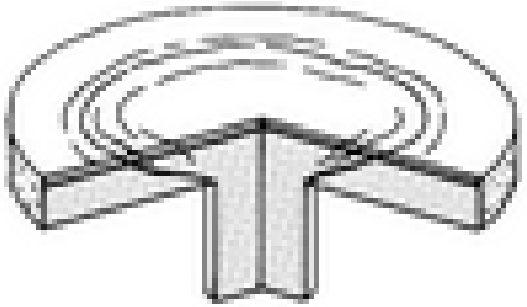


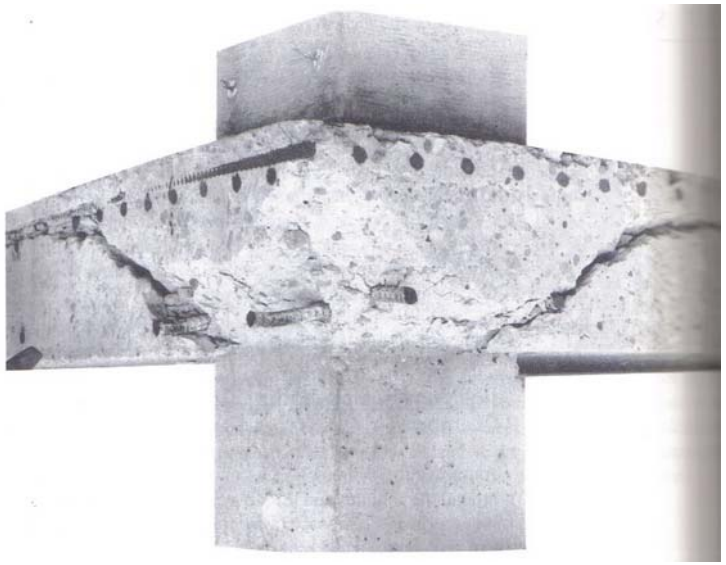
Cracks due to bending



Pattern of crack

Cracks due to punching





Punching surface for
Circular column section → truncated cone
Rectangular column section → truncated pyramid

Ways of failure

Failure within shear-reinforced area

Failure outside shear- reinforced area

Failure closed to column by crushing of concrete

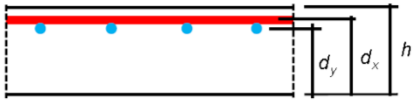
Delamination of concrete core

Failure between transverse reinforcement

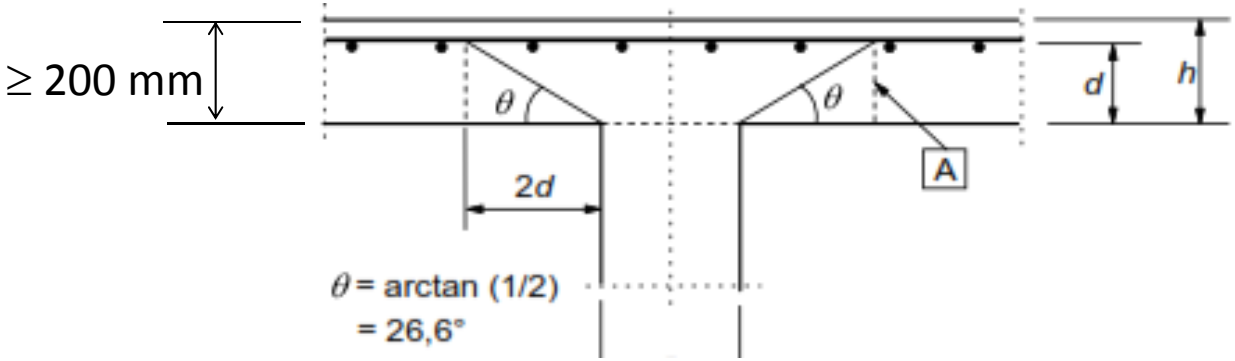
Flexural failure

Load distribution and basic control perimeter

$$d = 0.5(d_x + d_y)$$



effective depth of the slab is assumed constant



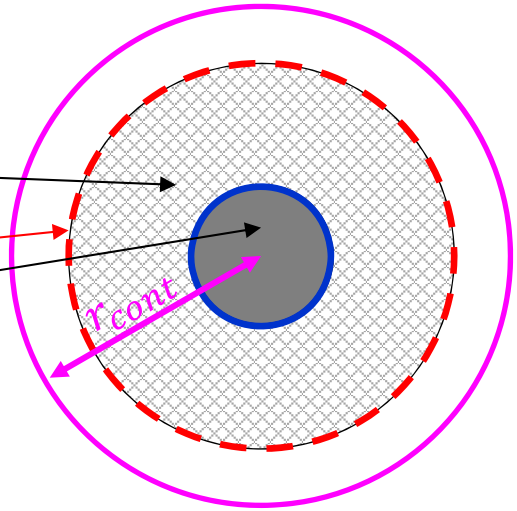
A - basic control section (u_0)

B - basic control area A_{cont}

C - basic control perimeter, $u_1 = 2d$

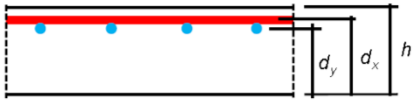
D - loaded area A_{load}

r_{cont} - further control perimeter

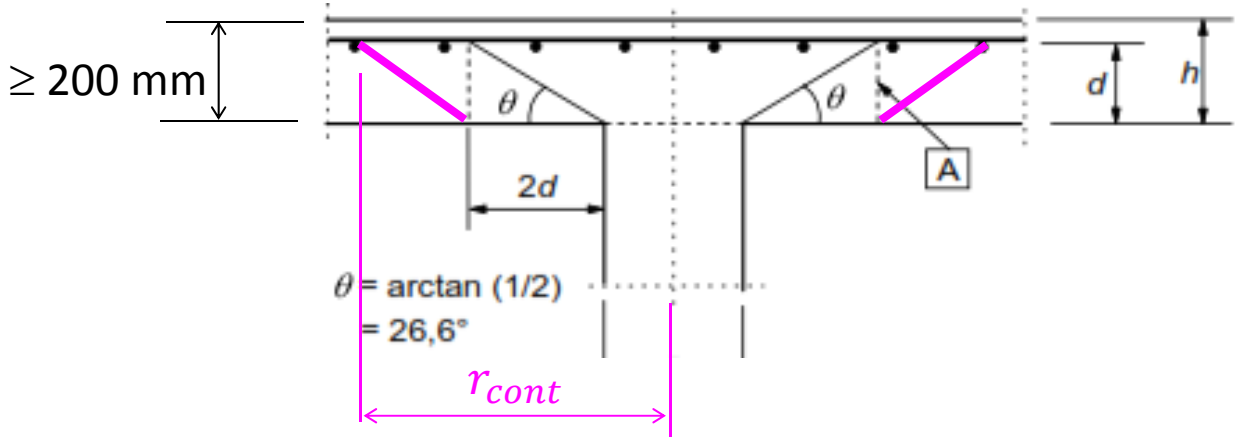


Load distribution and basic control perimeter

$$d = 0.5(d_x + d_y)$$



effective depth of the slab is assumed constant



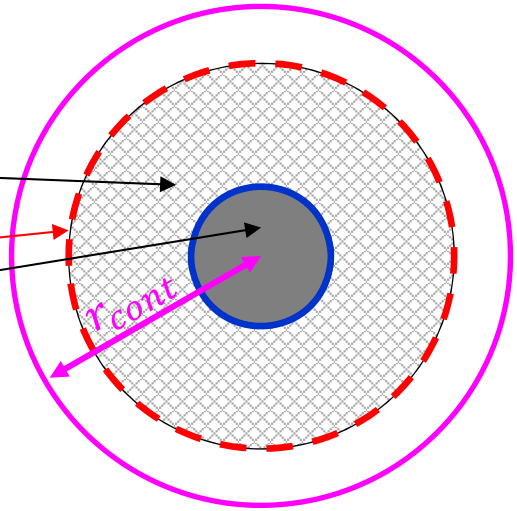
A - basic control section (u_0)

B - basic control area A_{cont}

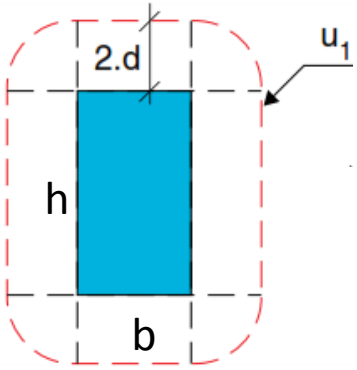
C - basic control perimeter, $u_1 = 2d$

D - loaded area A_{load}

r_{cont} - further control perimeter

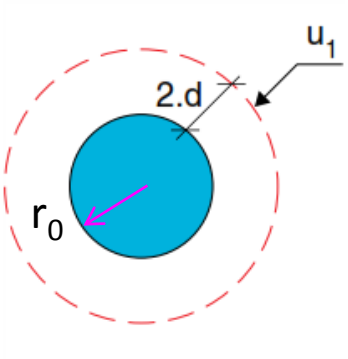


Load distribution and basic control perimeter

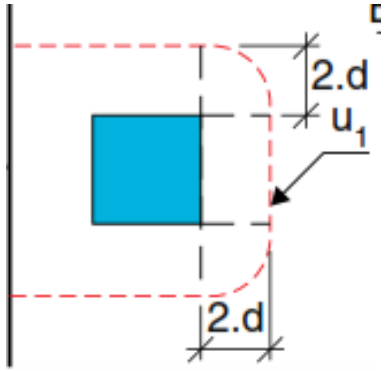


$u_1 = 2(b + h) + 2\pi(2d) = u_0 + 4\,\pi d$

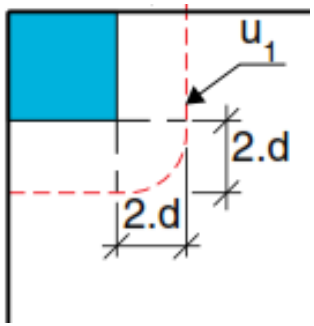
$u_0 = 2(b + h)$ - perimeter



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

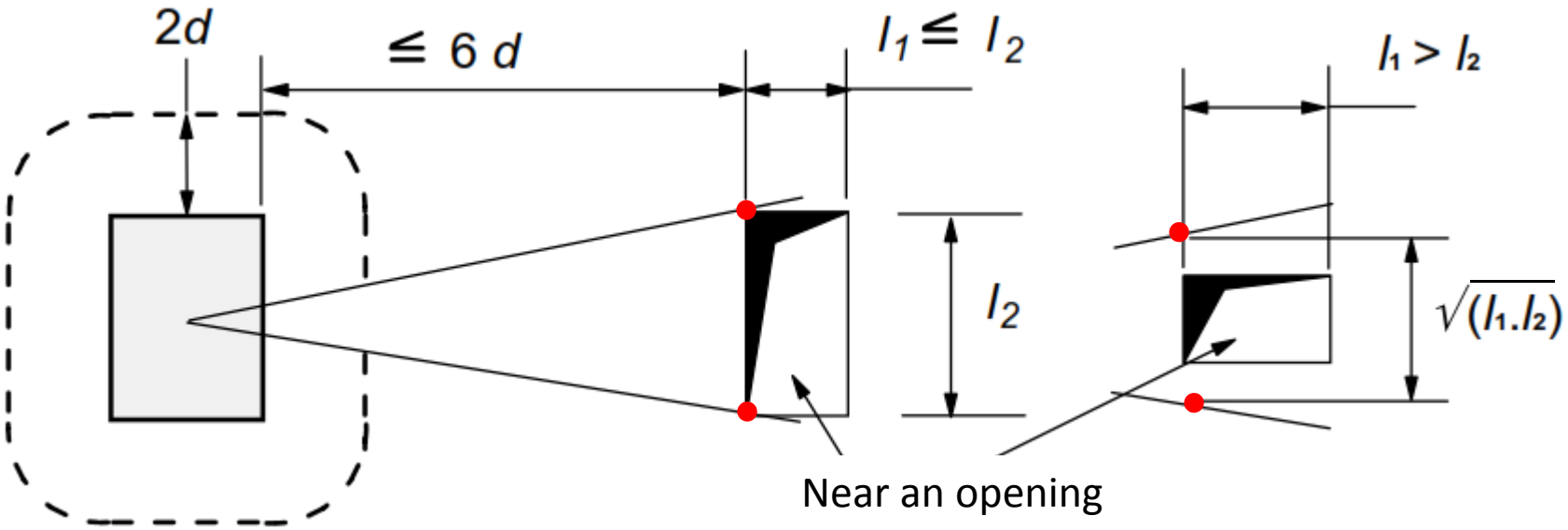


Near edge



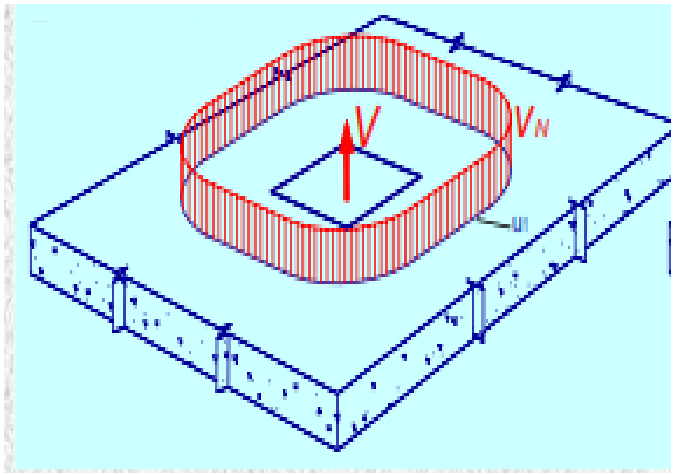
Corner

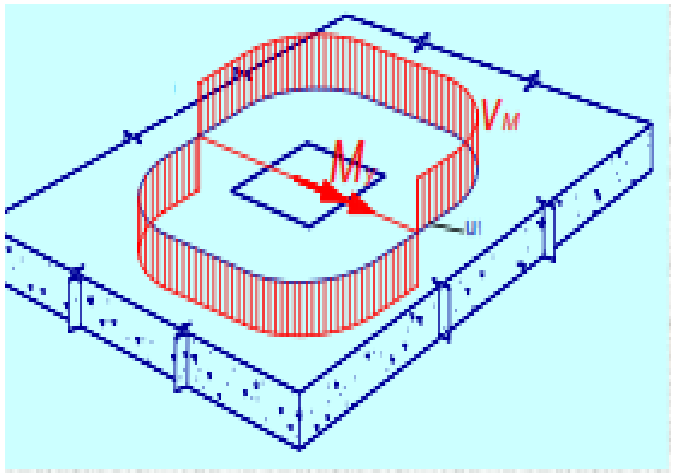
Load distribution and basic control perimeter



Punching shear calculation

Shear stress depends on:



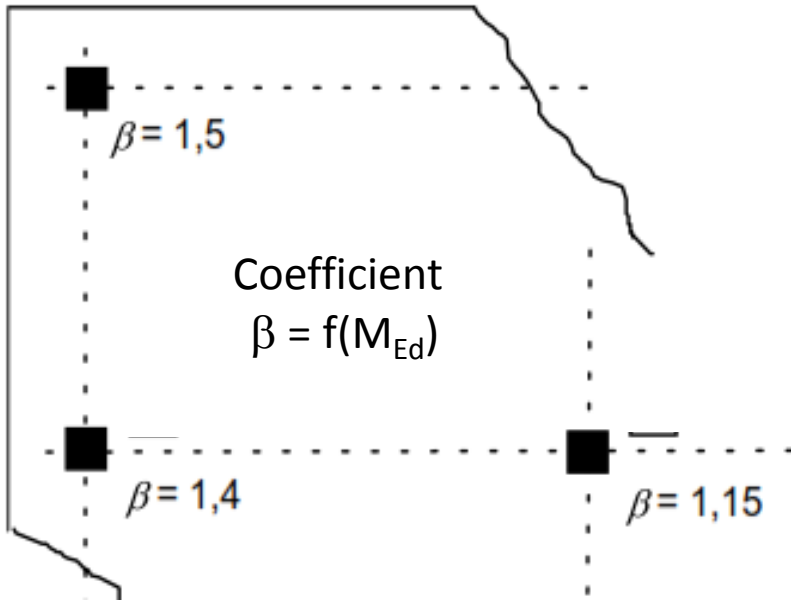


V_{Ed} & M_{Ed}

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 shear stress



Punching shear calculation

The design procedure for punching shear is based on checks at the:

- face of the column u_0
- basic control perimeter u_1

If shear reinforcement is required a further perimeter u_{out} should be found where shear reinforcement is no longer required.

The following design shear stresses along the control sections are defined:

$v_{Rd,c}$ is the design value of the punching shear resistance of a slab without punching shear reinforcement along the control section considered.

$v_{Rd,cs}$ is the design value of the punching shear resistance of a slab with punching shear reinforcement along the control section considered.

$v_{Rd,max}$ is the design value of the maximum punching shear resistance along the control section considered.

Punching shear calculation

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

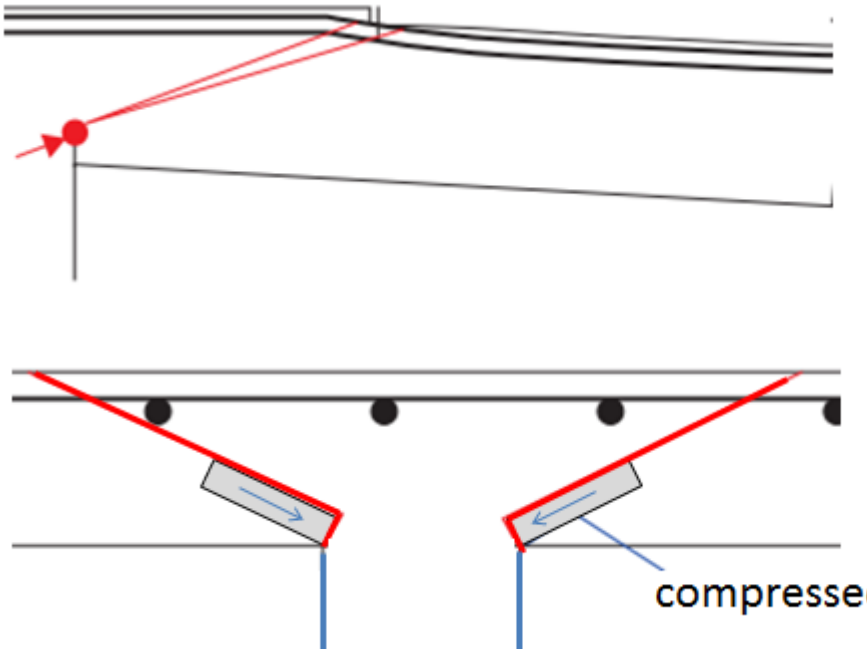
design value of the maximum punching shear resistance along the control section considered

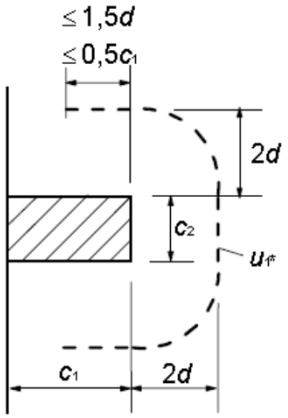
u_0 — u_0 = length of column periphery [mm]

for an interior column

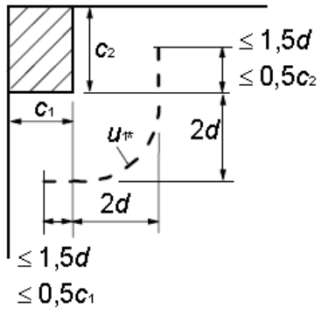
for an edge column — $u_0 = c_2 + 3d \leq c_2 + 2c_1$ [mm]

for a corner column — $u_0 = 3d \leq c_1 + c_2$ [mm]





a) edge column



b) corner column

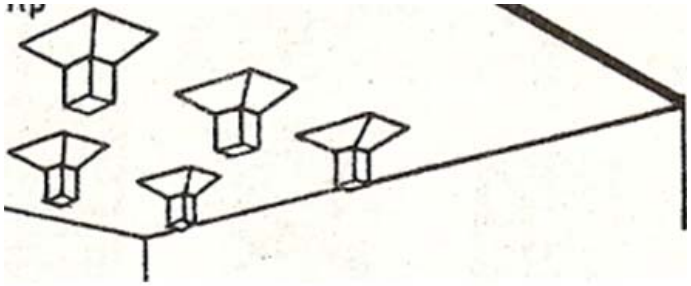
Punching shear calculation

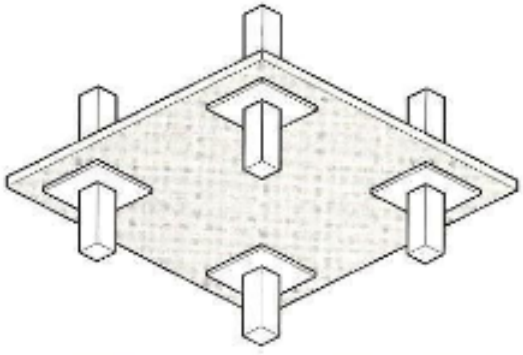
$$v_{Ed,u_0} = \beta \frac{V_{Ed}}{u_0 \cdot d} \geq v_{Rd,max}$$

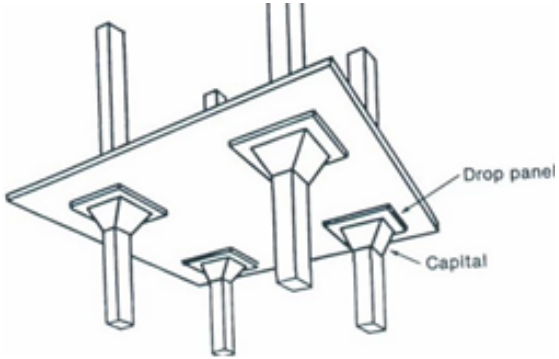
?

What to do ?

- locally, increased slab thickness



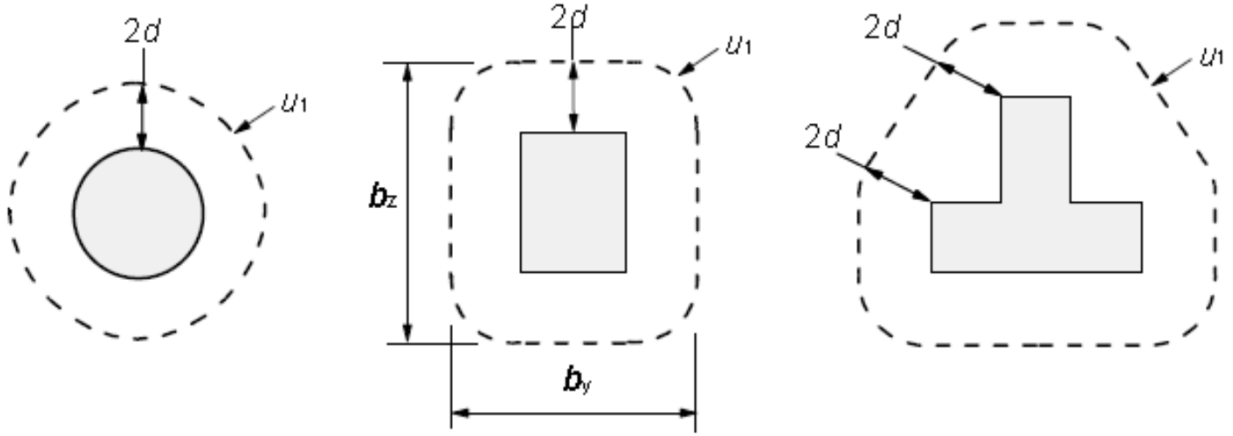




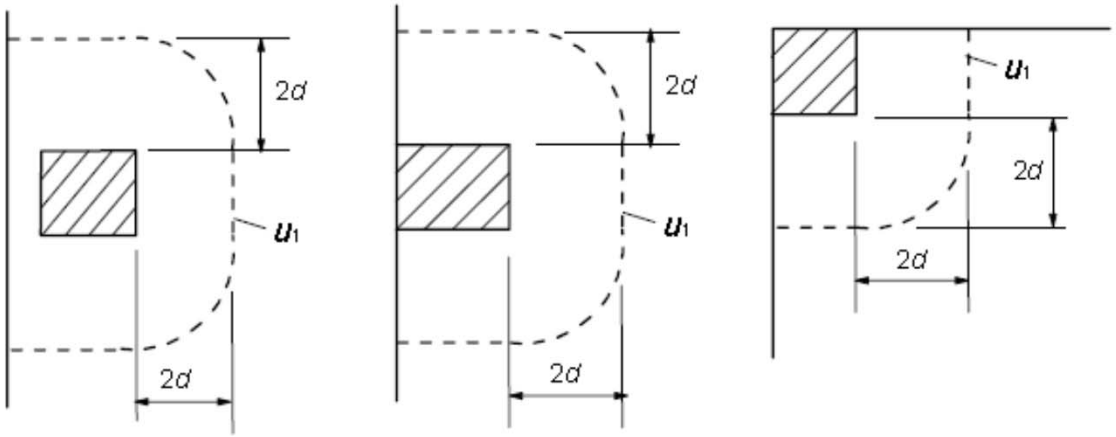
- increased dimensions of column
- higher quality concrete

Check at the basic control perimeter (u_1)

The punching resistance of column bases should be verified at control perimeters within 2*d* from the periphery of the column!



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 (u_1)

Slabs without shear reinforcement

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

The design punching shear resistance:

$$v_{Rd,c} = C_{Rd,c} k (100 \rho_l f_{ck})^{1/3} + k_1 \sigma_{cp} \geq (v_{min} + k_1 \sigma_{cp})$$

where:

f_{ck} is in MPa

$k = 1 + \sqrt{\frac{200}{d}} \leq 2{,}0$ d in mm

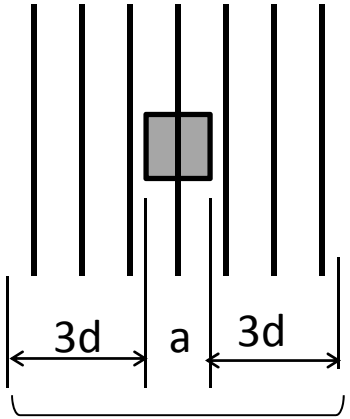
$\rho_l = \sqrt{\rho_{ly} \cdot \rho_{lz}} \leq 0{,}02$

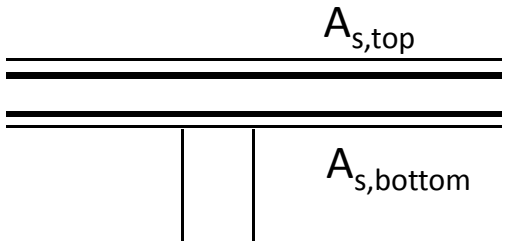
ρ_{ly}, ρ_{lz} relate to the bonded tension steel in y- and z- directions respectively. The values ρ_{ly} and ρ_{lz} should be calculated as mean values taking into account a slab width equal to the column width plus 3d each side.

Check at the basic control perimeter (u_1)

Slabs without shear reinforcement

$$\rho = \frac{A_s}{(6d + a)d}$$





$\sigma_{cp} = (\sigma_{cy} + \sigma_{cz})/2$

σ_{cy}, σ_{cz} are the normal concrete stresses in the critical section in y- and z-directions (MPa, positive if compression):

$$\sigma_{c,y} = \frac{N_{Ed,y}}{A_{cy}} \quad ; \quad \sigma_{c,z} = \frac{N_{Ed,z}}{A_{cz}}$$

$$C_{Rd,c} = 0{,}18/\gamma_c = 0{,}18/1{,}5 = 0{,}12$$

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

$k_1 = 1{,}0$

Check at the basic control perimeter (u_1)

Slabs with shear reinforcement

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

The control perimeter $\mathbf{u_{out}}$ at which reinforcement is not require is obtained from:

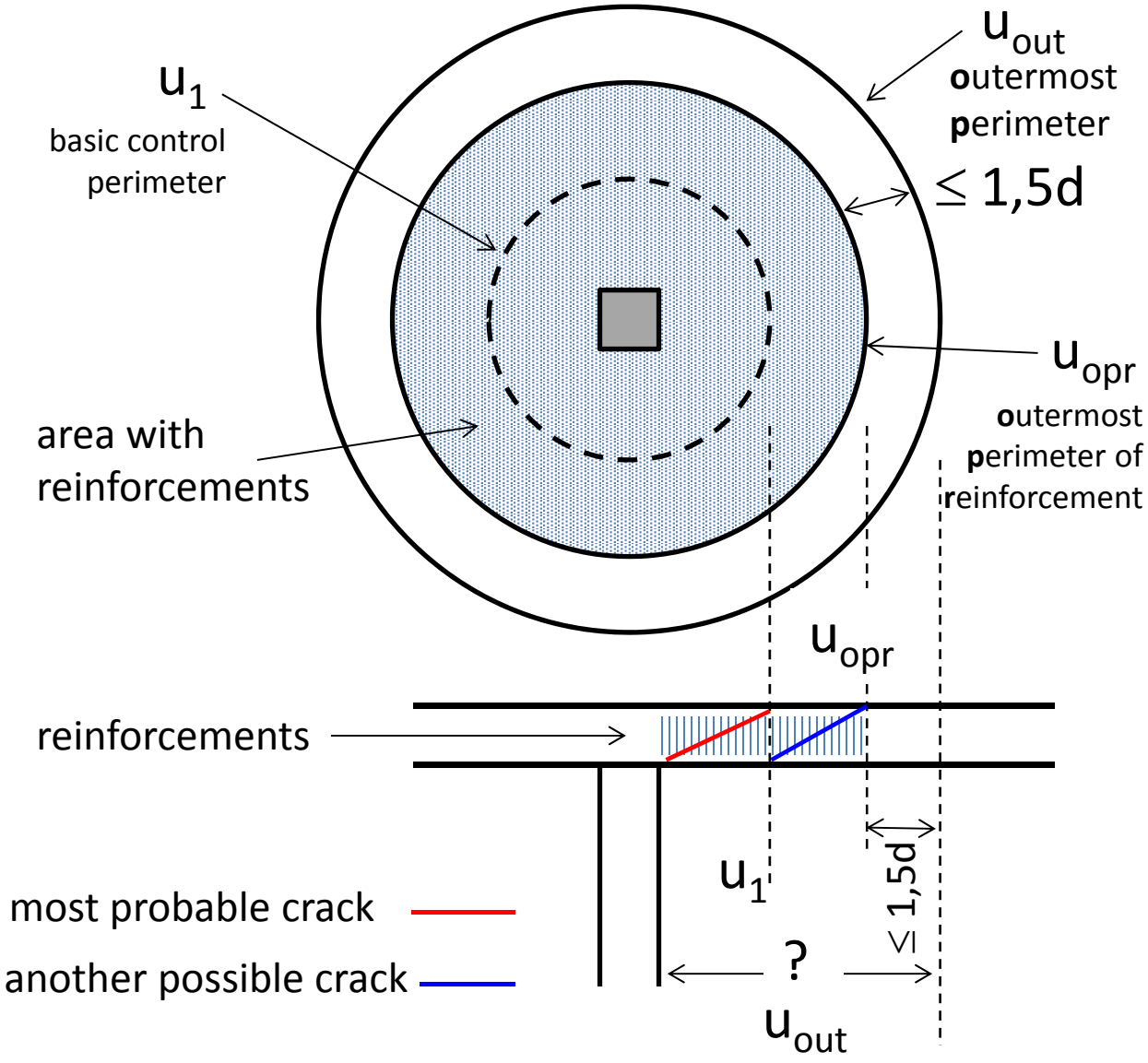
$V_{Rd,c} = \beta V_{Ed} \rightarrow$ (resistance force of plain concrete = load)

$v_{Rd,c}\, u_{out} d = \beta V_{Ed}$

$$u_{out} = \frac{\beta V_{Ed}}{v_{Rd,c} d}$$

The **o**utermost **p**erimeter of **r**einforcement $\mathbf{u_{opr}}$ should be placed at a distance $\leq 1{,}5d$ from $\mathbf{u_{out}}$

Check at the basic control perimeter (u_1)



Check at the basic control perimeter (u_1)

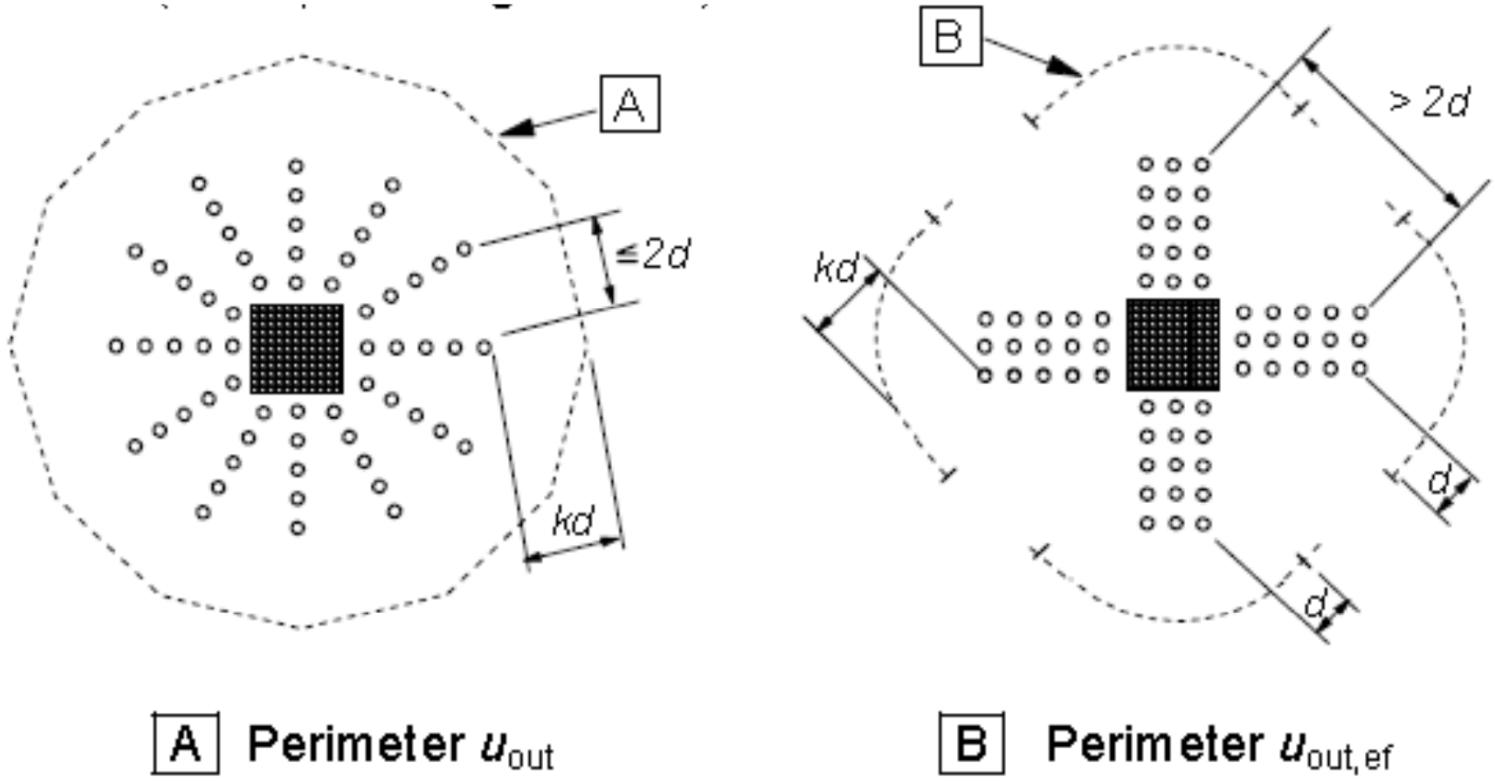
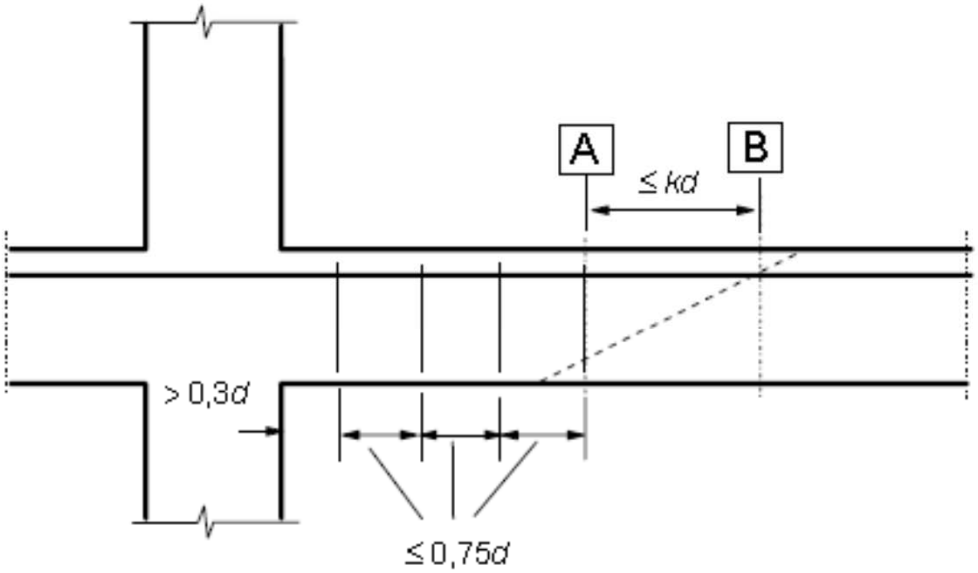
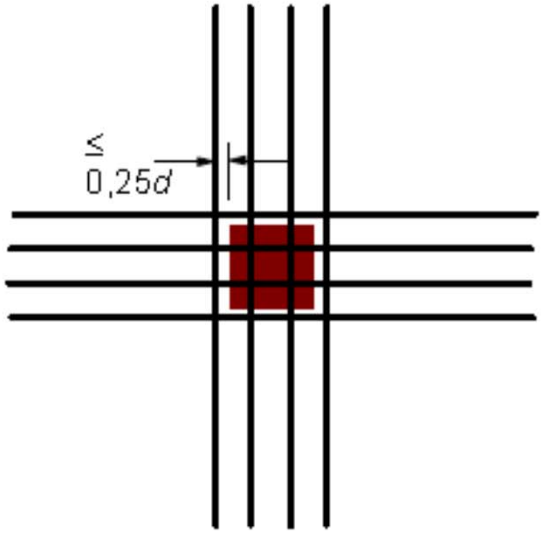


Figure 6.22: Control perimeters at internal columns

Check at the basic control perimeter (u_1)

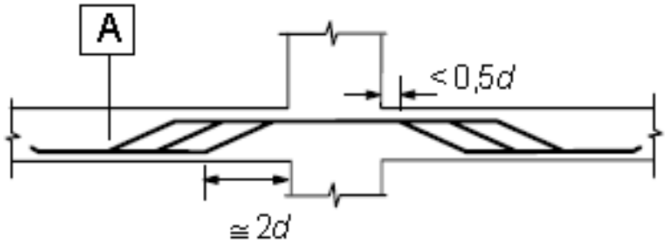




A - outer control perimeter requiring shear reinforcement

B - first control perimeter not requiring shear reinforcement

a) Spacing of links

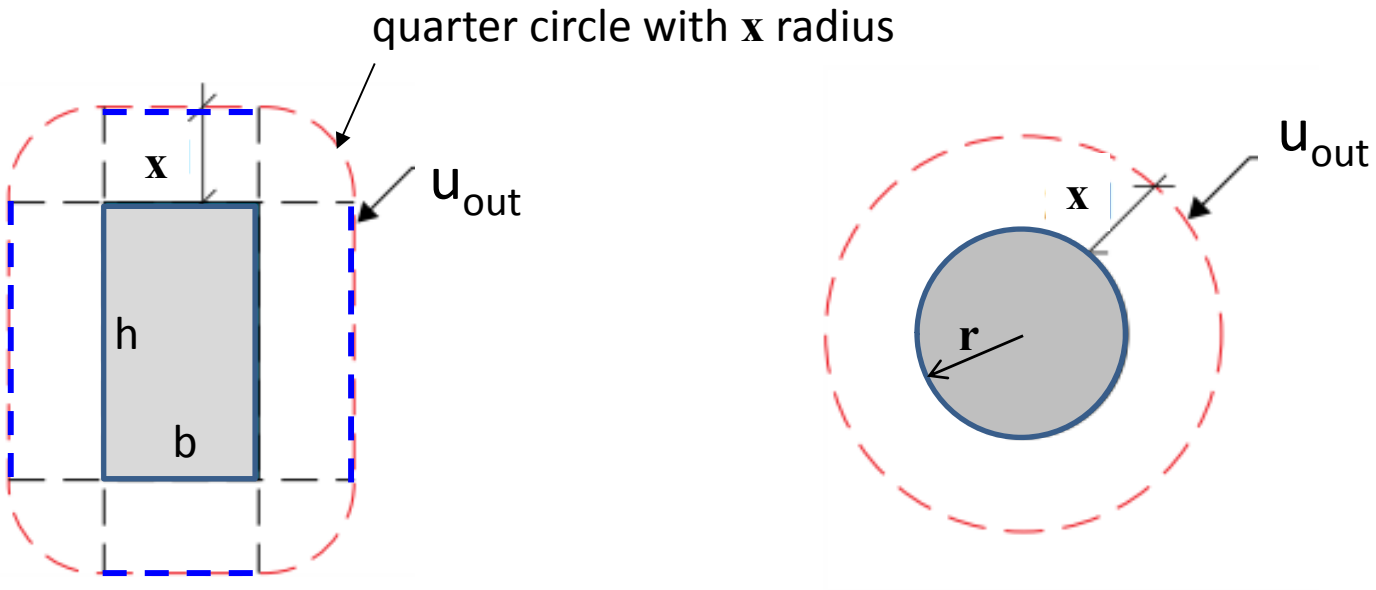


b) Spacing of bent-up bars

Figure 9.10: Punching shear reinforcement

Check at the basic control perimeter (u_1)

Problem: how far from the edge of the column is u_{out} ?

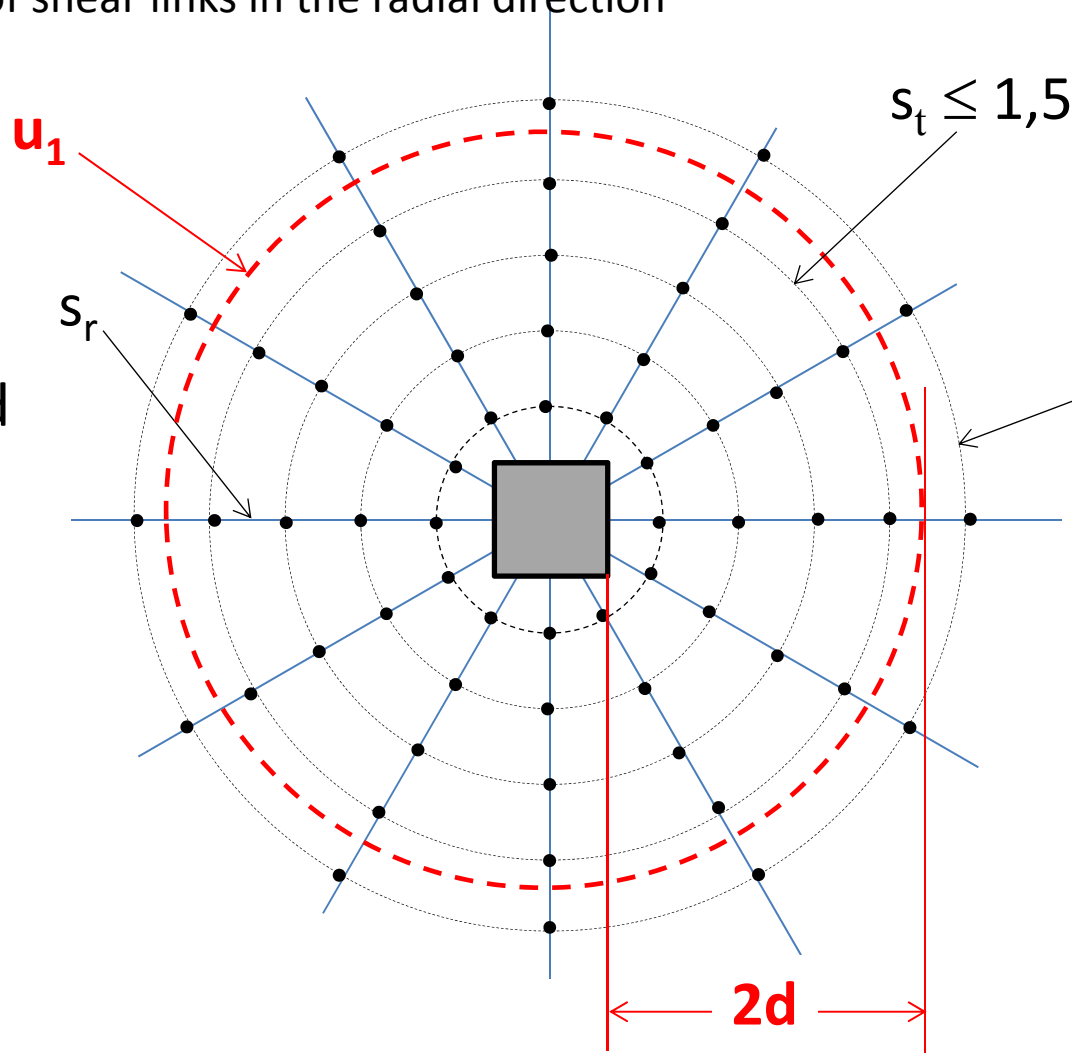


$u_{out} = 2b + 2h + 4 \cdot quarters = u_o + 2\pi \cdot xd$ $\quad u_{out} = 2\pi \cdot (r + x)$

$x = (u_{out} - u_o)/2\pi d$ $\quad x = u_{out}/2\pi - r$

Check at the basic control perimeter (u_1)

s_t - spacing of shear links in the tangential direction
s_r - spacing of shear links in the radial direction



$s_t \leq 1{,}5d$ inside u_1

$s_t \leq 2{,}0d$ outside u_1

$s_r \leq 0.75d$

Checking of punching shear resistance with shear reinforcement

$$v_{Rd,cs} = 0{,}75(v_{Rd,c} + v_{Rd,s}) \leq v_{Ed}$$

0,75 ← imprecision in assessment of resistance

Concrete contribution: $v_{Rd,c} = C_{Rd,c}\, k\, (100\rho_l\ f_{ck})^{1/3} + k_1\sigma_{cp} \geq (v_{min} + k_1\sigma_{cp})$

Reinforcement contribution: $v_{Rd,s} = 1{,}5\ (d/s_r)\ A_{sw}\, f_{ywd,ef}\ (1/(u_1 d))\ \sin\alpha$

NOTE:

1. Contribution of concrete and reinforcement to the shear induced by punching !

2. No such contribution of concrete and reinforcement in case of shear induced by shear force !

Checking of punching shear resistance with shear reinforcement

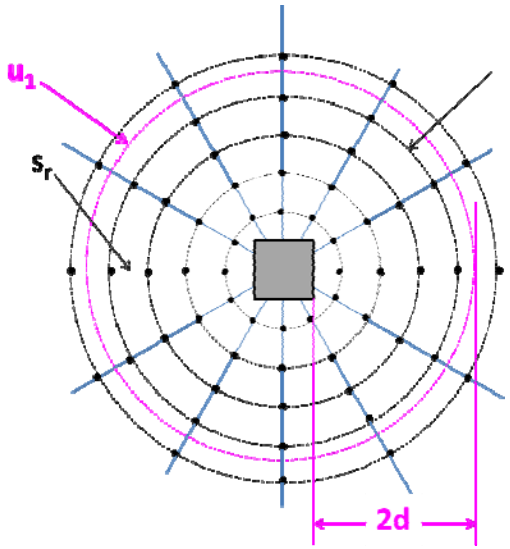
$$V_{Rd,s} = A_{sw,tot} f_{ywd,ef}$$

$$V_{Rd,s} = \frac{2d}{s_r} A_{sw} f_{ywd,ef}$$

number of perimeters

area of bars in one perimeter

/ $u_1 d$



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

$$v_{Rd,s} = \frac{2}{u_1 \cdot s_r} A_{sw} f_{ywd,ef}$$

Checking of punching shear resistance with shear reinforcement

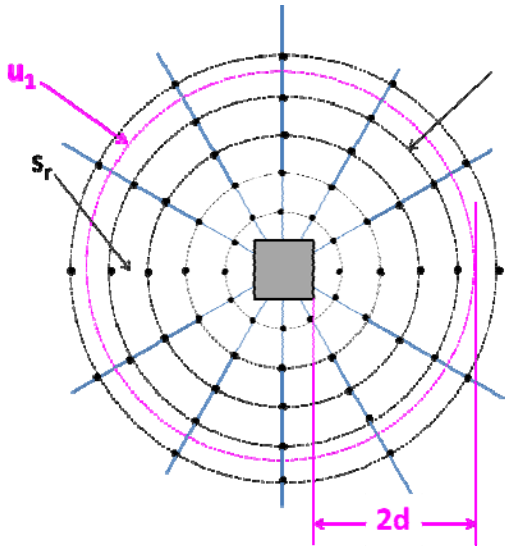
$$v_{Rd,cs} = 0{,}75(v_{Rd,c} + v_{Rd,s}) \leq v_{Ed}$$

$$v_{Rd,s} = \frac{2}{u_1 s_r} A_{sw} f_{ywd,ef}$$

$$v_{Rd,cs} = 0{,}75 v_{Rd,c} + 1{,}5 \frac{A_{sw} f_{ywd,ef}}{u_1 s_r} \quad \text{(EC2 format)}$$

where

$$f_{ywd,ef} = 250 + 0.25d < f_{ywd}$$



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

Reinforcement calculation

Assessment of basic control perimeter u_1

There is chosen s_r $\rightarrow$ number of rings inside u_1

There is chosen s_t $\rightarrow$ number of bars for one ring

Area of bars for control perimeter is obtained from condition: $v_{Rd,cs} = v_{Ed}$

$$0{,}75 v_{Rd,c} + 1{,}5 \frac{A_{sw} f_{ywd,ef}}{u_1 s_r} = v_{Ed}$$

$$A_{sw,req} = \frac{v_{Ed} - 0{,}75 v_{Rd,c}}{1{,}5 f_{ywd,ef}} u_1 s_r \quad (mm^2/\text{perimeter } u_1)$$

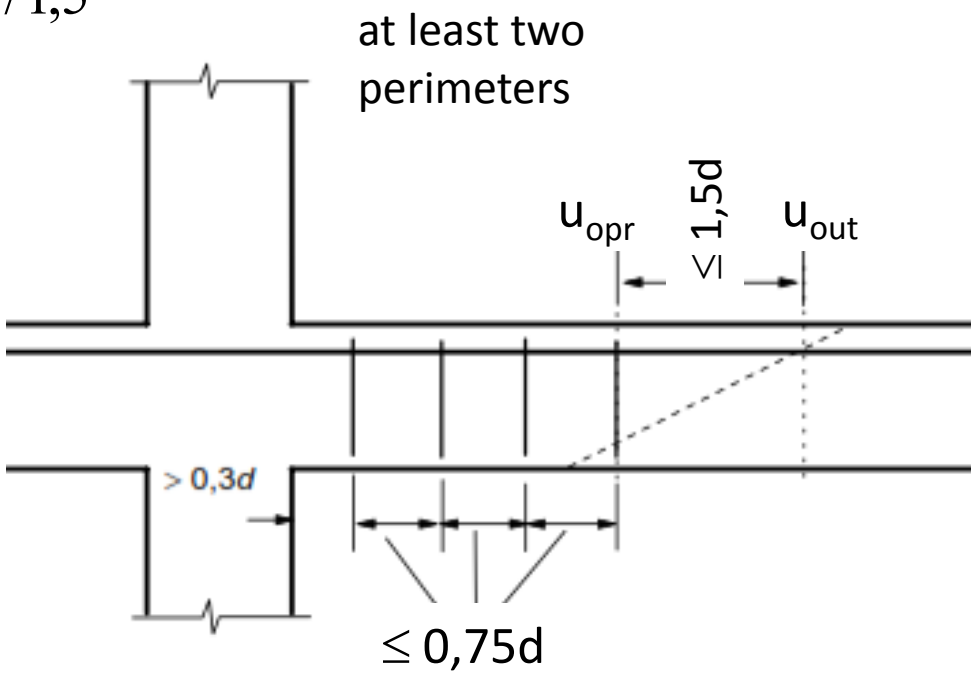
$\frac{A_{sw,req}}{u_1}$ (mm^2/mm) – area for unit length of control perimeter

$$A_{1\phi,req} = \frac{A_{sw}}{u_1} s_t \quad (mm^2)$$ – required area of one bar in perimeter u_1

Reinforcement calculation

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

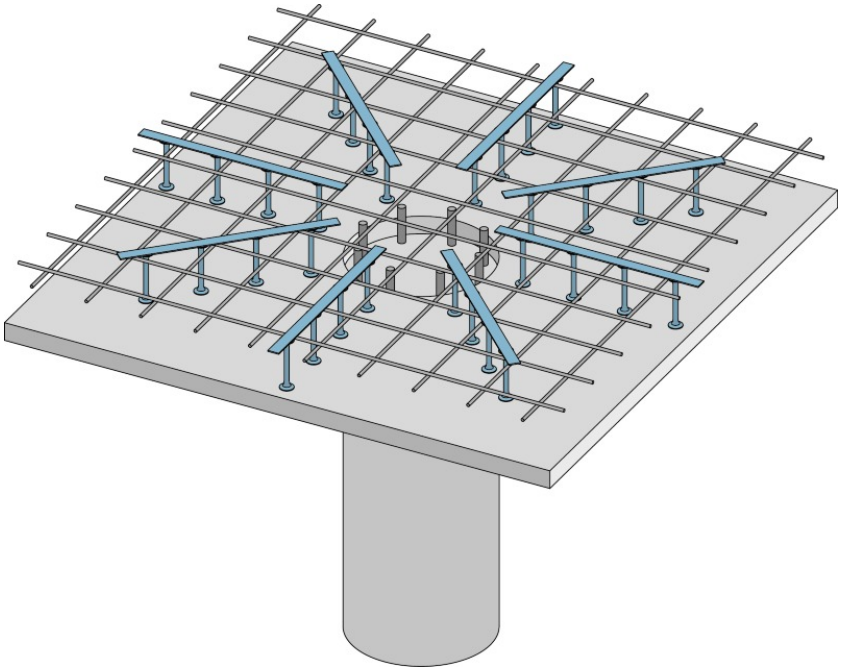
$$A_{1\phi,eff} \geq \rho_{min} s_r s_t / 1{,}5$$

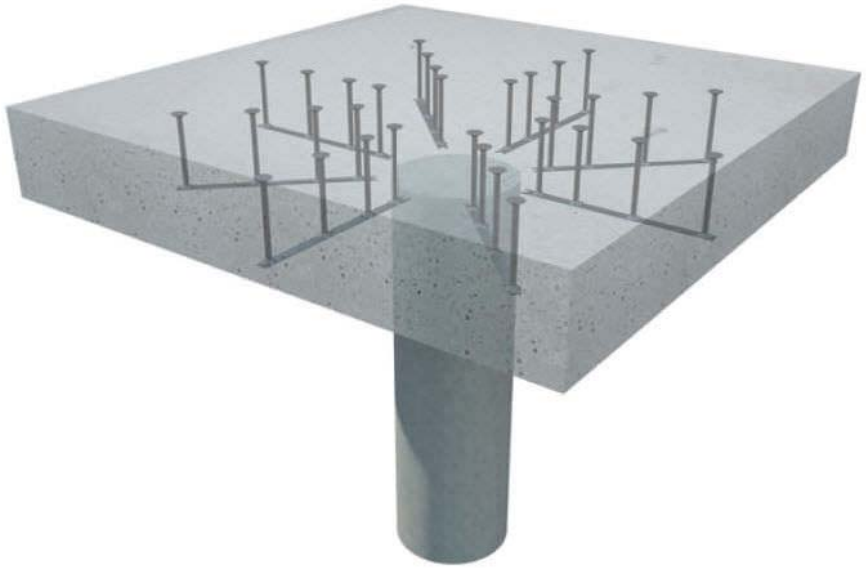


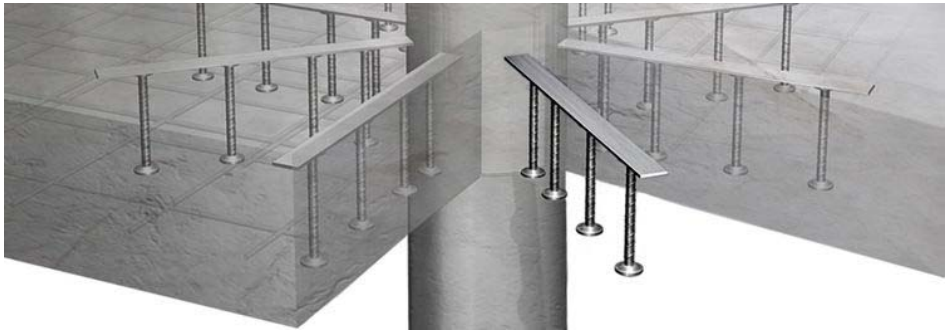
Minimum/Maximum distance between the face of a support and the nearest shear reinforcement

$> 0{,}30d \;\&\; \leq 0{,}50d$

Punching shear reinforcements

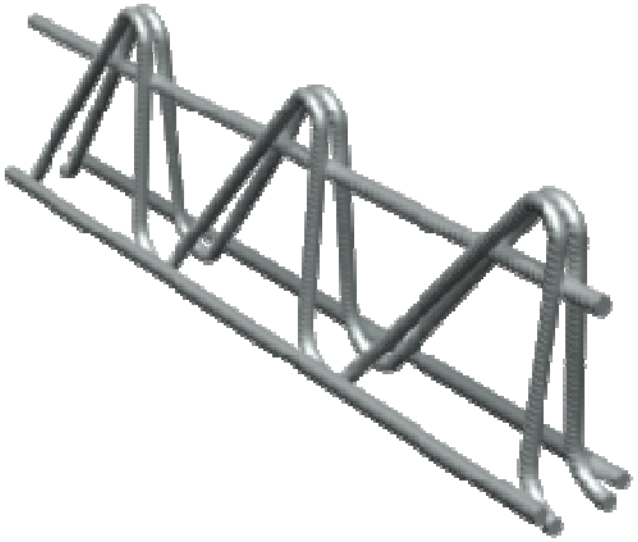




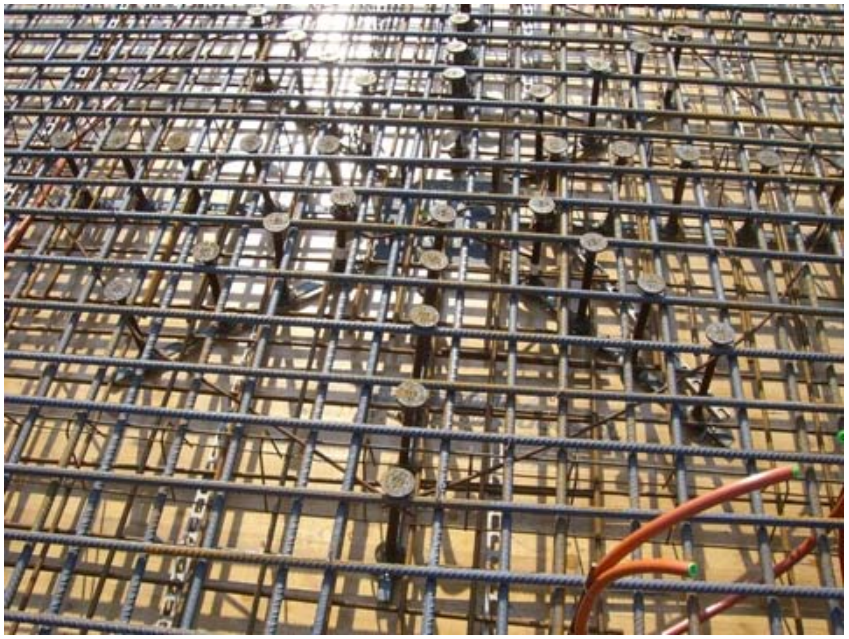


Punching shear reinforcements

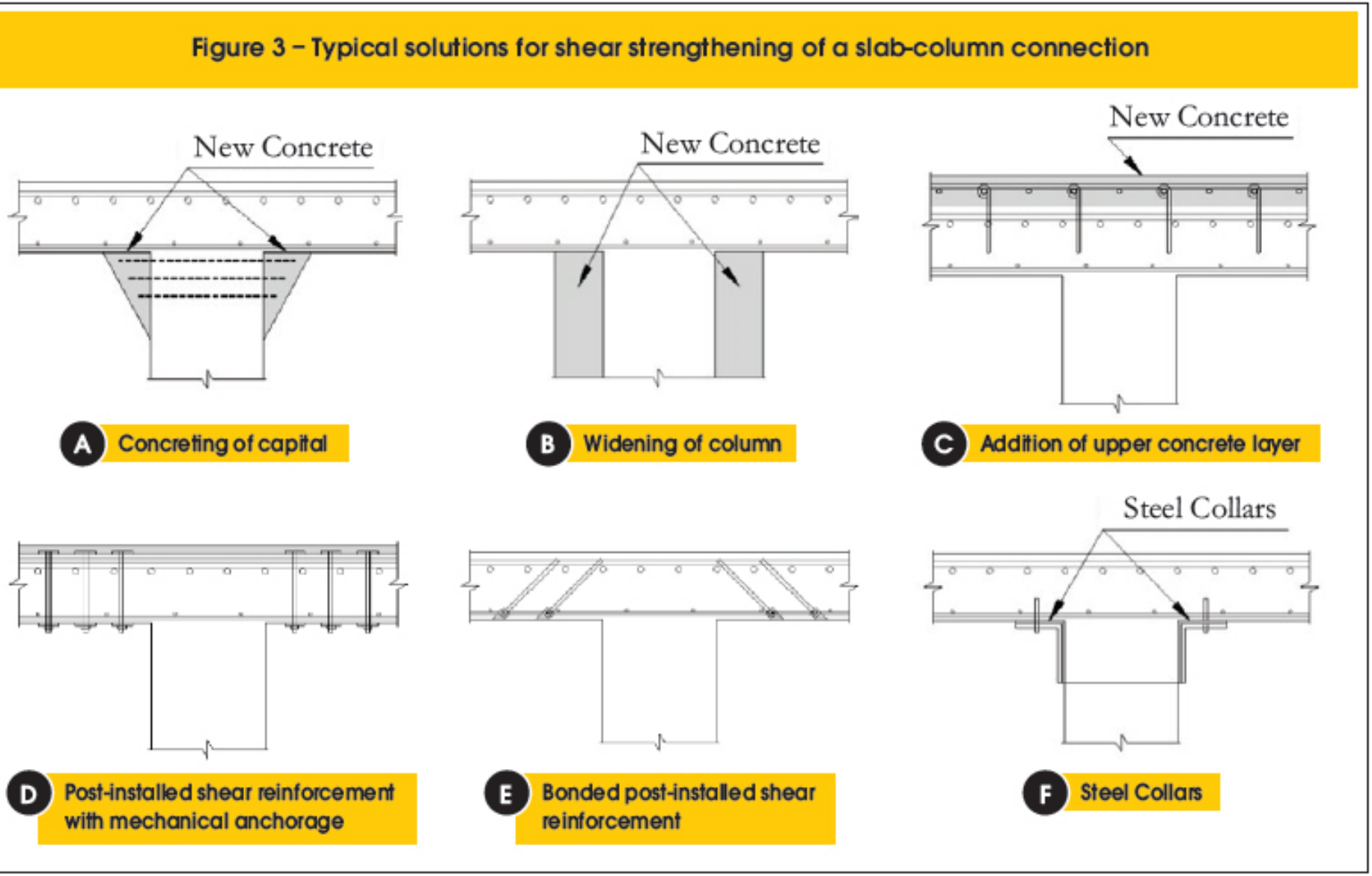
Punching shear reinforcements



Punching shear reinforcements



Retrofitting



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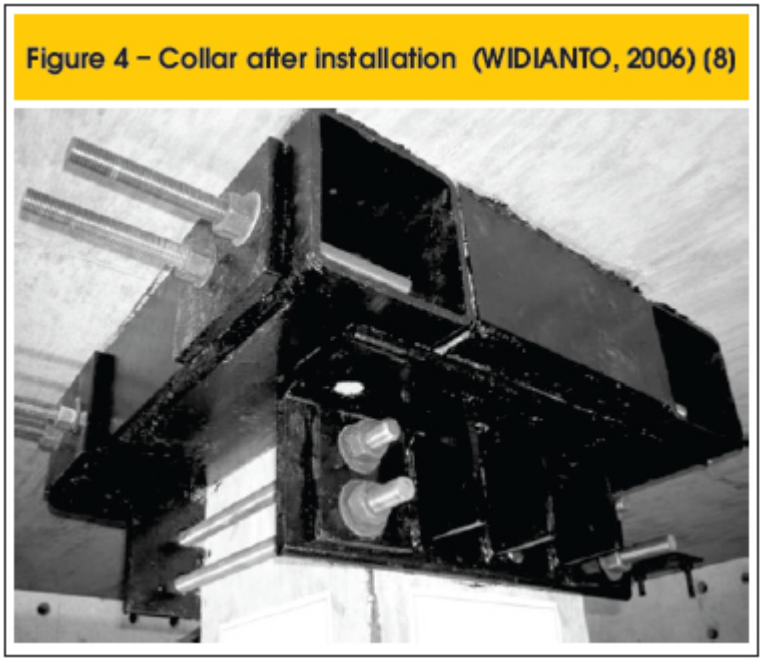
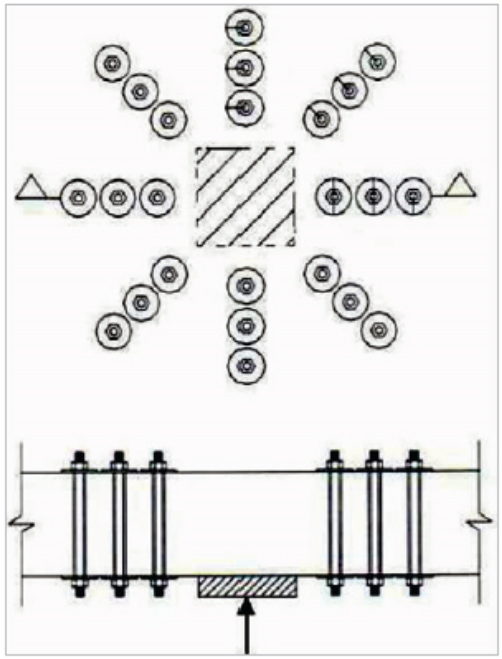
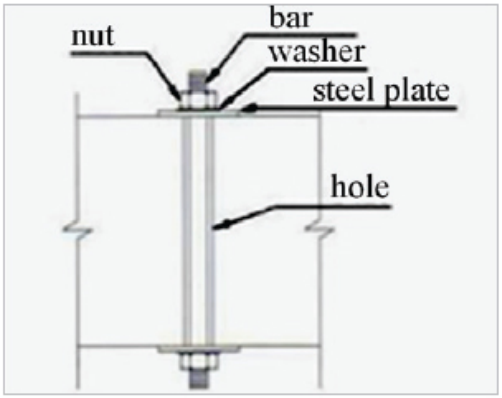
Retrofitting



Retrofitting

Figure 6 – Post-installed shear reinforcement with steel plates as anchorage (CARVALHO, 2001) (10)





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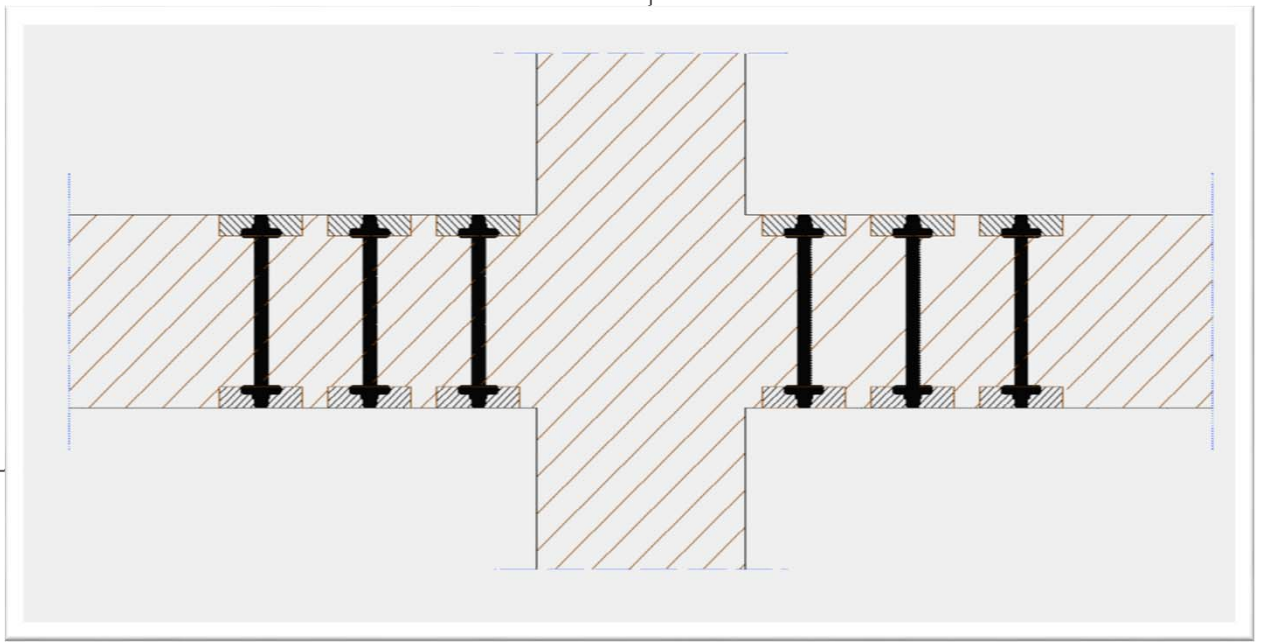

Retrofitting

THANK YOU FOR YOUR ATTENTION!

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