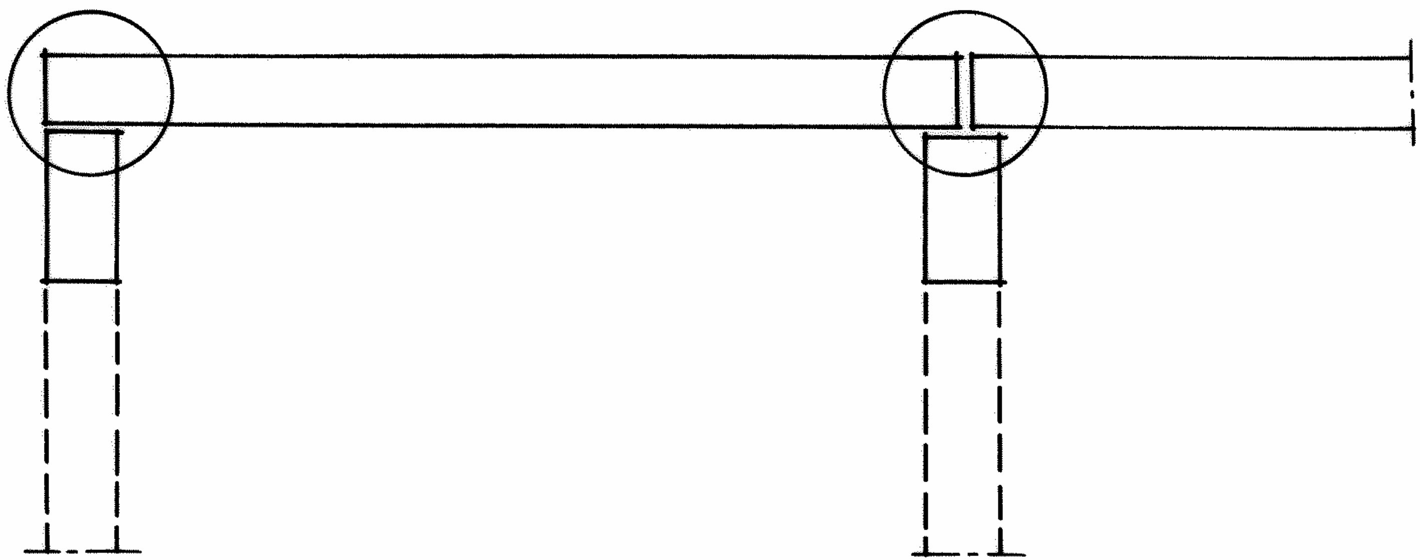
Design of Structural Connections

Björn Engström
Chalmers University of Technology
Göteborg, Sweden

Content

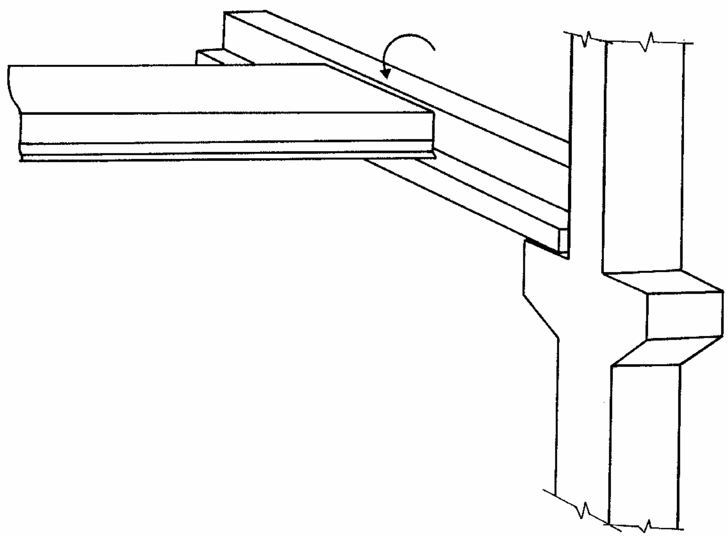
- Design philosophy
  - Structural purpose
  - Force paths at different levels
  - Mechanical behaviour – design aspects
- Basic force transfer mechanisms
  - Compression
  - Shear
  - Tension
  - Bending - torsion
- fib Bulletin on –Structural connections

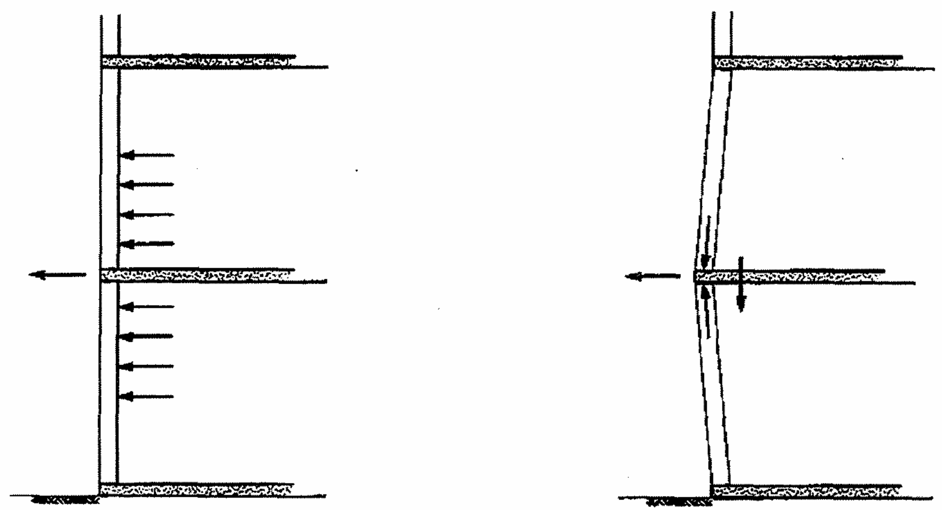
Design of structural connections



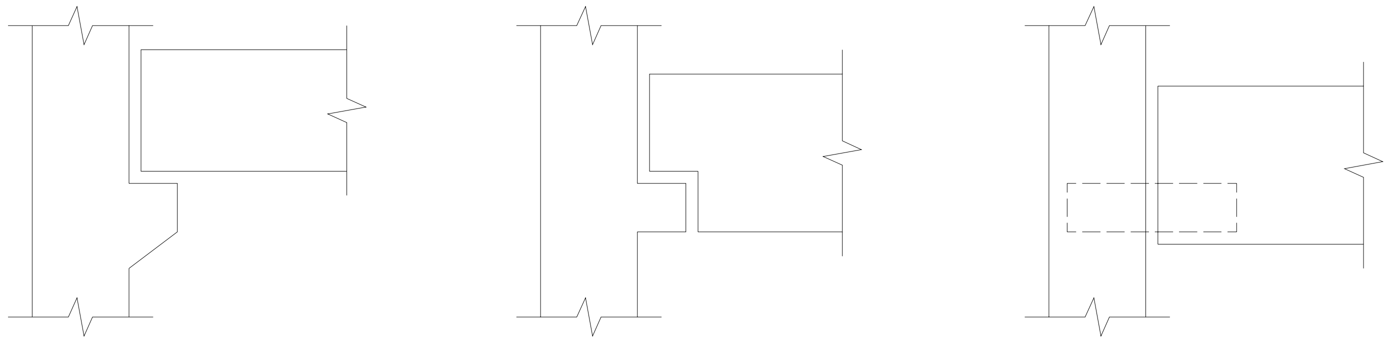
Design aspects:

Structural behaviour for ordinary and excessive loads

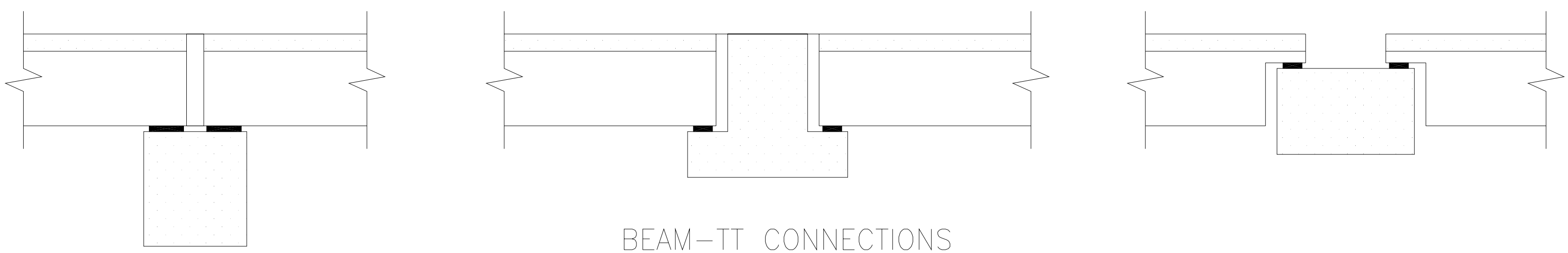




Appearance and function in the service state

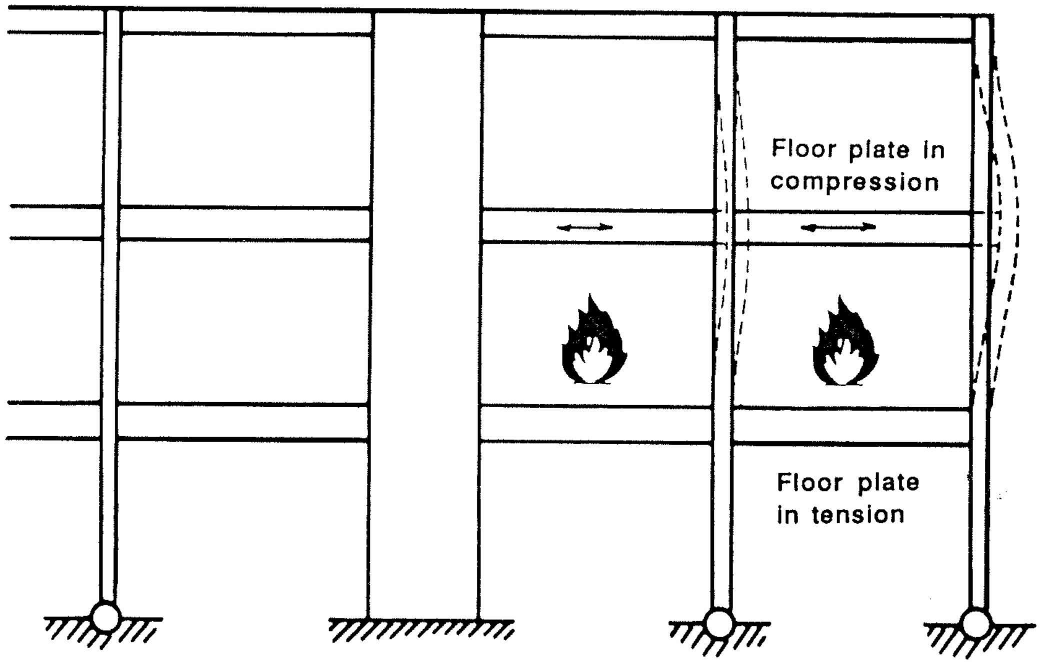


COLUMN–BEAM CONNECTIONS



BEAM–TT CONNECTIONS

Structural fire protection



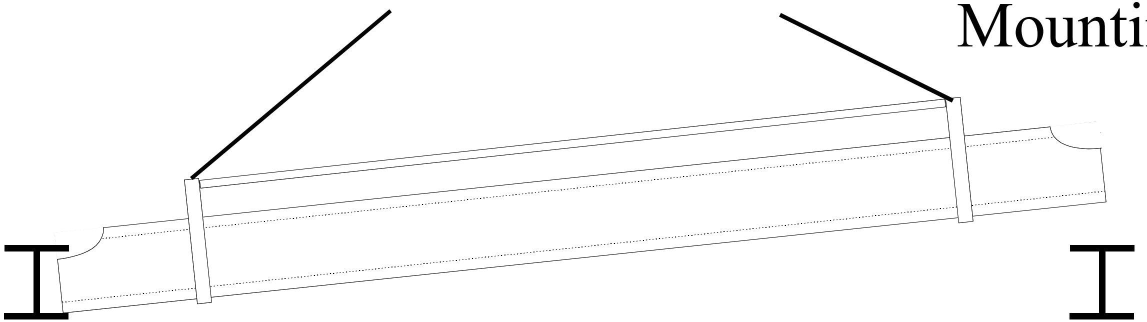
- Load bearing function
- Separating function

Manufacture

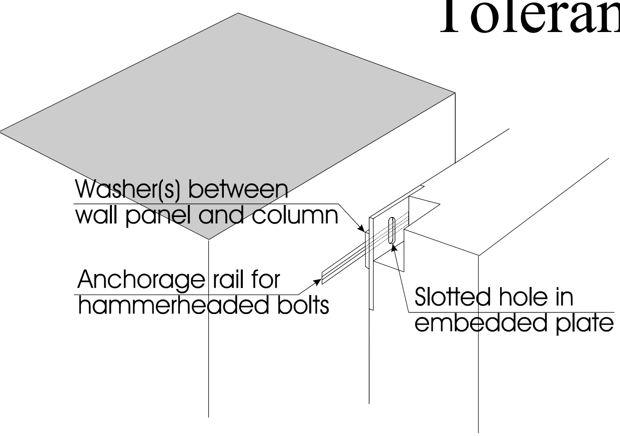
- Production of precast elements
- Handling, storage and transportation of precast elements

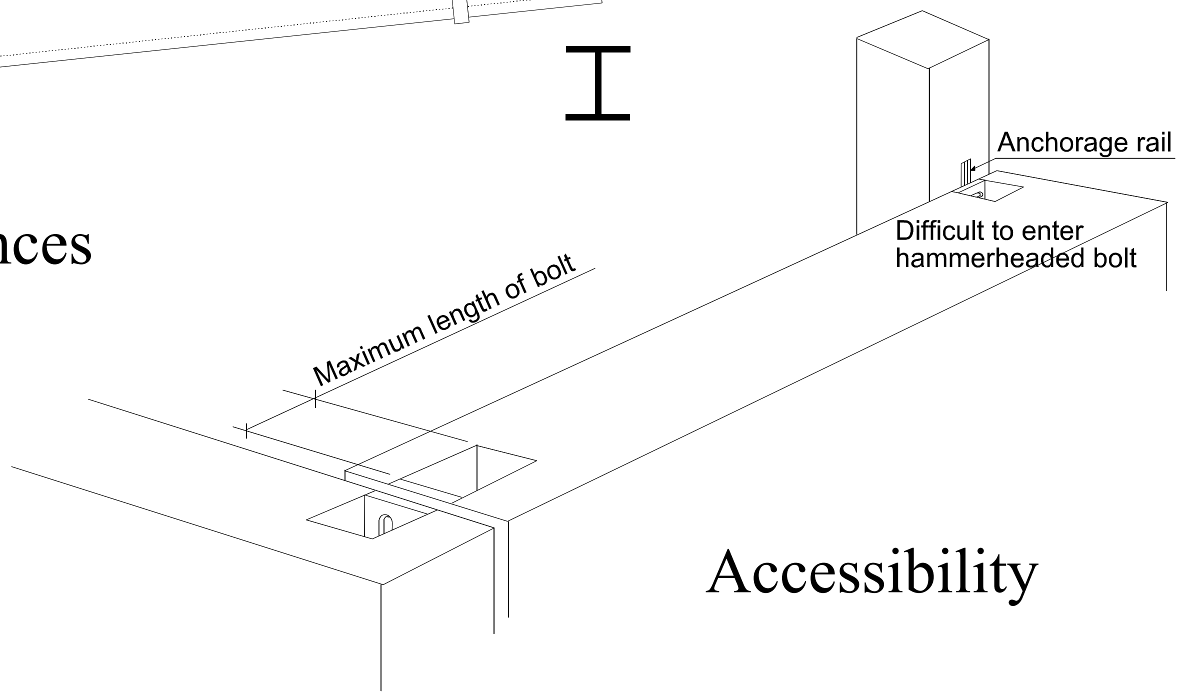
Mounting of precast systems

Mounting should be possible



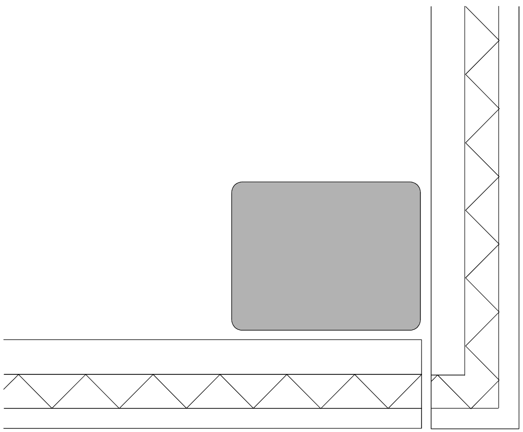
Tolerances



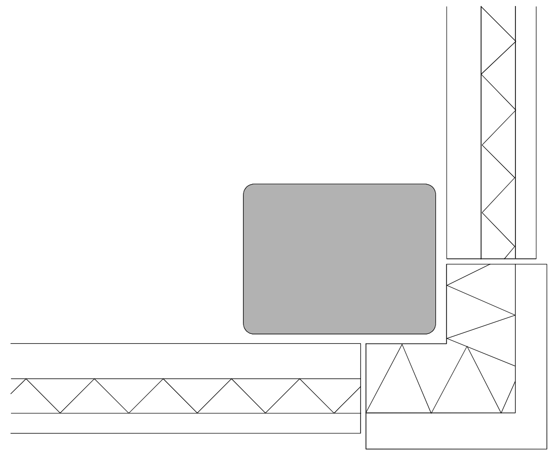


Accessibility

Modular co-ordination

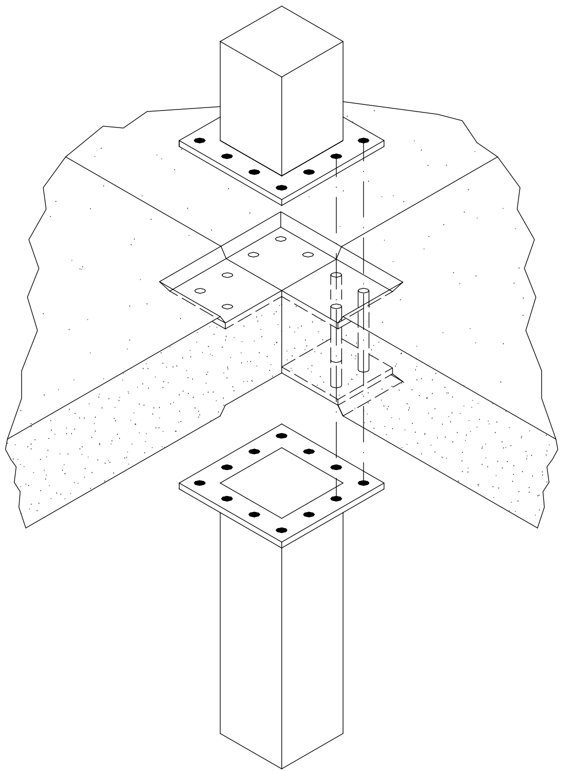


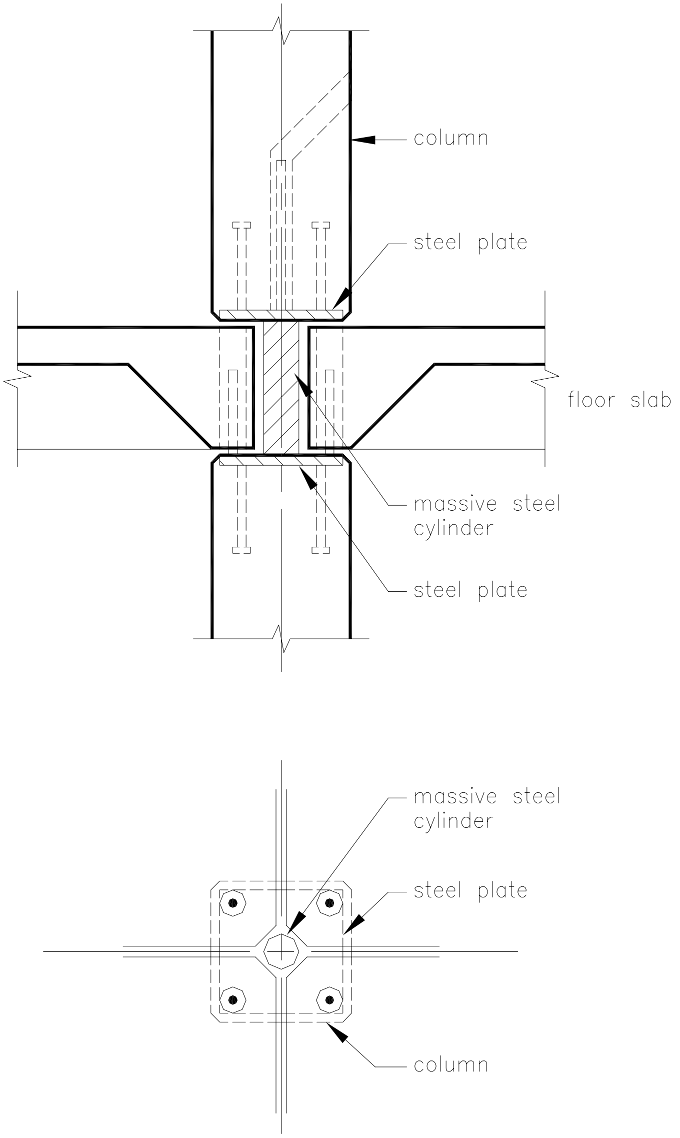
Traditional detail



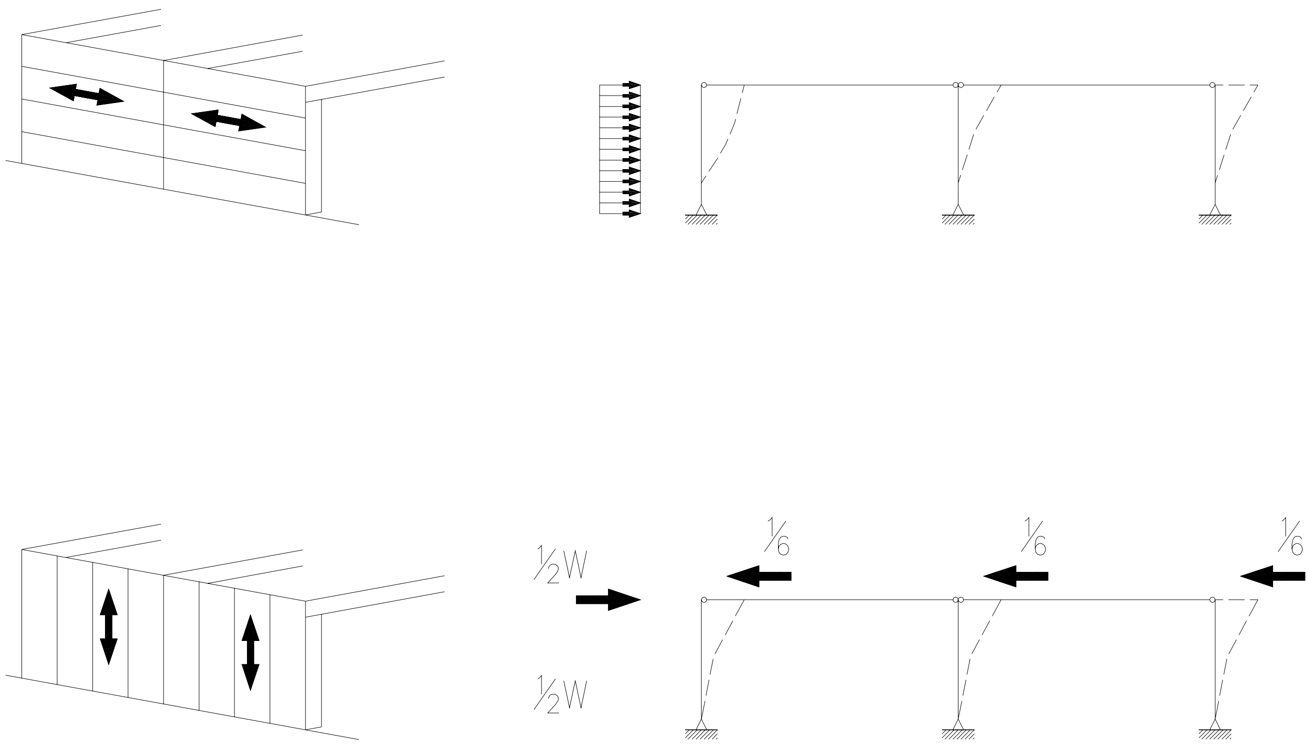
Alternative detail

Demountability

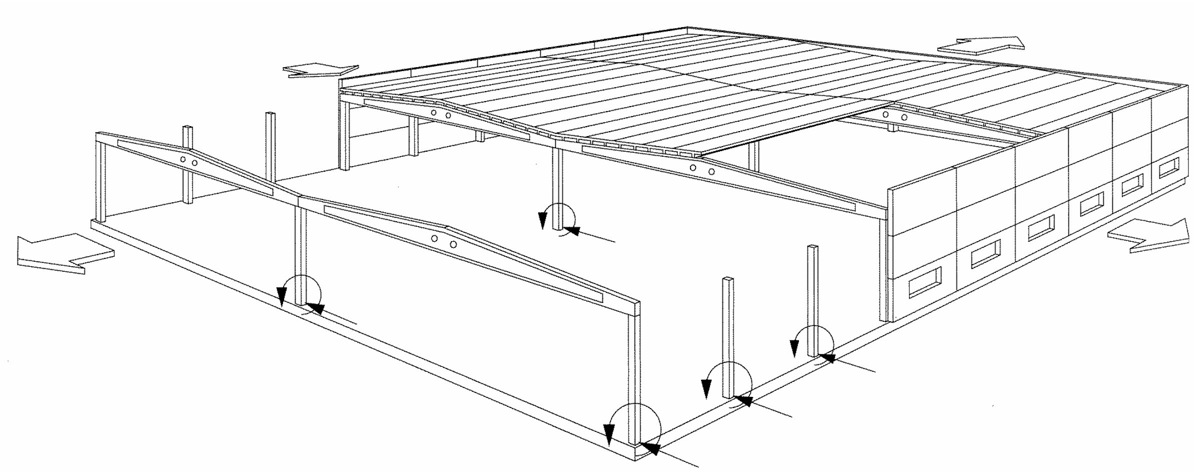




Force paths – structural level

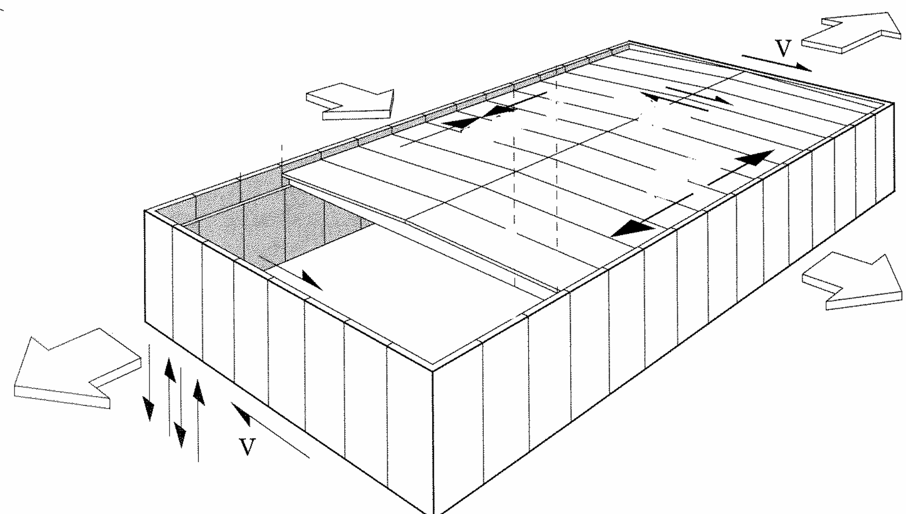


Force paths – structural level



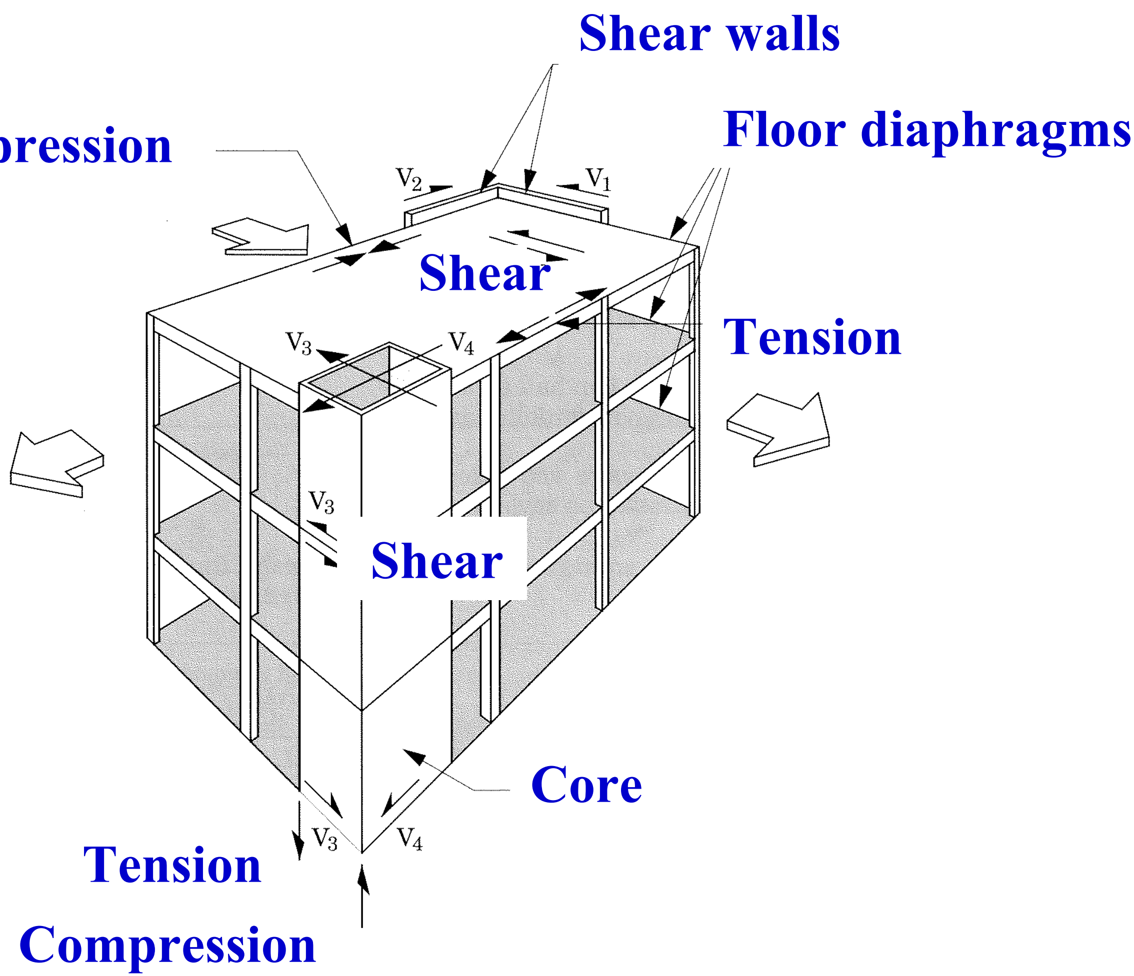
Fixed end columns

Diaphragm action

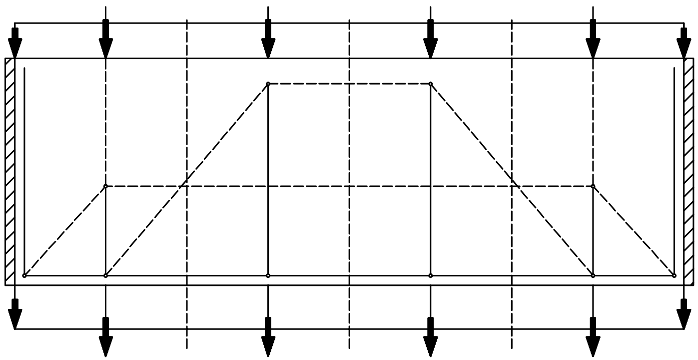


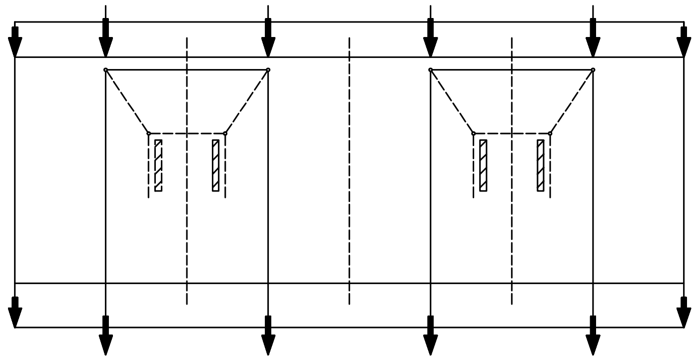
Shear panels

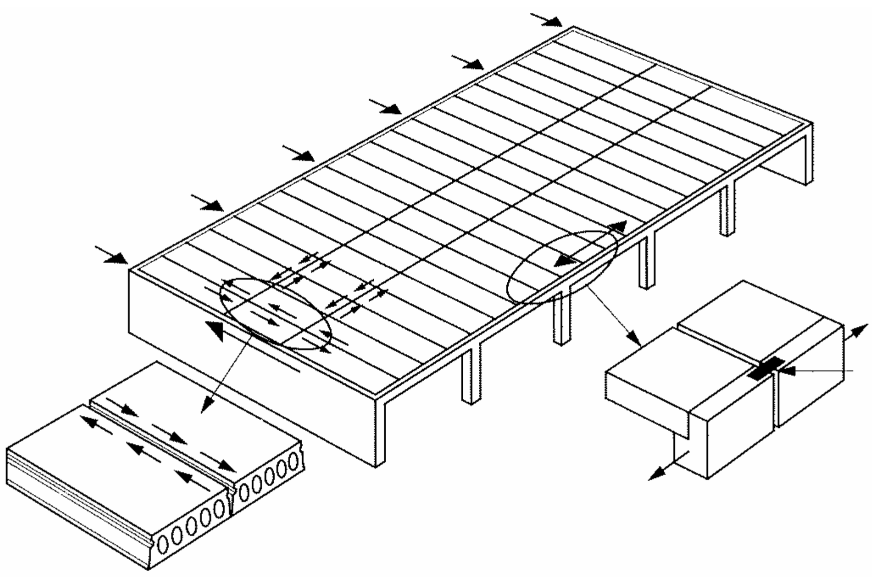
Force paths –structural level



Force paths – structural subsystems

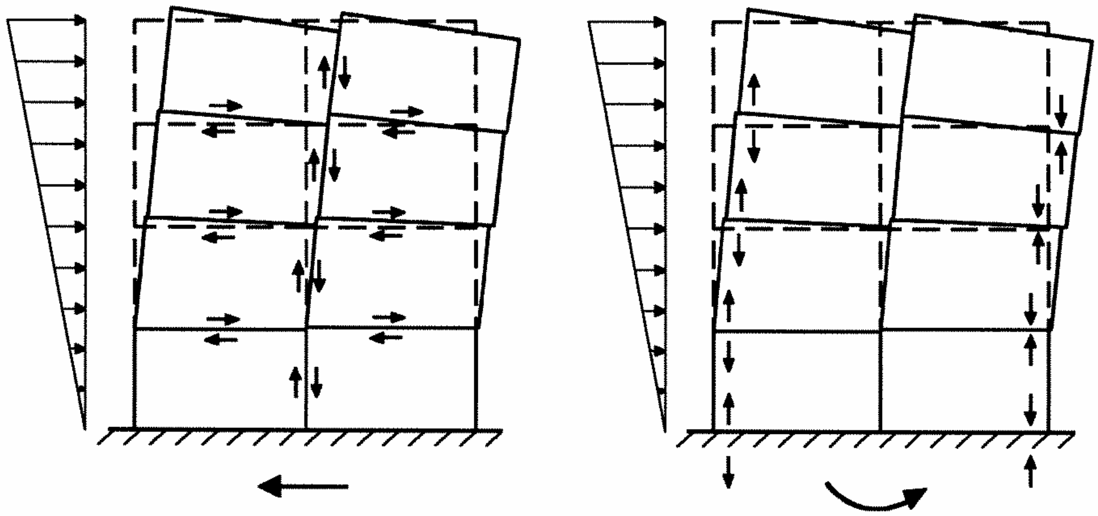






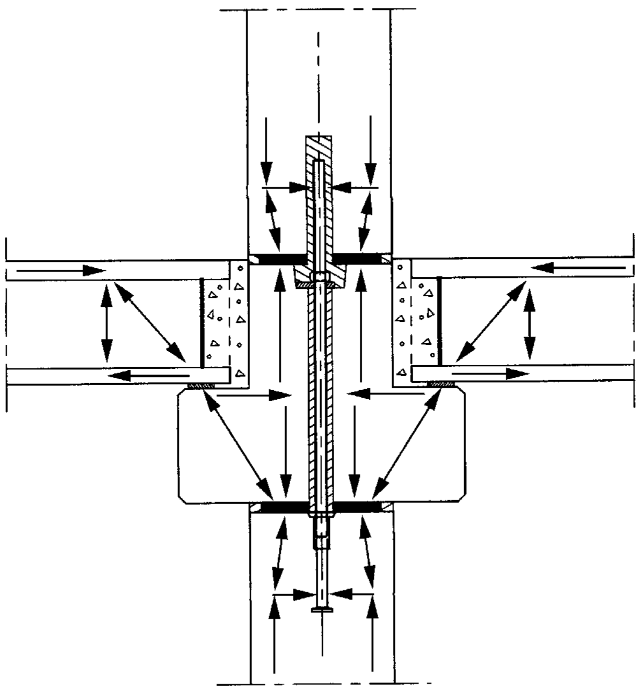
In-plane action of precast floor

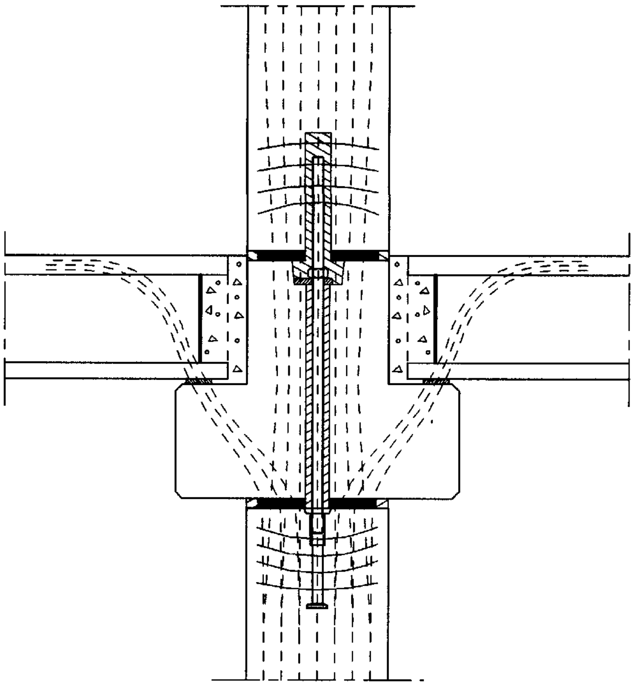
Force paths – structural subsystems



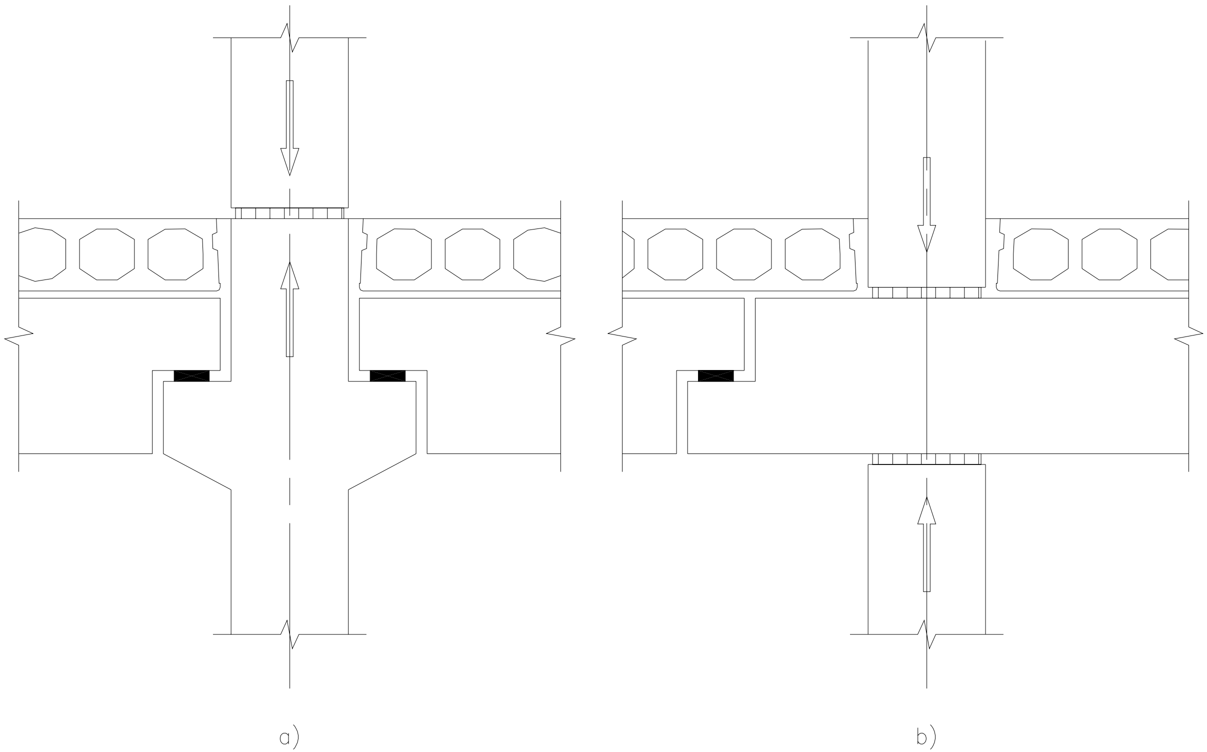
In-plane action of precast wall

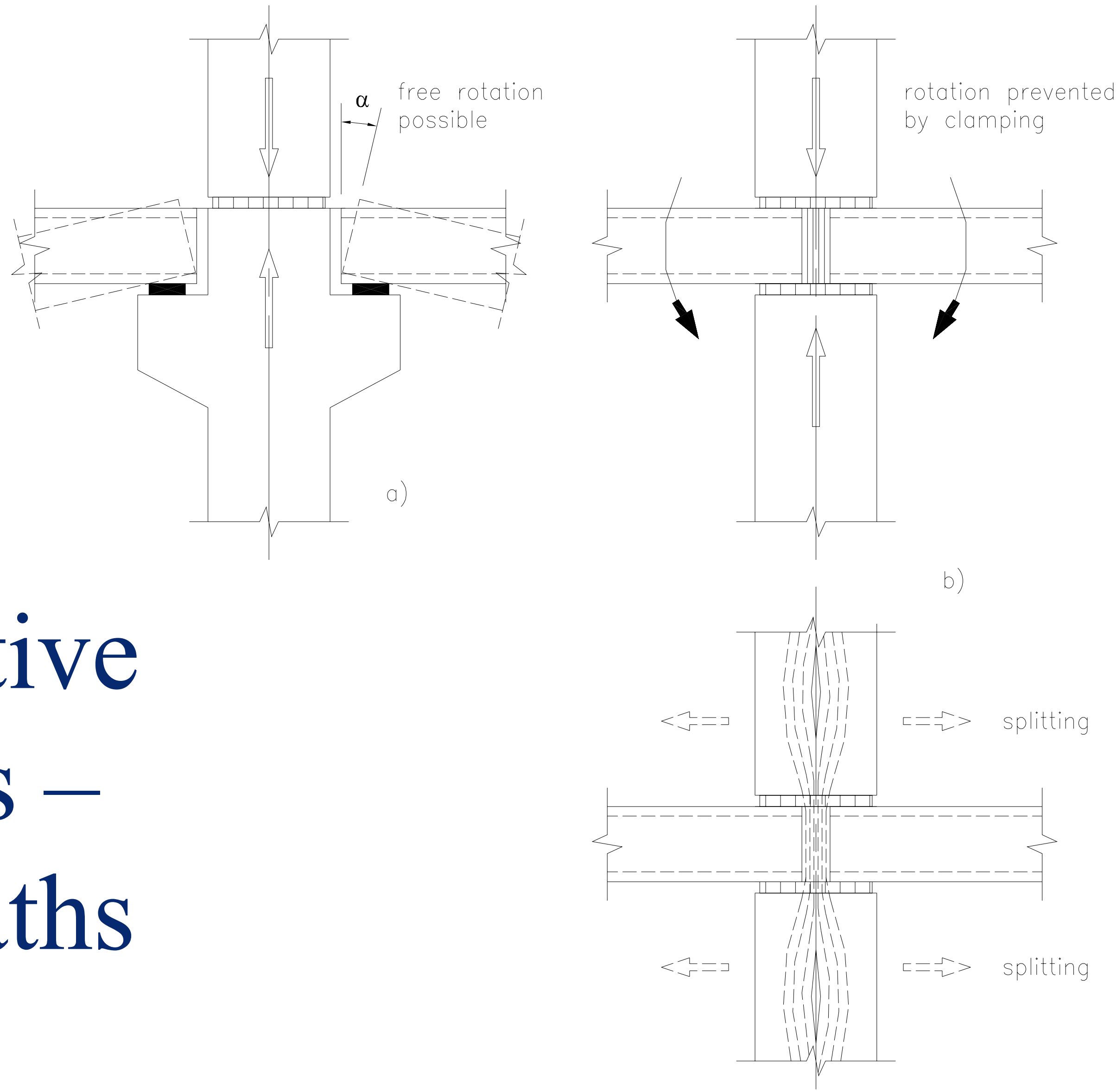
The force paths – local level





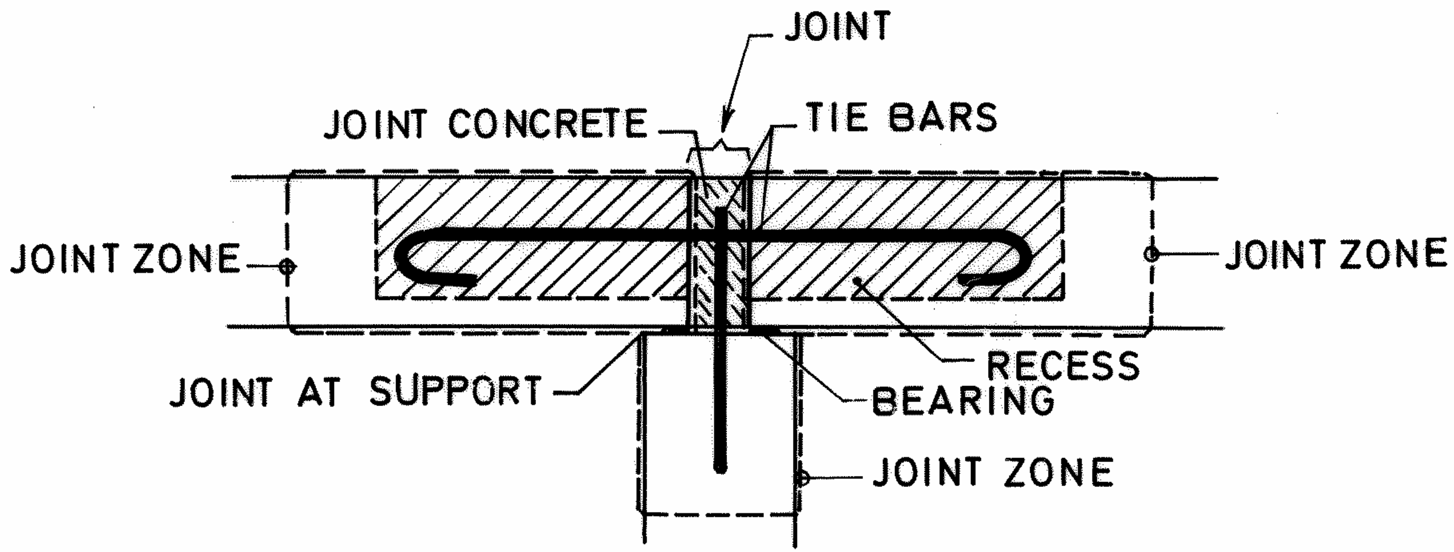
Alternative designs – force paths





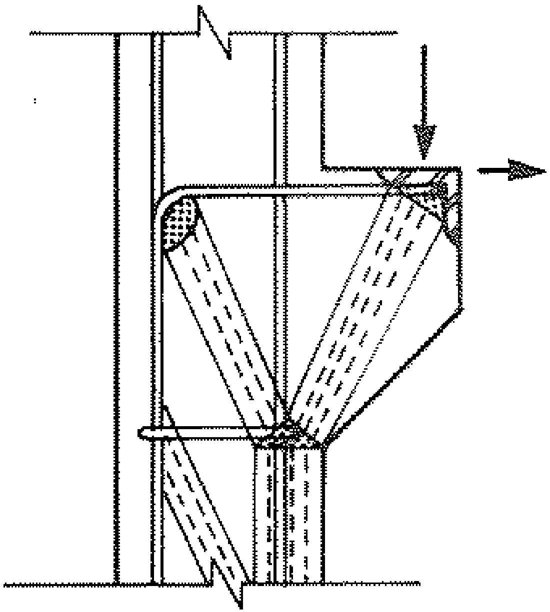
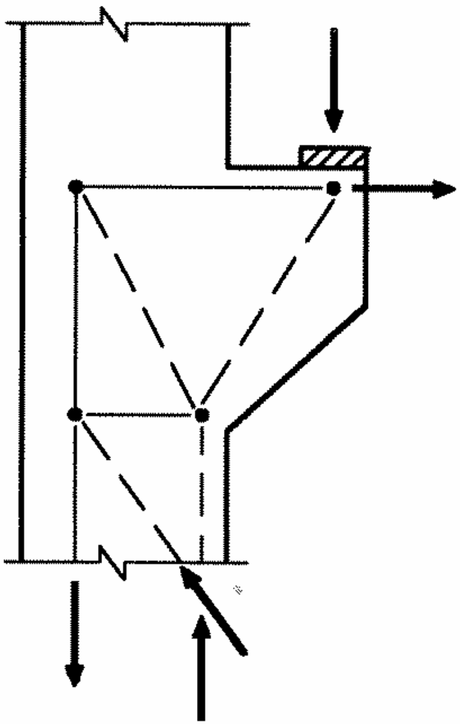
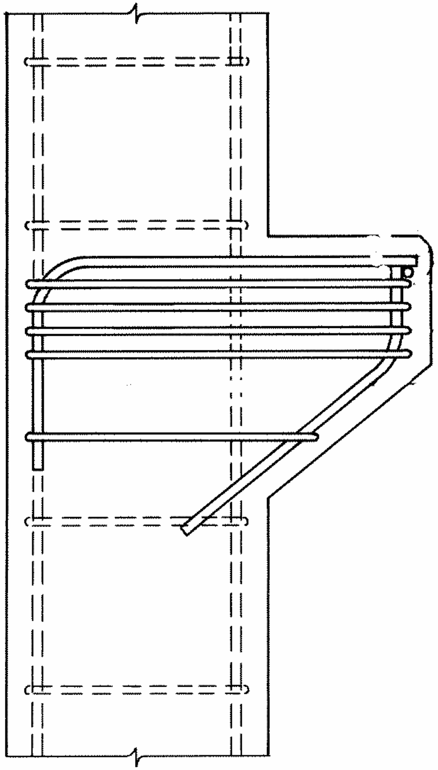
Alternative designs – force paths

Design of the whole connection

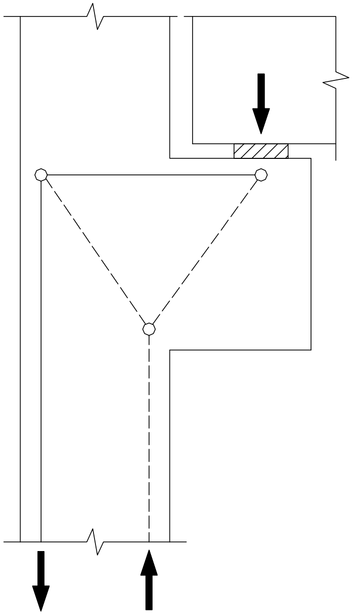


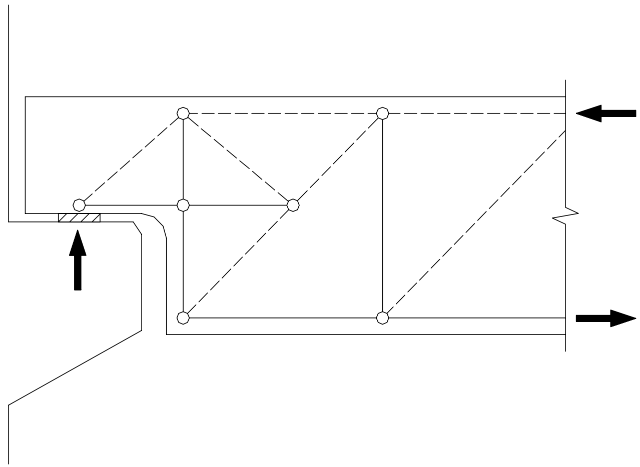
The connection as part of the structural system

Design and detailing for safe force paths

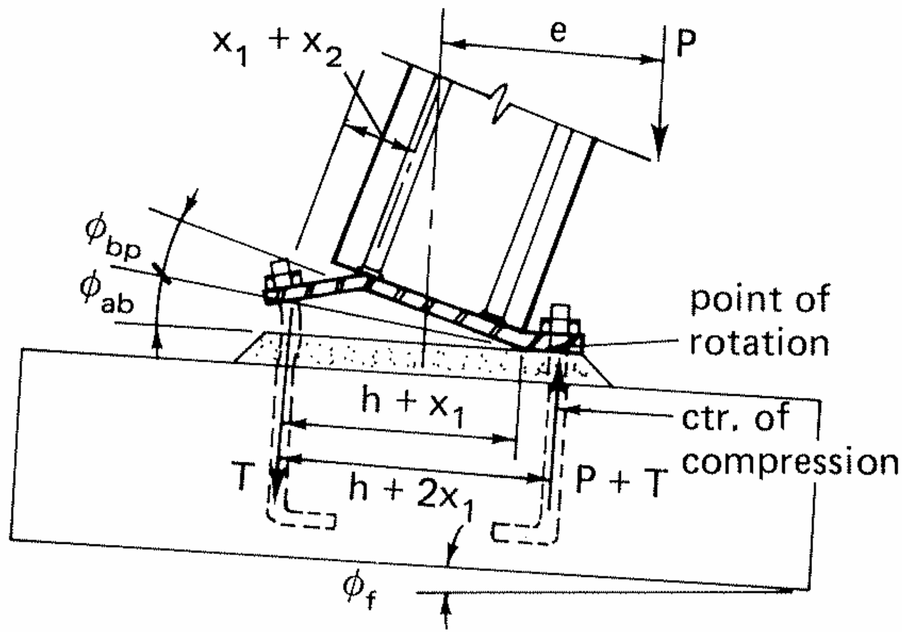
  

Flow of forces through the connection and further away

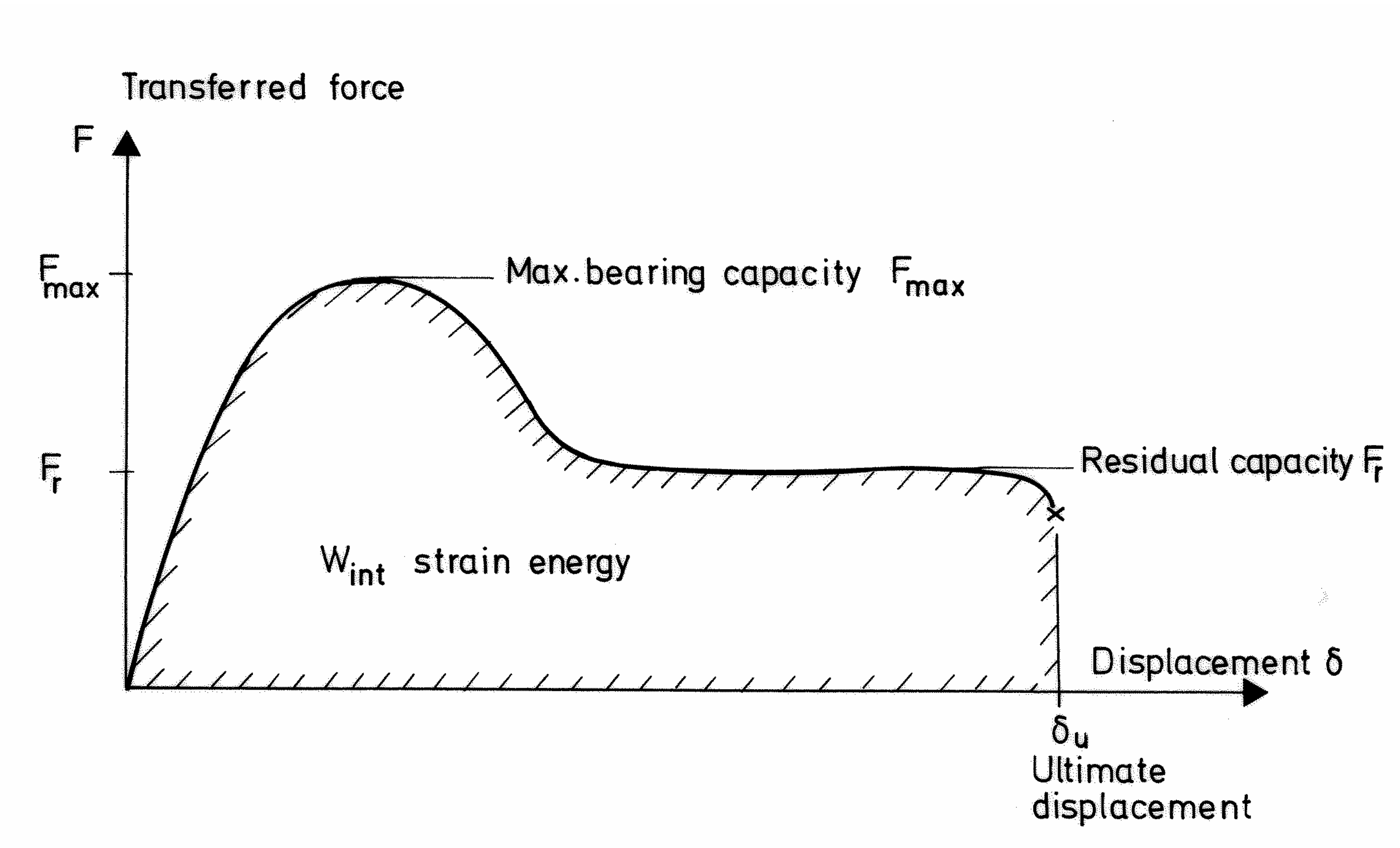




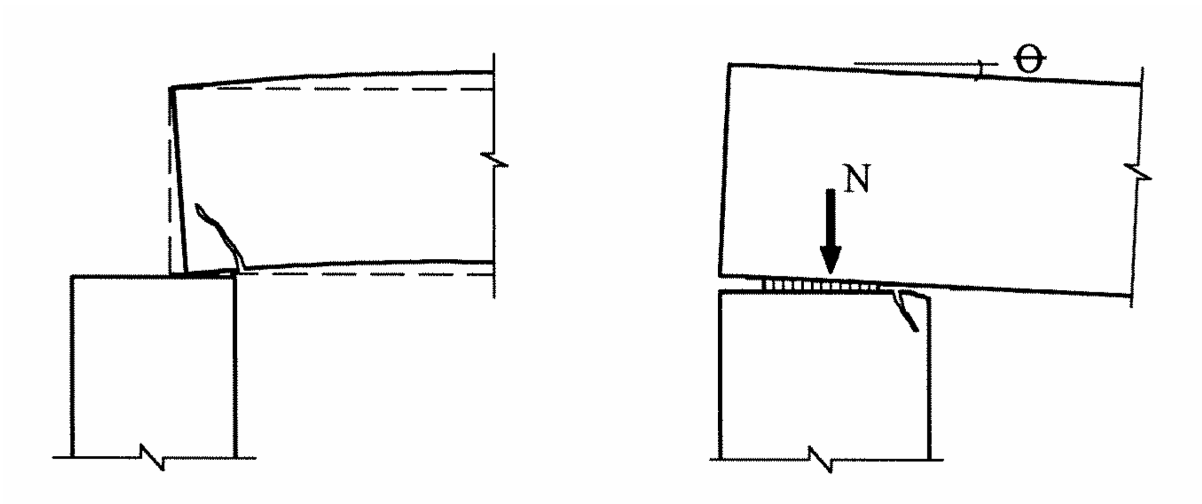
Mechanical behaviour

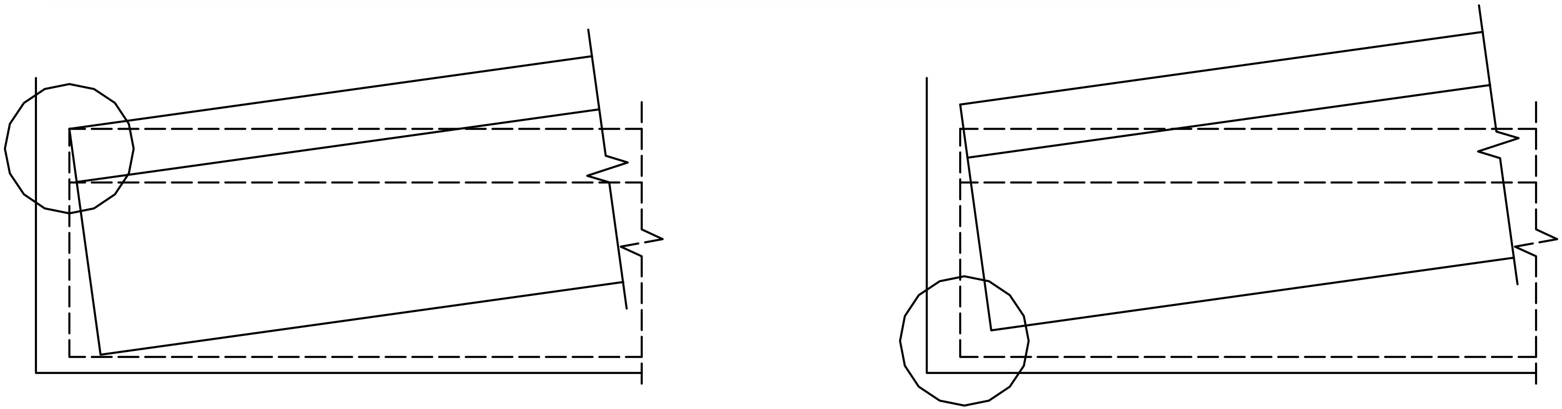


Mechanical response

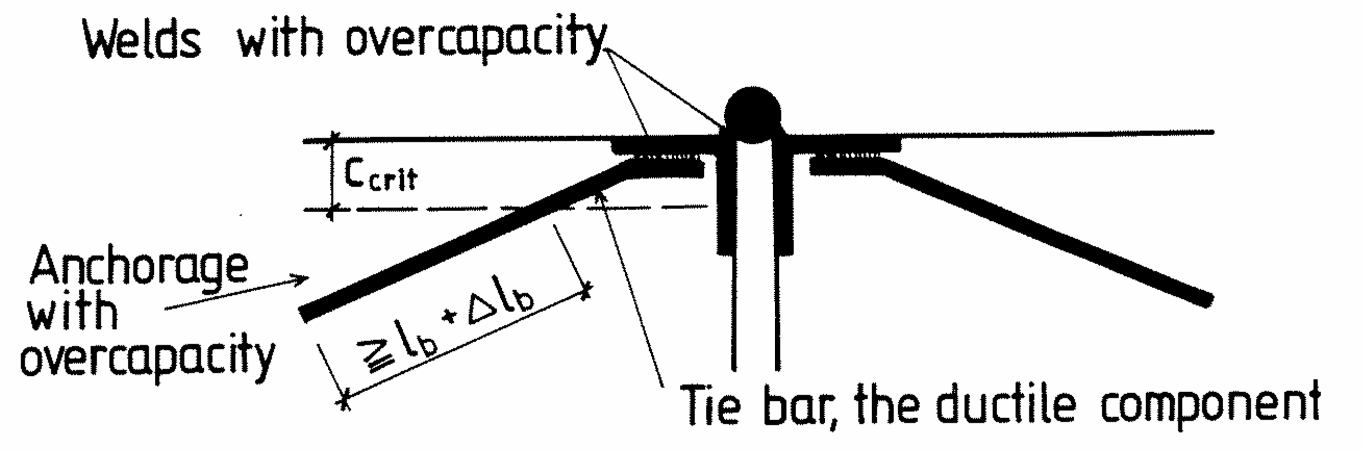


Need for movement

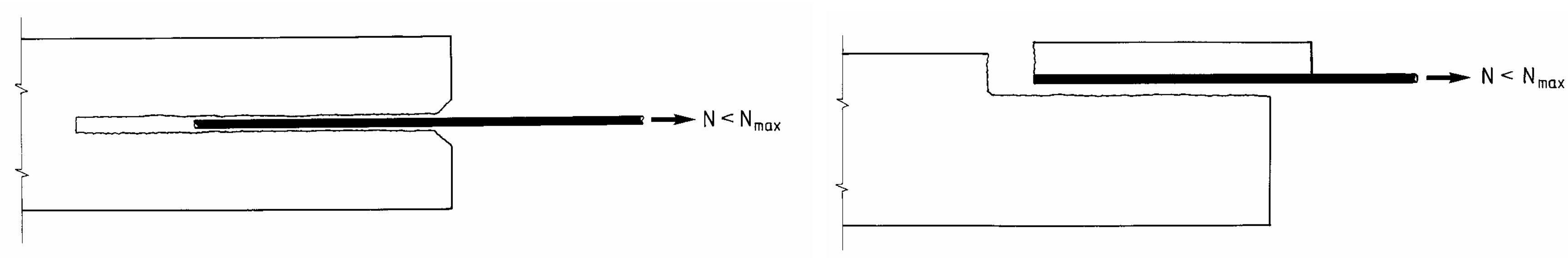




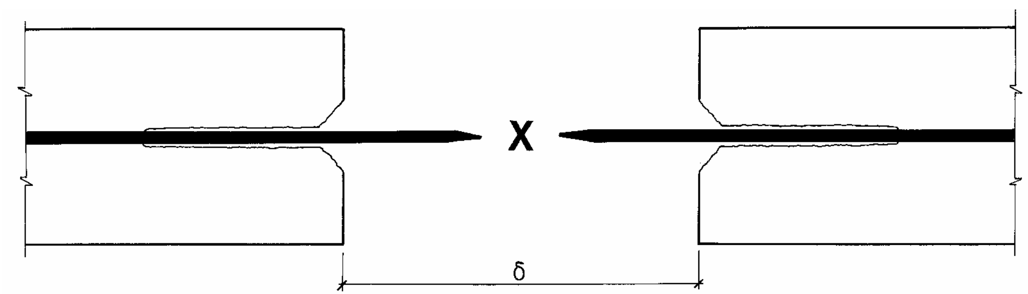
Balanced design for ductility



Anchorage for ductility

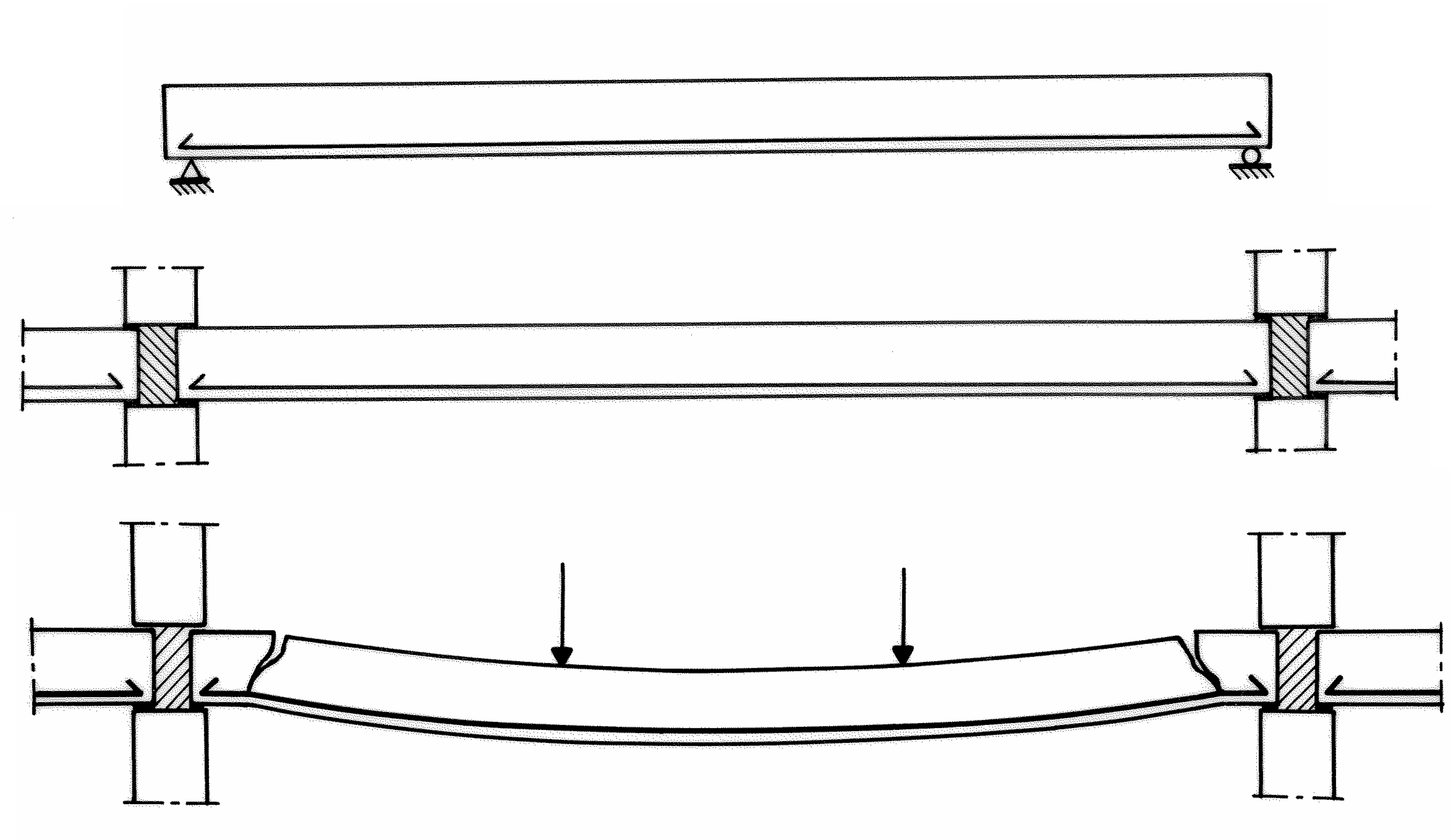


Avoid anchorage failures



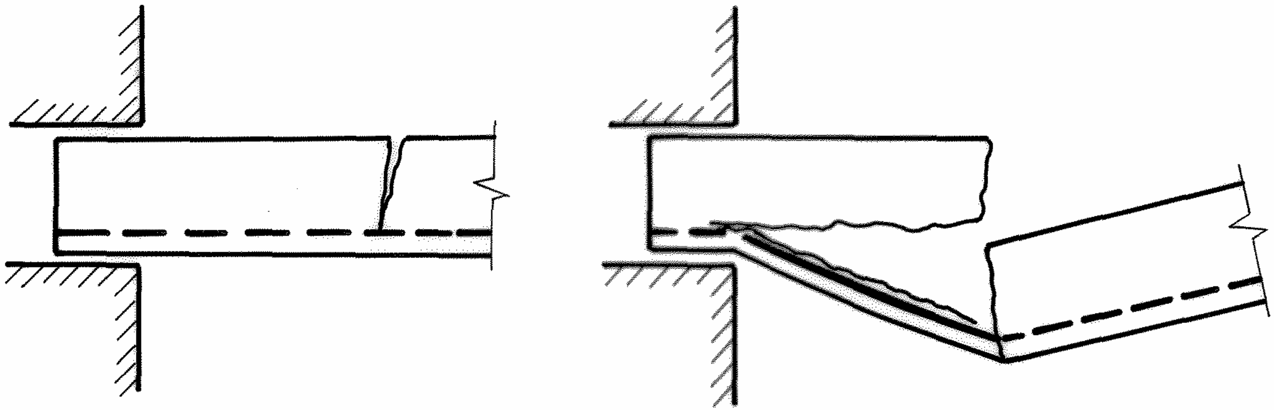
Provide anchorage for rupture of the steel

Unintended restraint

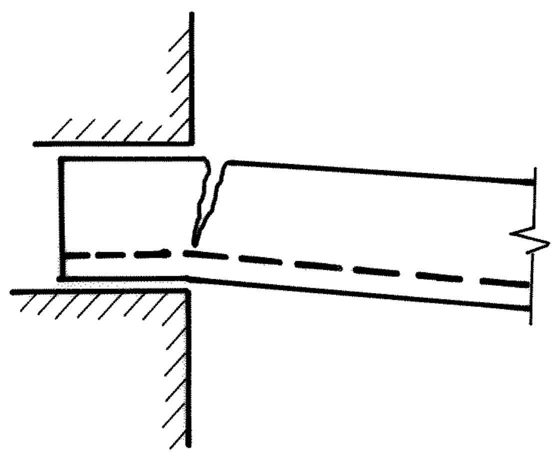


Avoid unfavourable crack locations

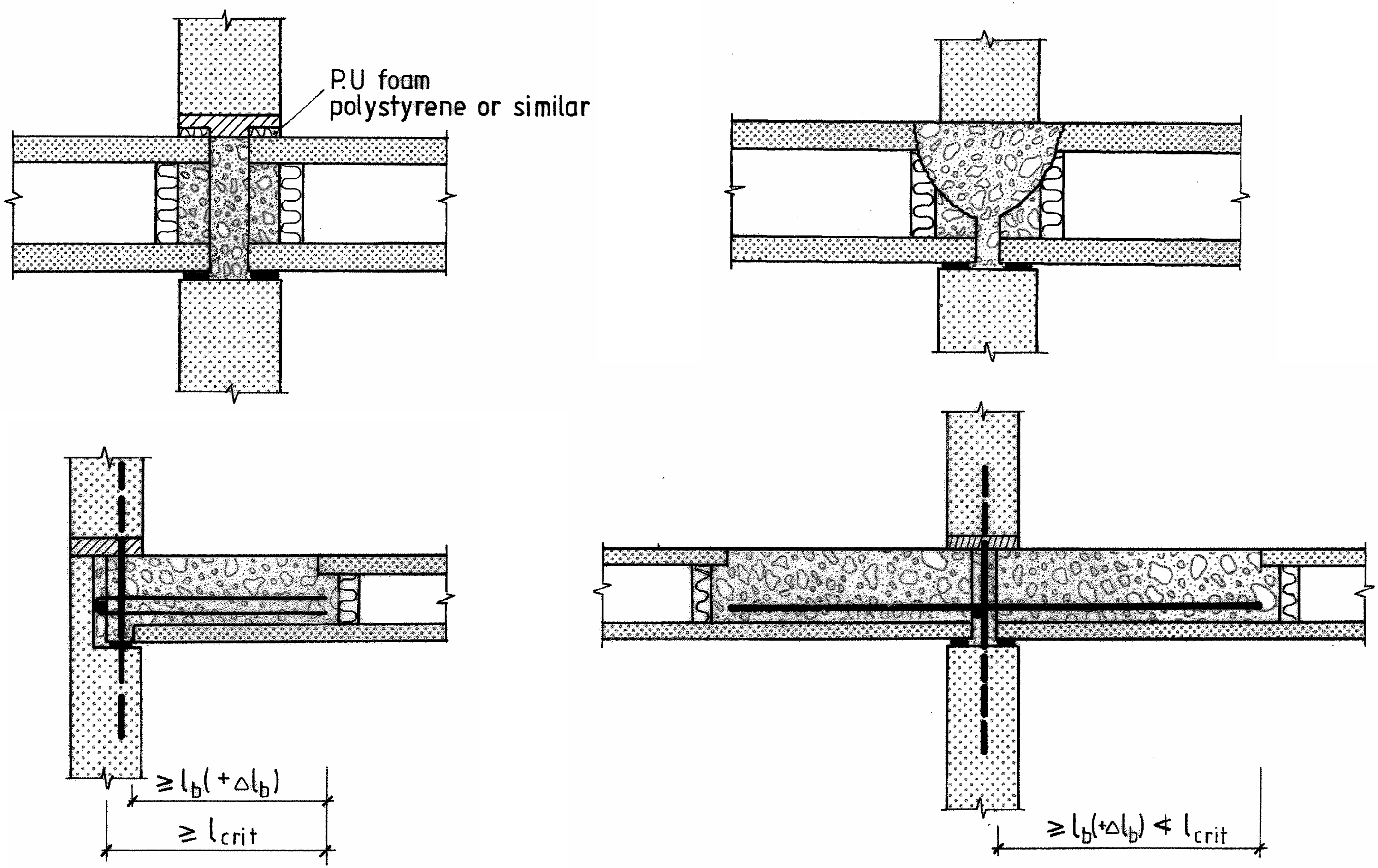
Unfavourable



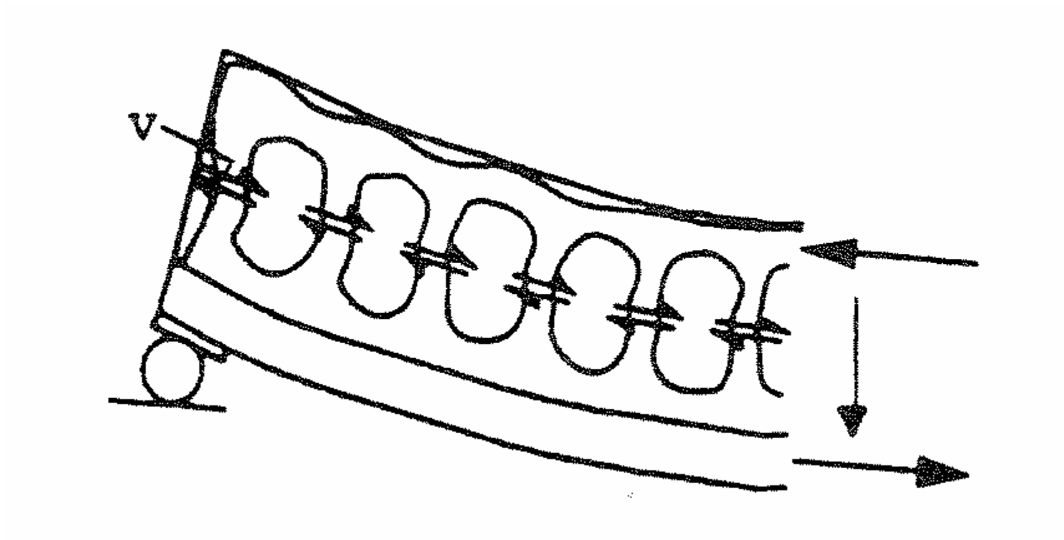
Preferred



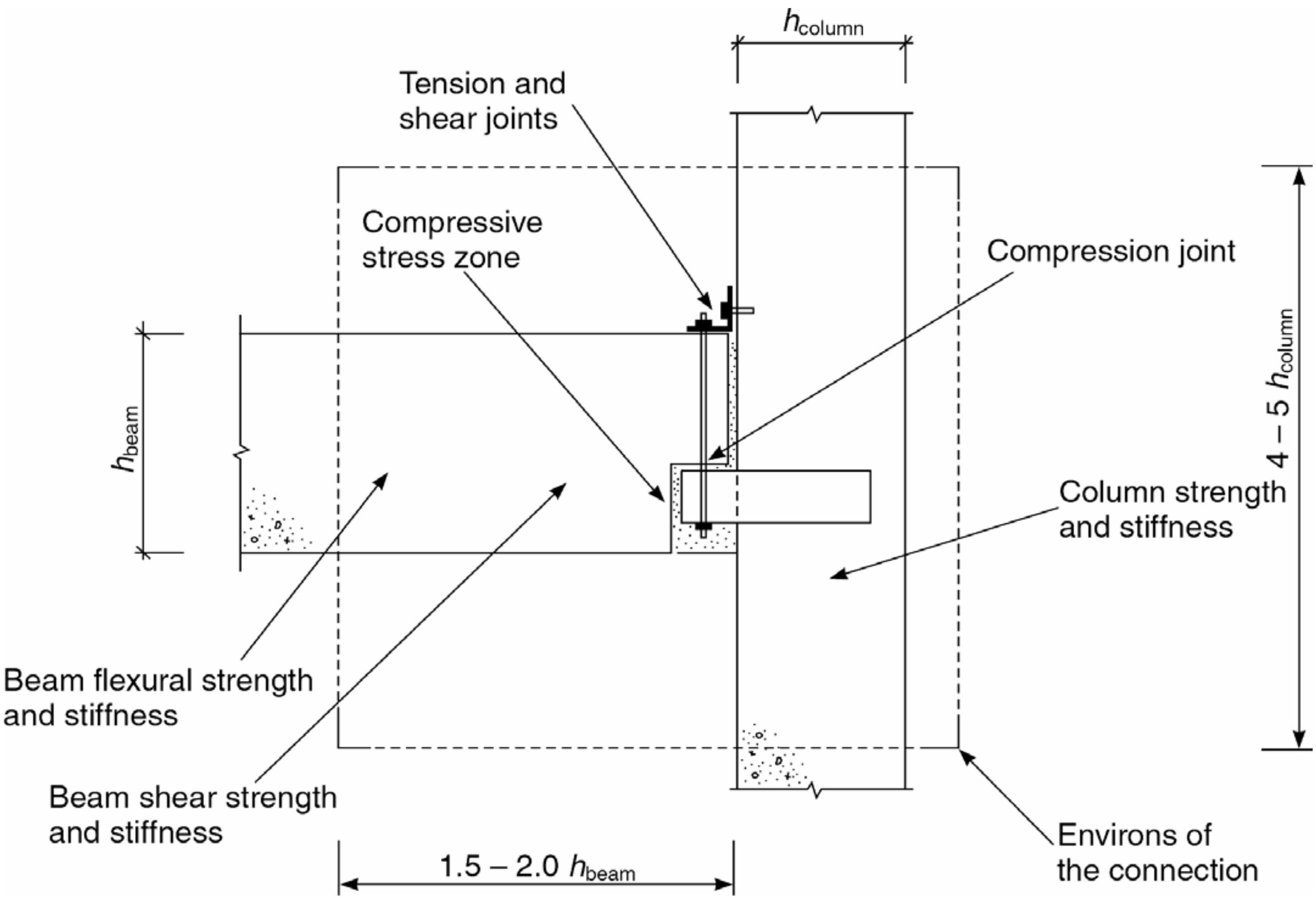
Alternative solutions



Unintended composite action

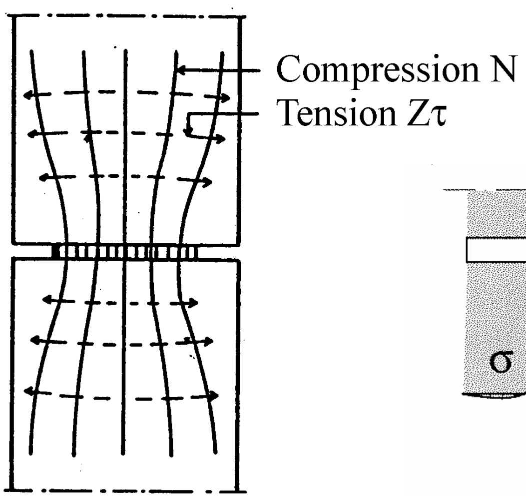


Force transfer in connections

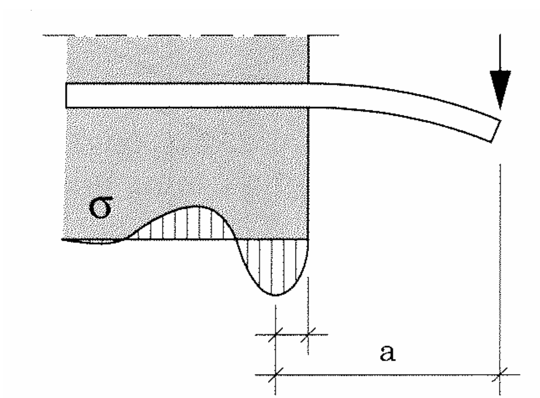


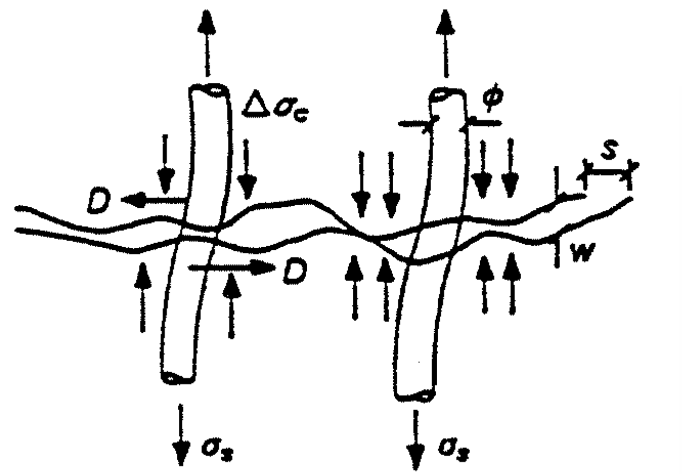
Basic force transfer mechanisms

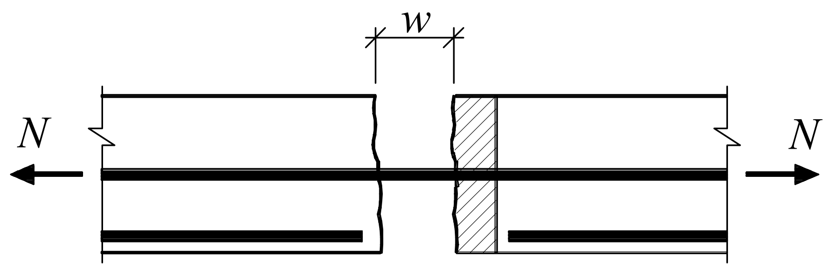
Shear



Compression

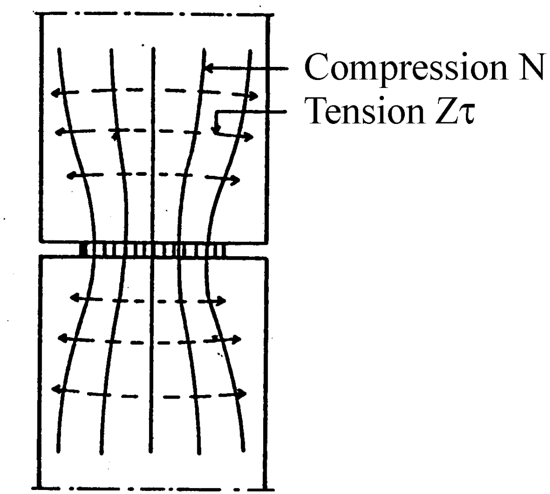




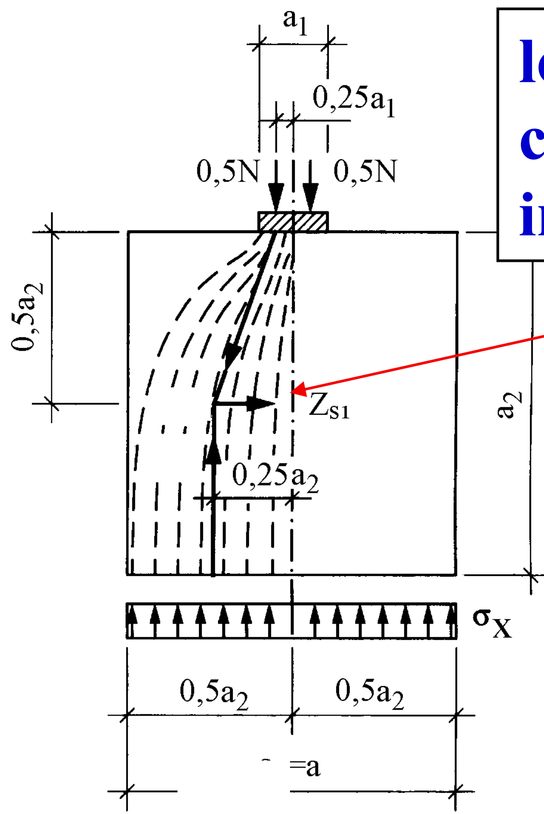


Tension

Transfer of compression



b)



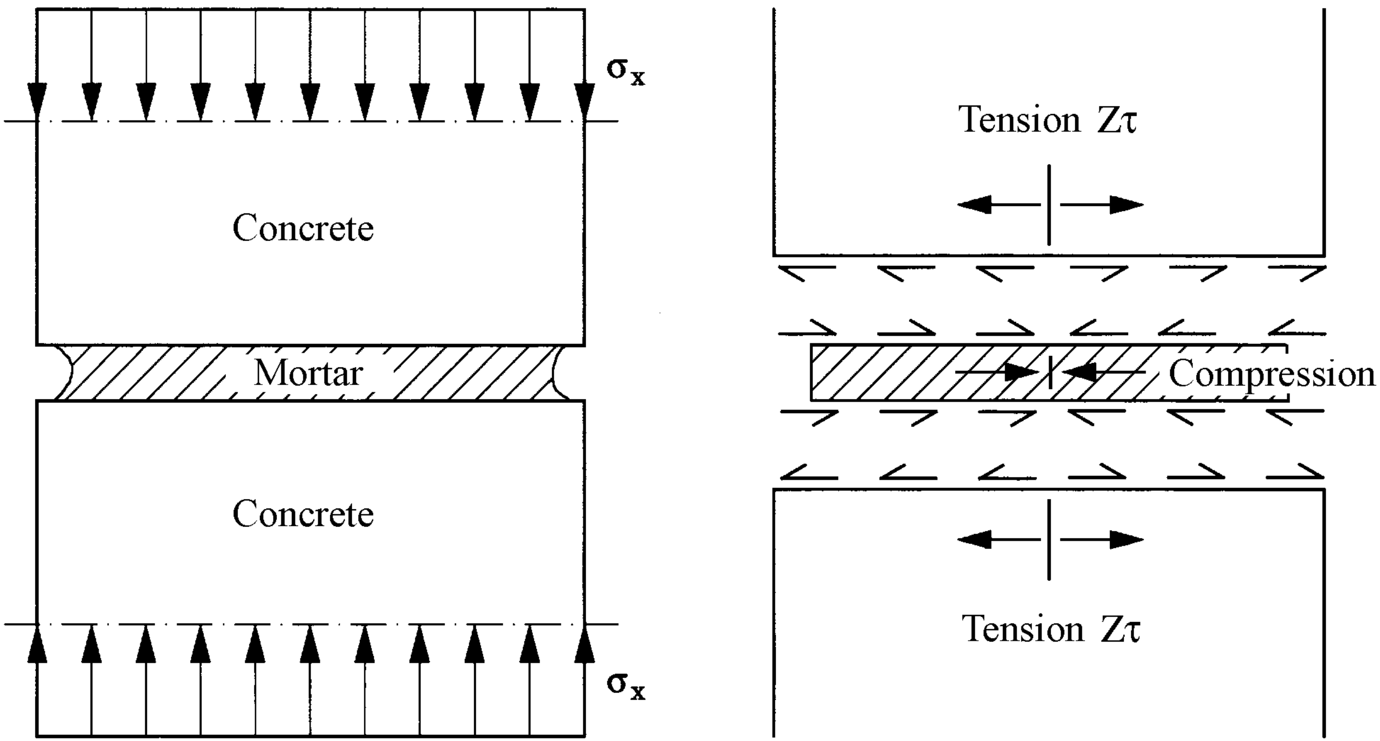
b)

local compression, compressive strength in confined concrete

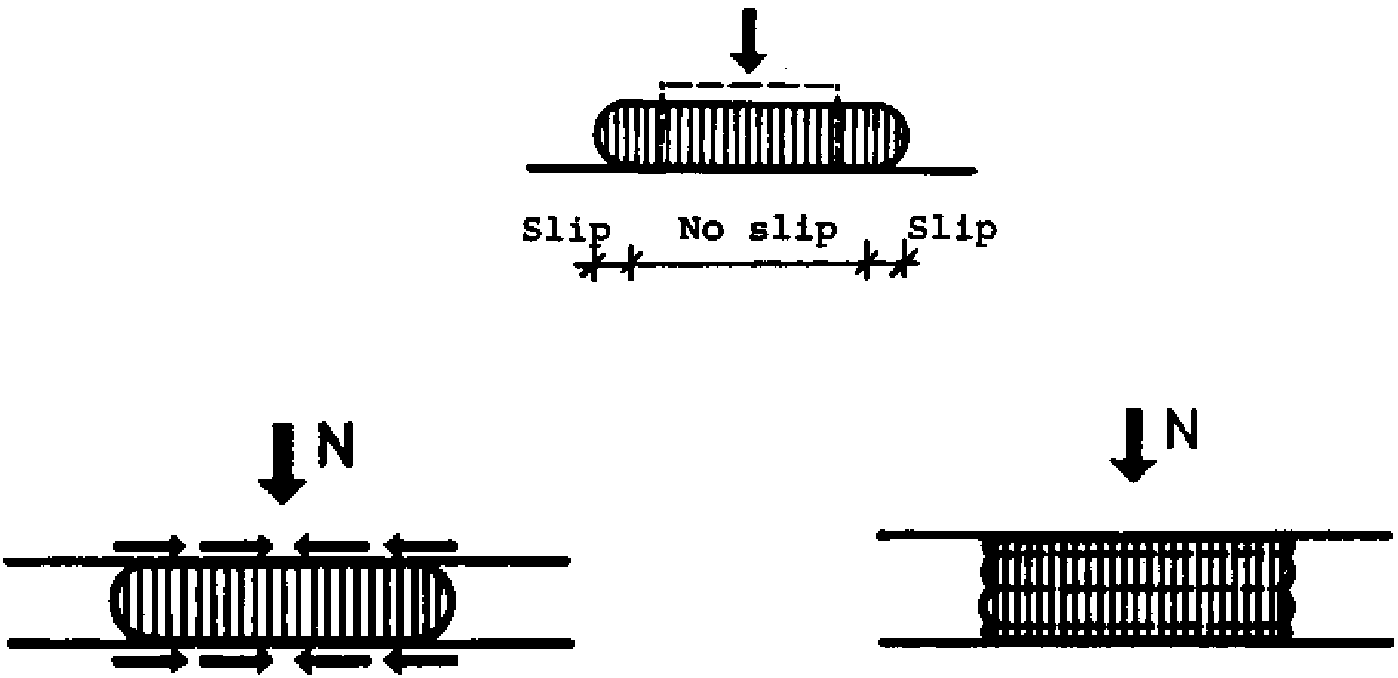
tension

stress dispersion splitting effects

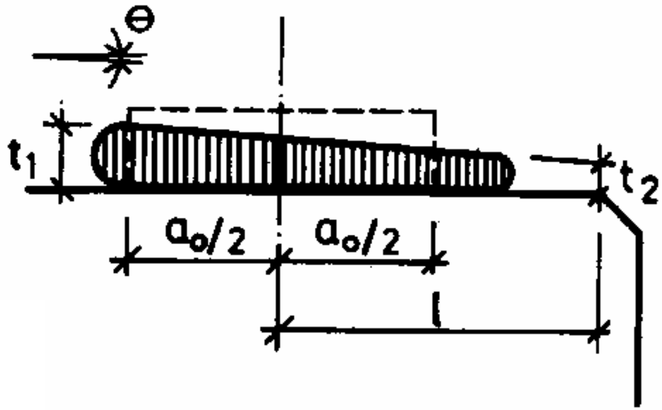
Compression through several layers

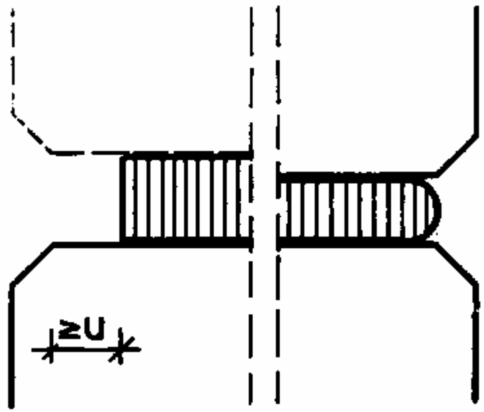


Design of bearings



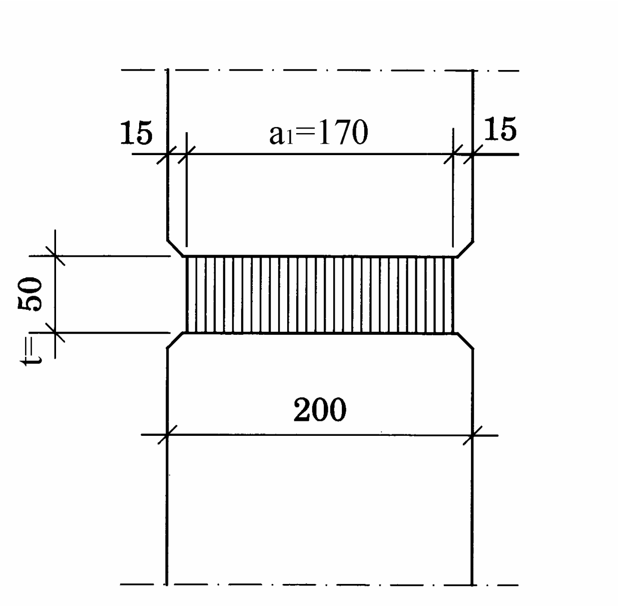
Design of soft bearings

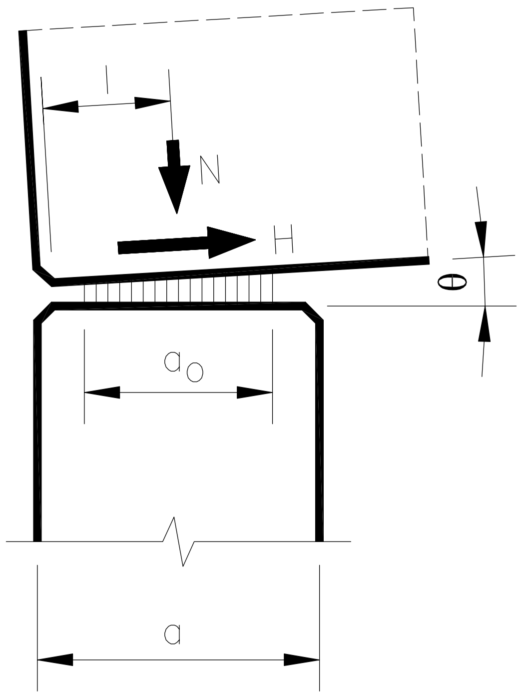




- Consider vertical resistance
- Limit shear deformation for horizontal loads
- Compression over the entire face of the bearing pad
- Avoid direct contact in case of rotation
- Avoid that the bearing protrudes outside the edges

Design examples

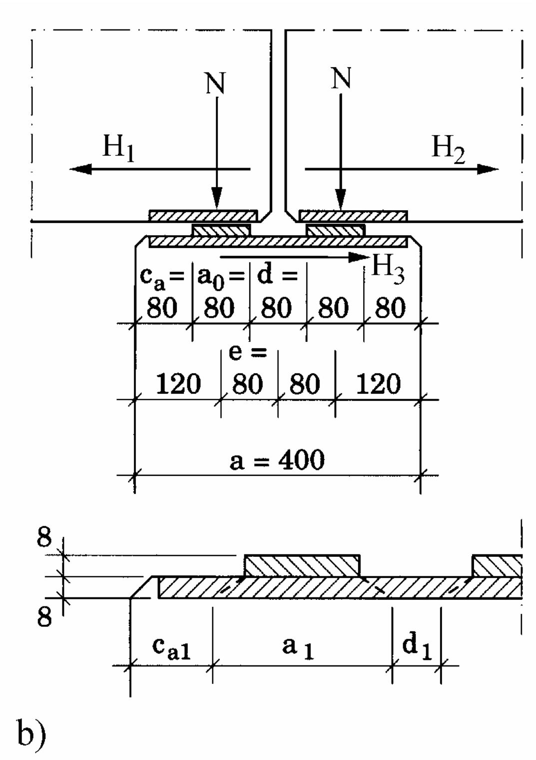


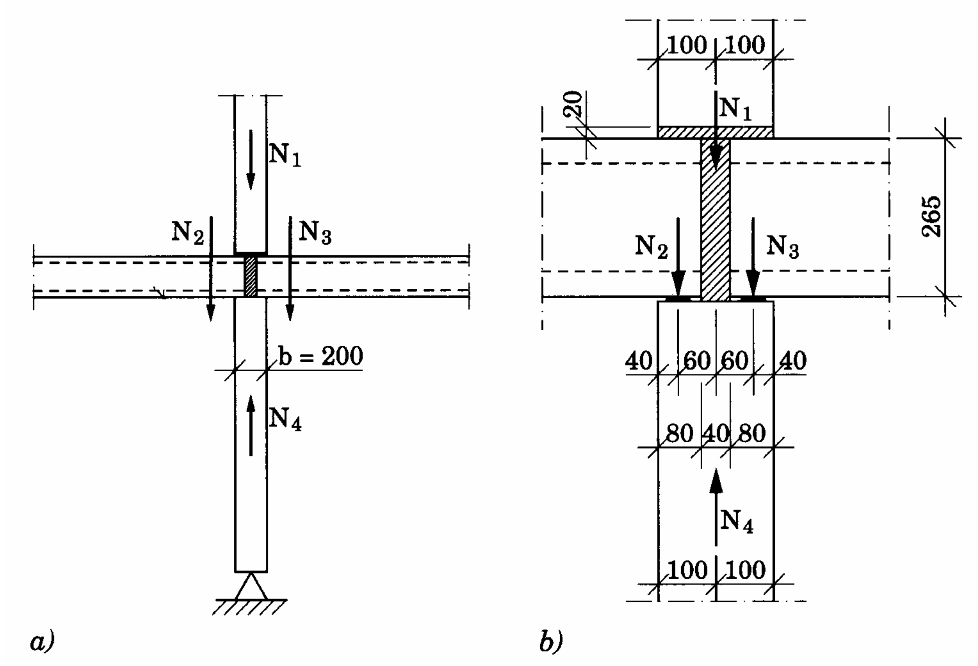


Wall connection
with mortar joint

Beam support
with soft bearing

Design examples

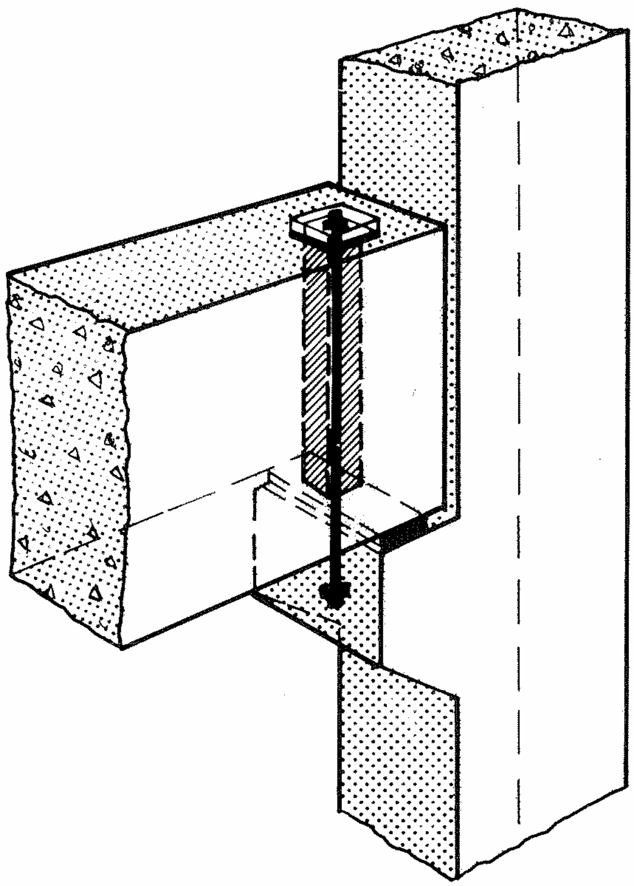




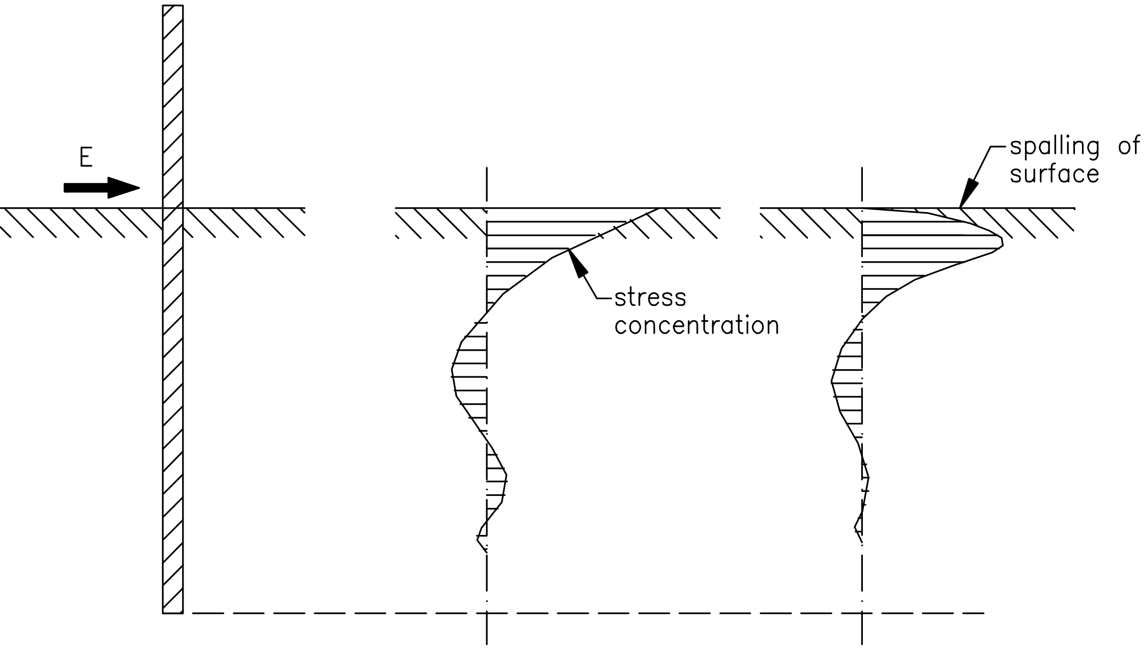
Beam column connection with steel plates

Hollow core floor wall connection

Bolted connections

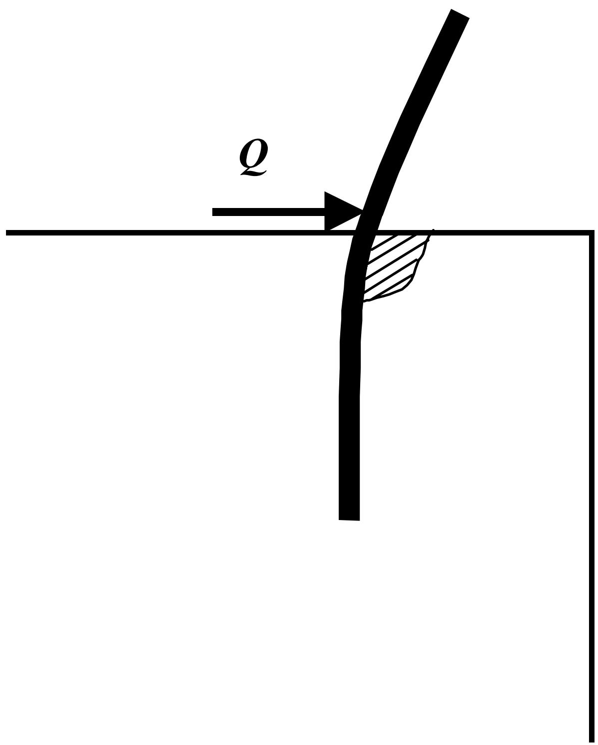


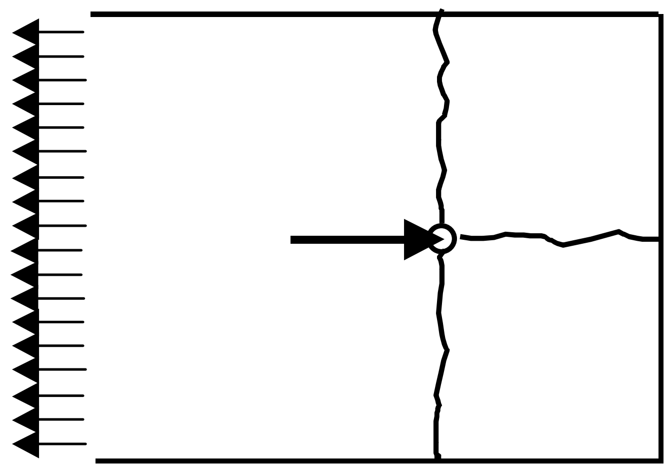
Failure modes of bolted connection



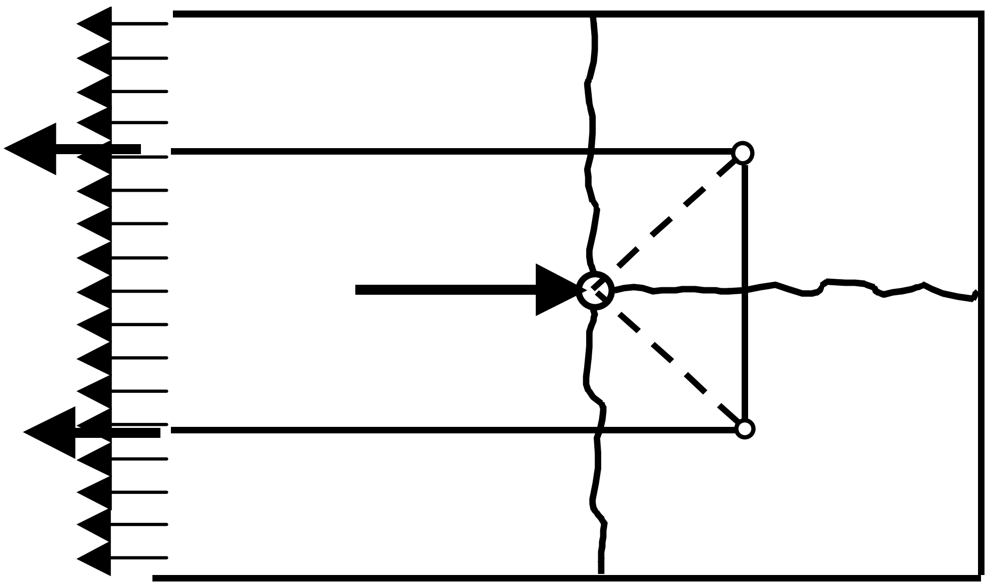
- Shear failure of bolt
- Splitting of concrete
- Combined bending in bolt and crushing of concrete

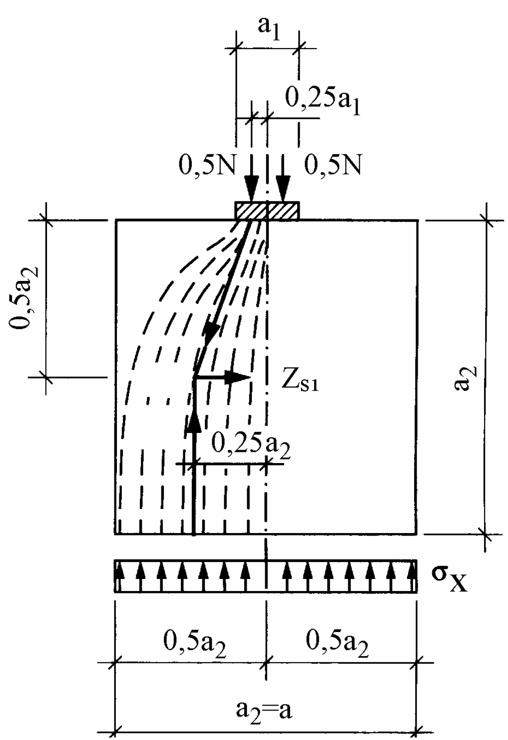
Avoid splitting failure





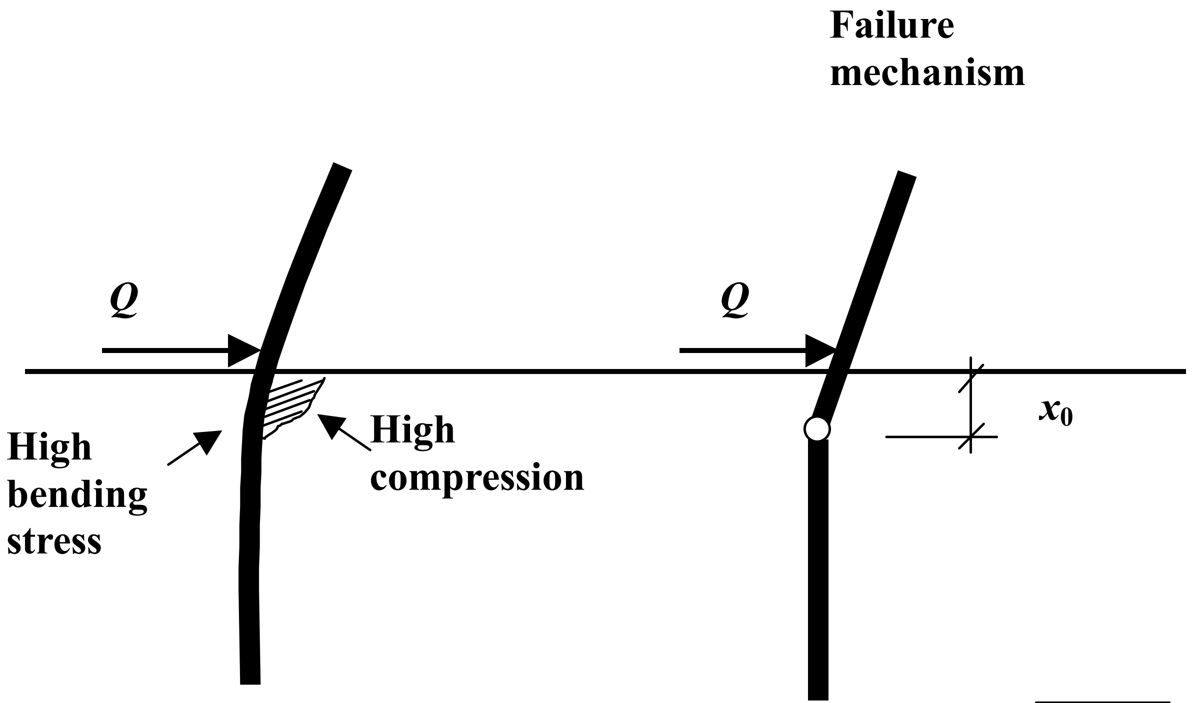
Design of splitting reinforcement





Compare with local compression

Dowel action – one-sided

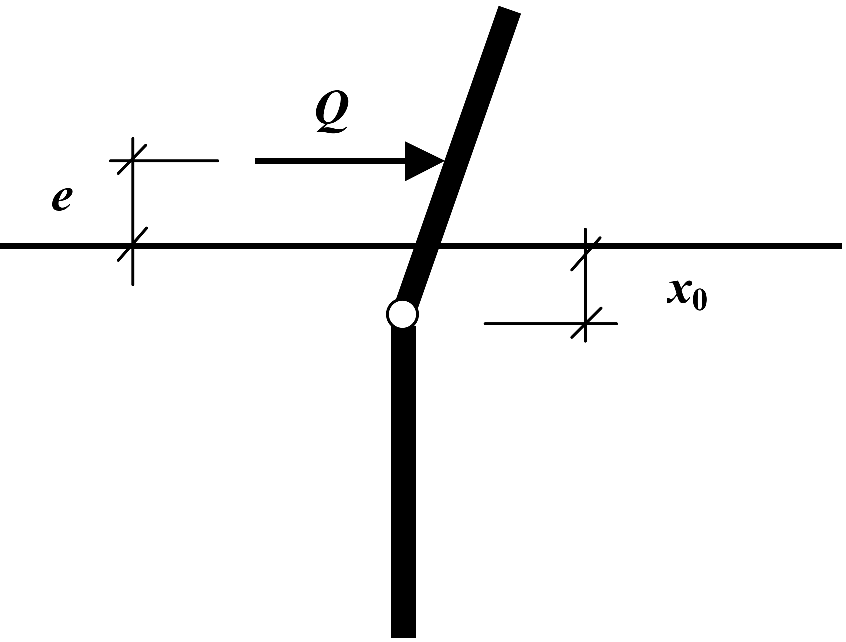


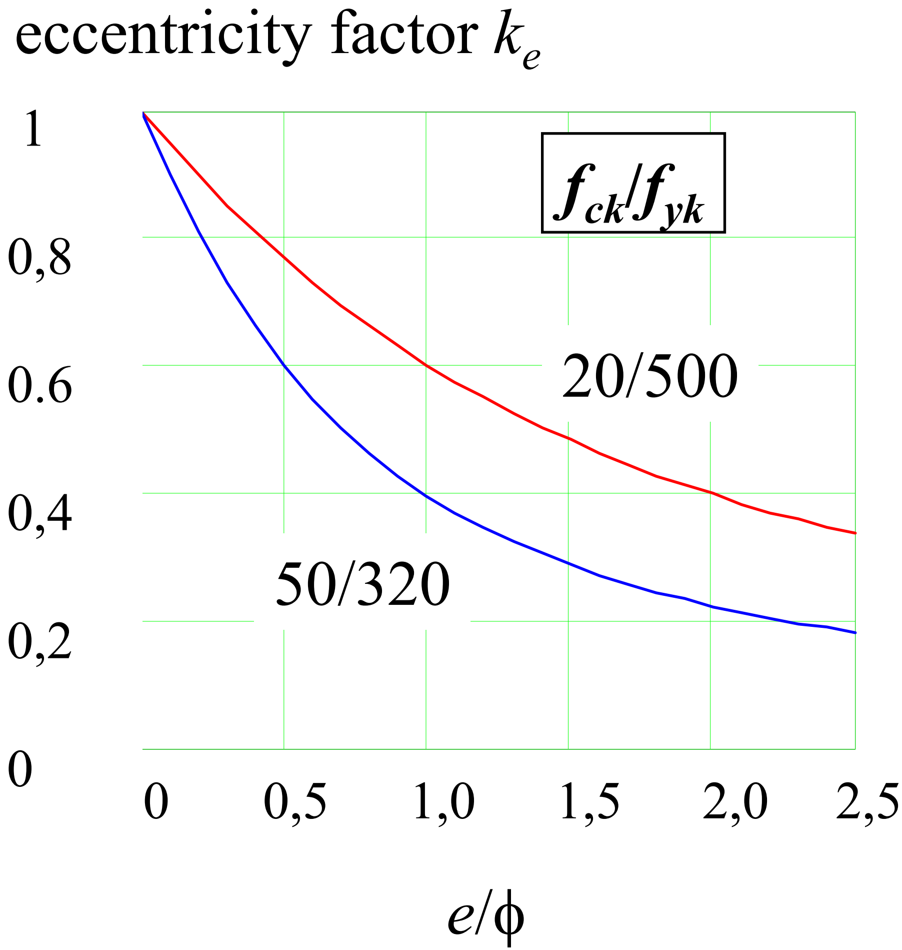
$$V_R = \phi^2 \sqrt{f_{cc} \cdot f_{sy}}$$

$$x_0 = \frac{V_R}{3 f_{cc} \cdot \phi}$$

Bending failure in bolt
crushing of concrete

Effect of eccentricity





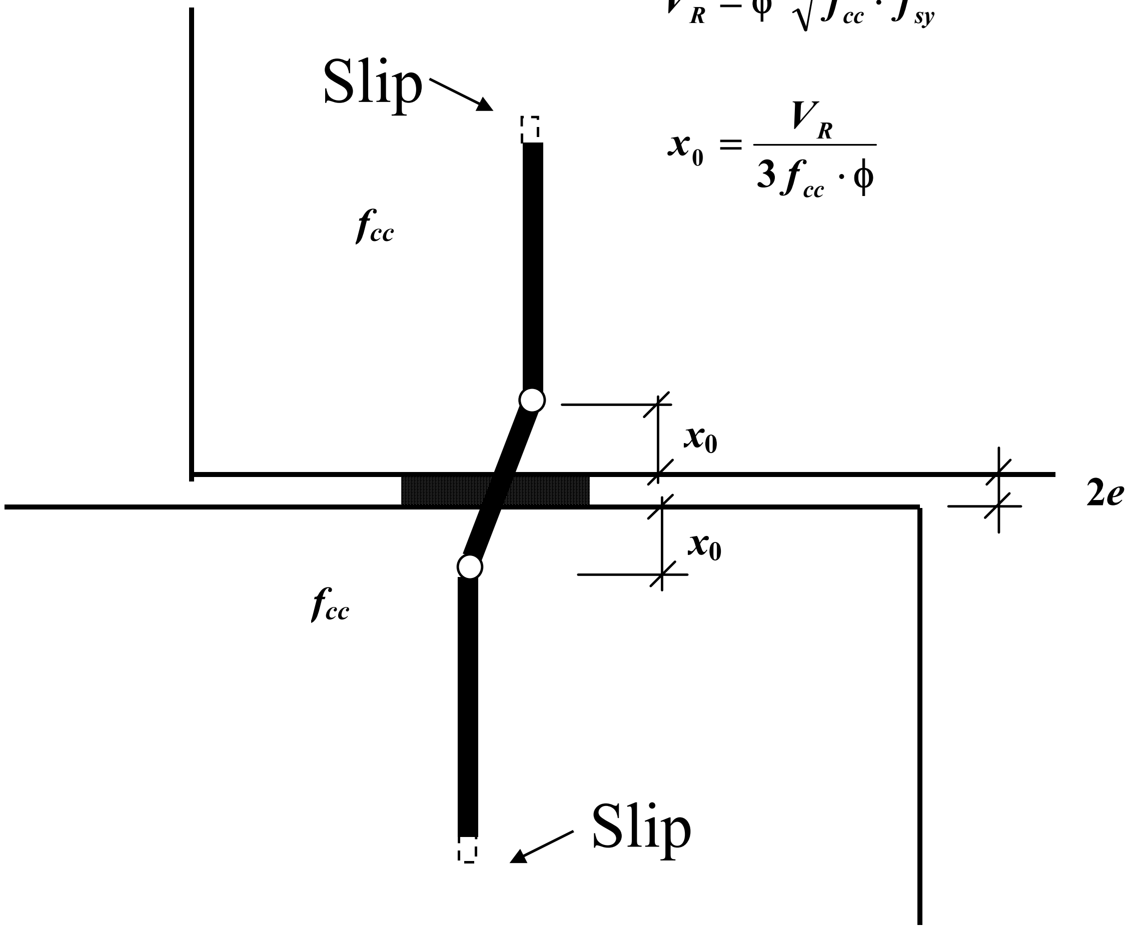
$$V_R = k_e \phi^2 \sqrt{f_{cc} \cdot f_{sy}}$$

$$x_0 = \frac{V_R}{3 f_{cc} \cdot \phi}$$

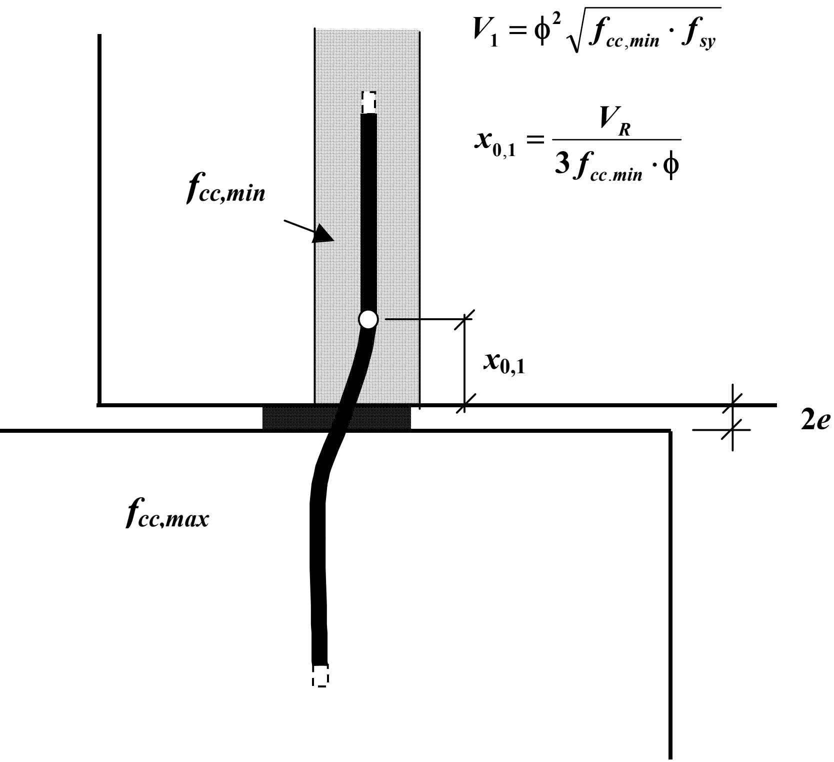
Dowel action – two-sided

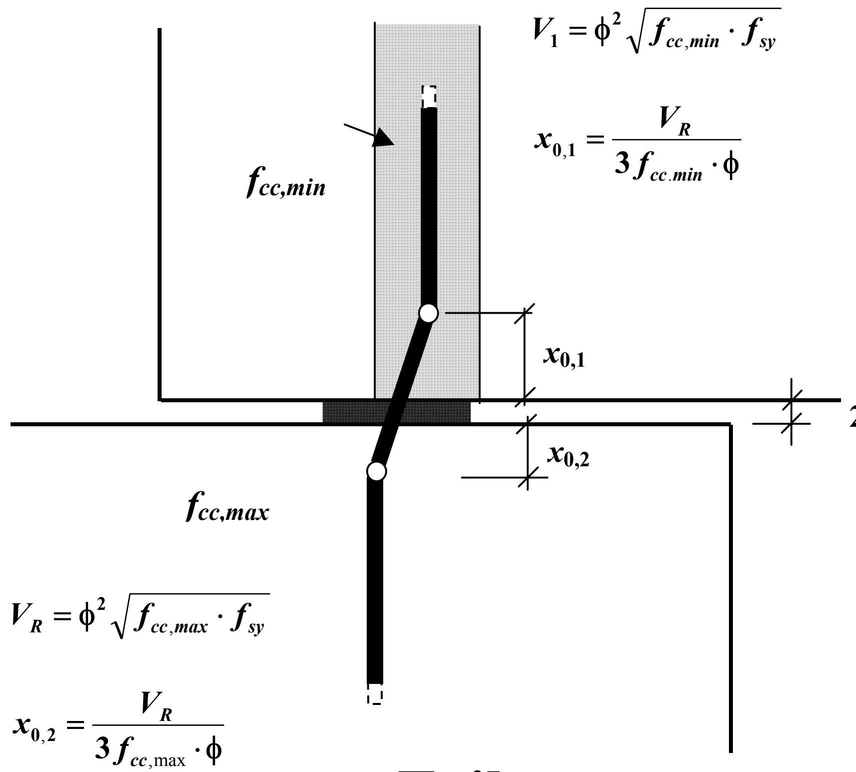
$$V_R = \phi^2 \sqrt{f_{cc} \cdot f_{sy}}$$

$$x_0 = \frac{V_R}{3 f_{cc} \cdot \phi}$$



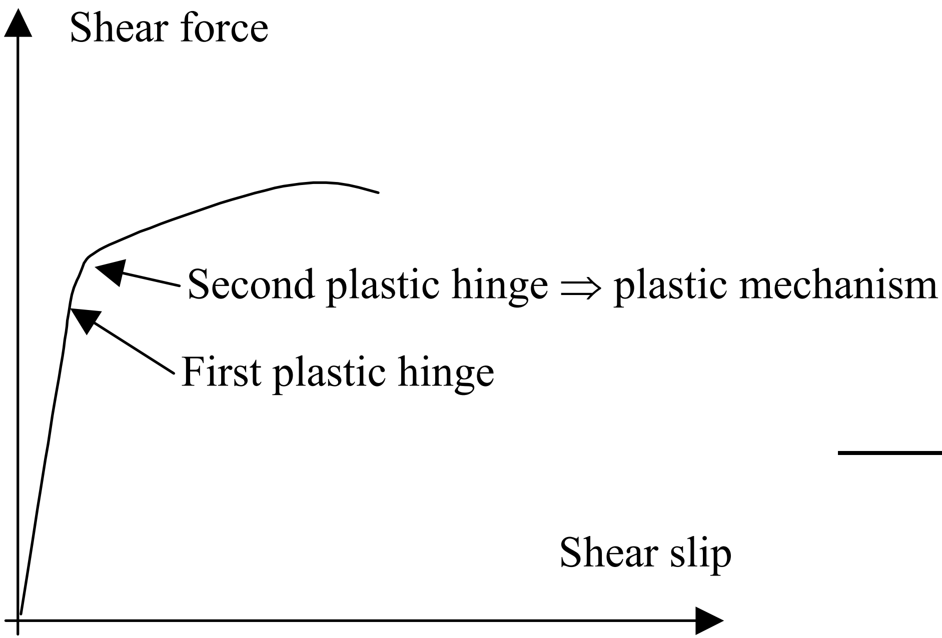
Different conditions

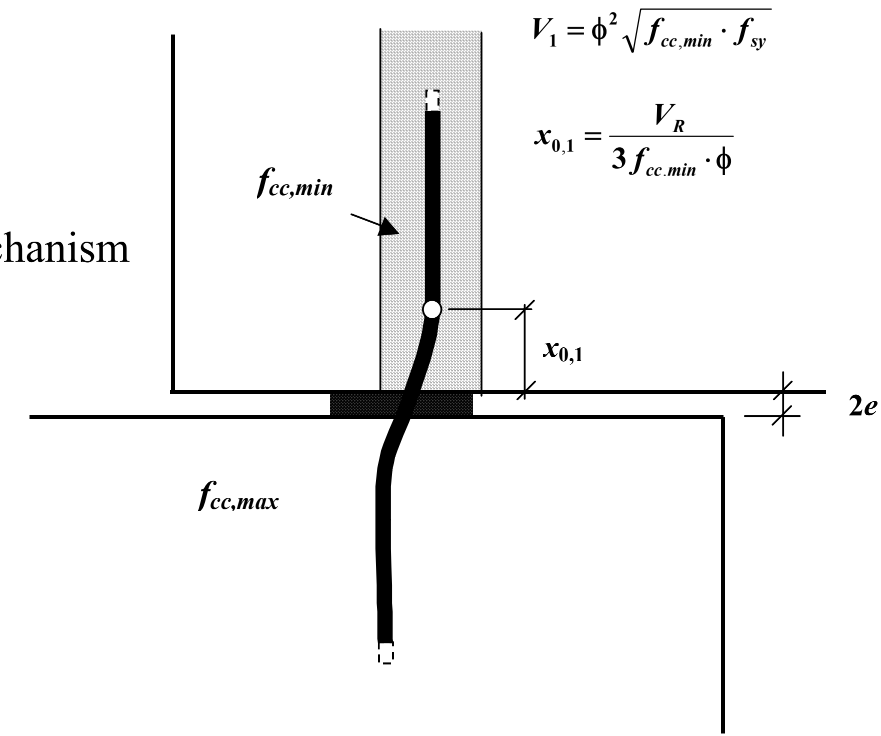




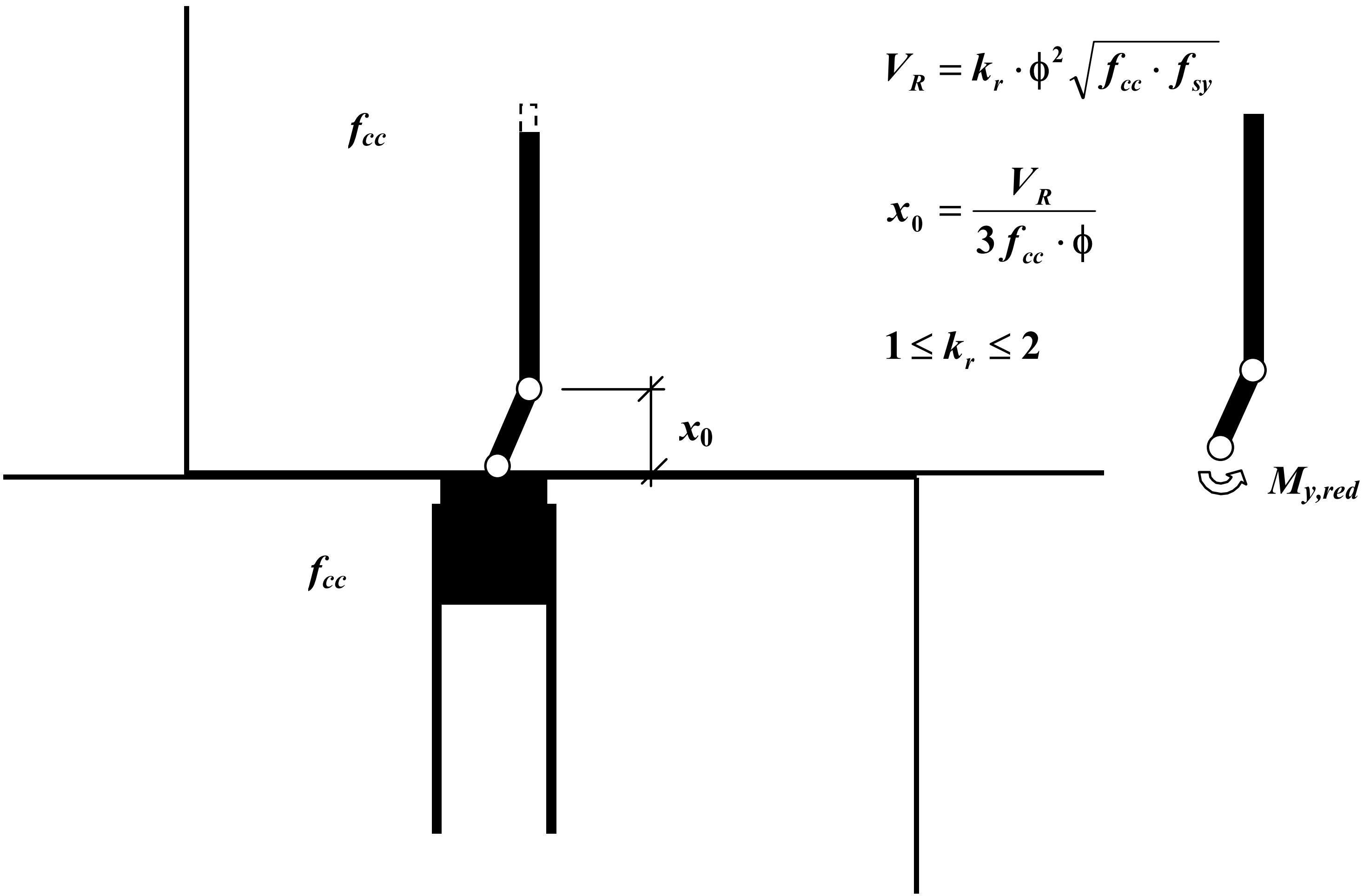
Failure mechanism

Response in shear





Effect of restraint



$$V_R = k_r \cdot \phi^2 \sqrt{f_{cc} \cdot f_{sy}}$$

$$x_0 = \frac{V_R}{3 f_{cc} \cdot \phi}$$

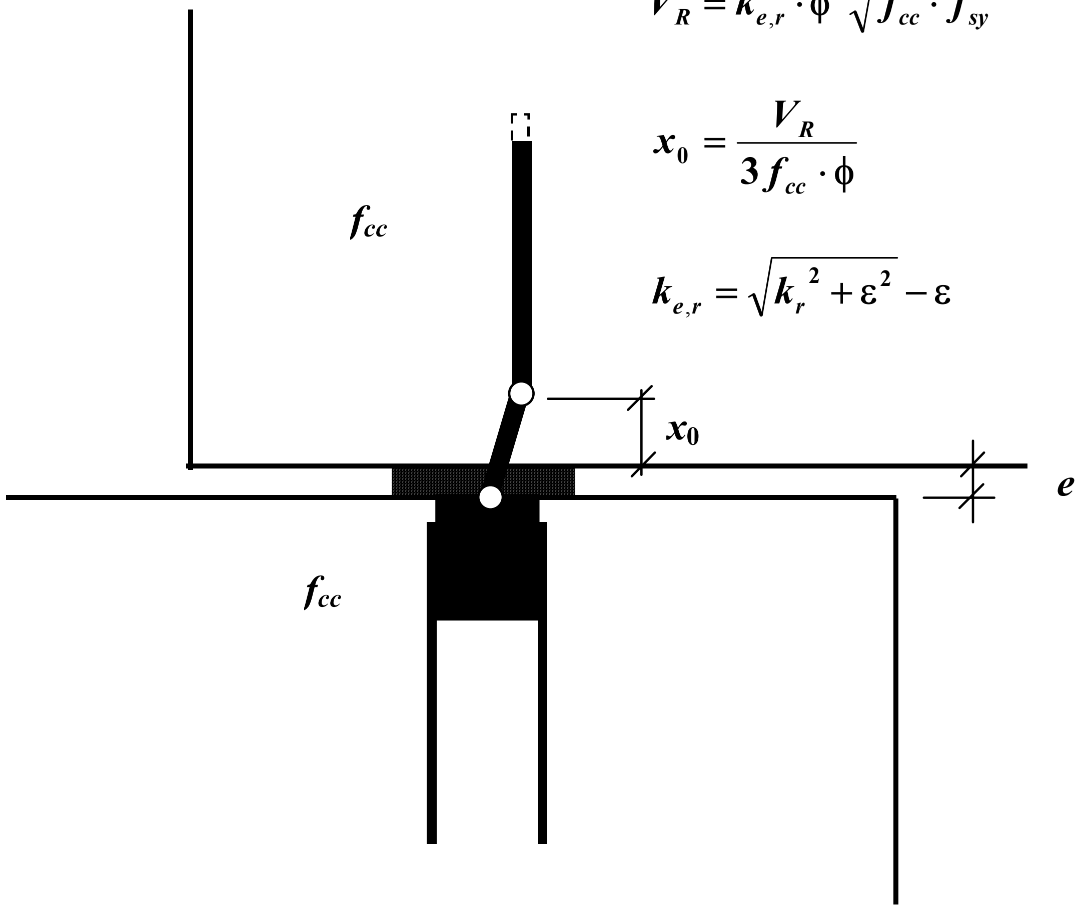
$$1 \le k_r \le 2$$

Restraint and eccentricity

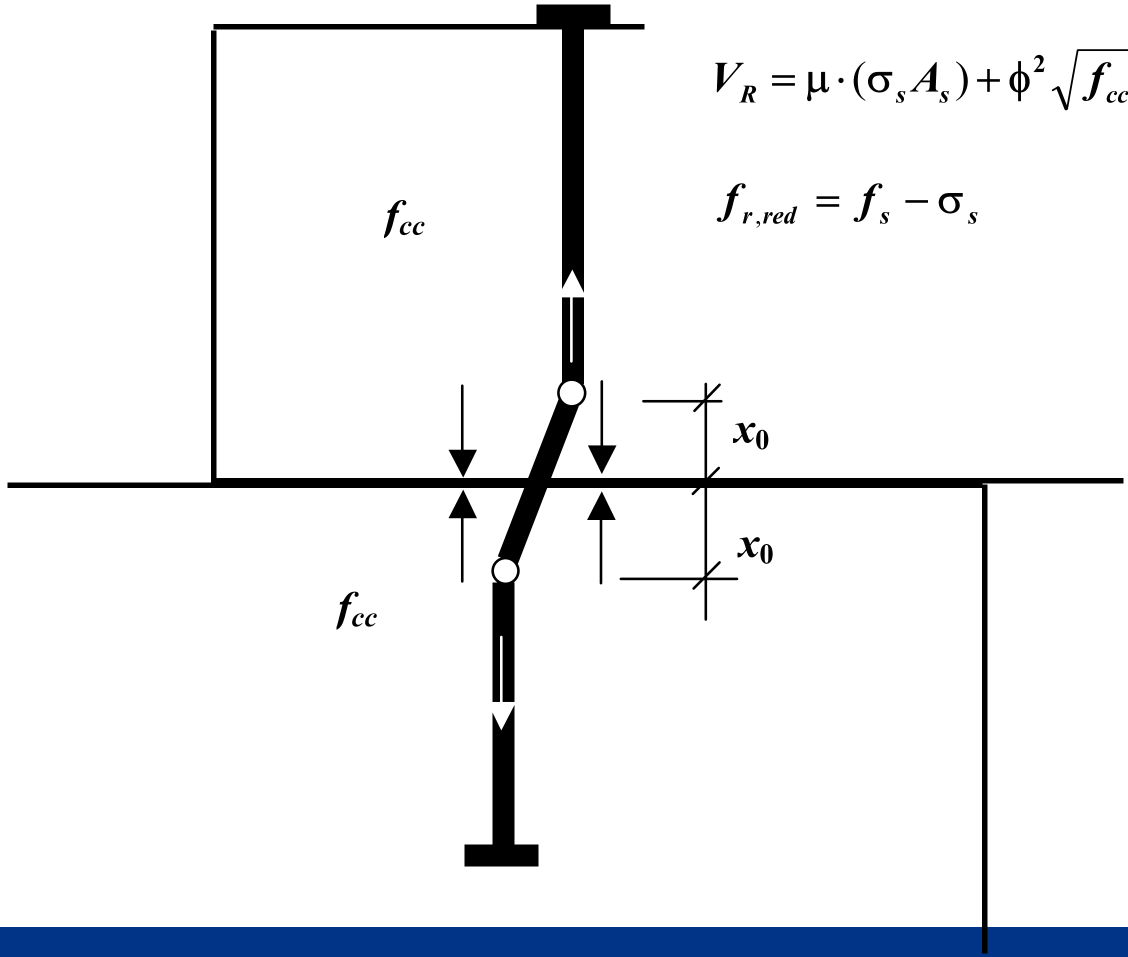
$$V_R = k_{e,r} \cdot \phi^2 \sqrt{f_{cc} \cdot f_{sy}}$$

$$x_0 = \frac{V_R}{3 f_{cc} \cdot \phi}$$

$$k_{e,r} = \sqrt{k_r^2 + \varepsilon^2} - \varepsilon$$



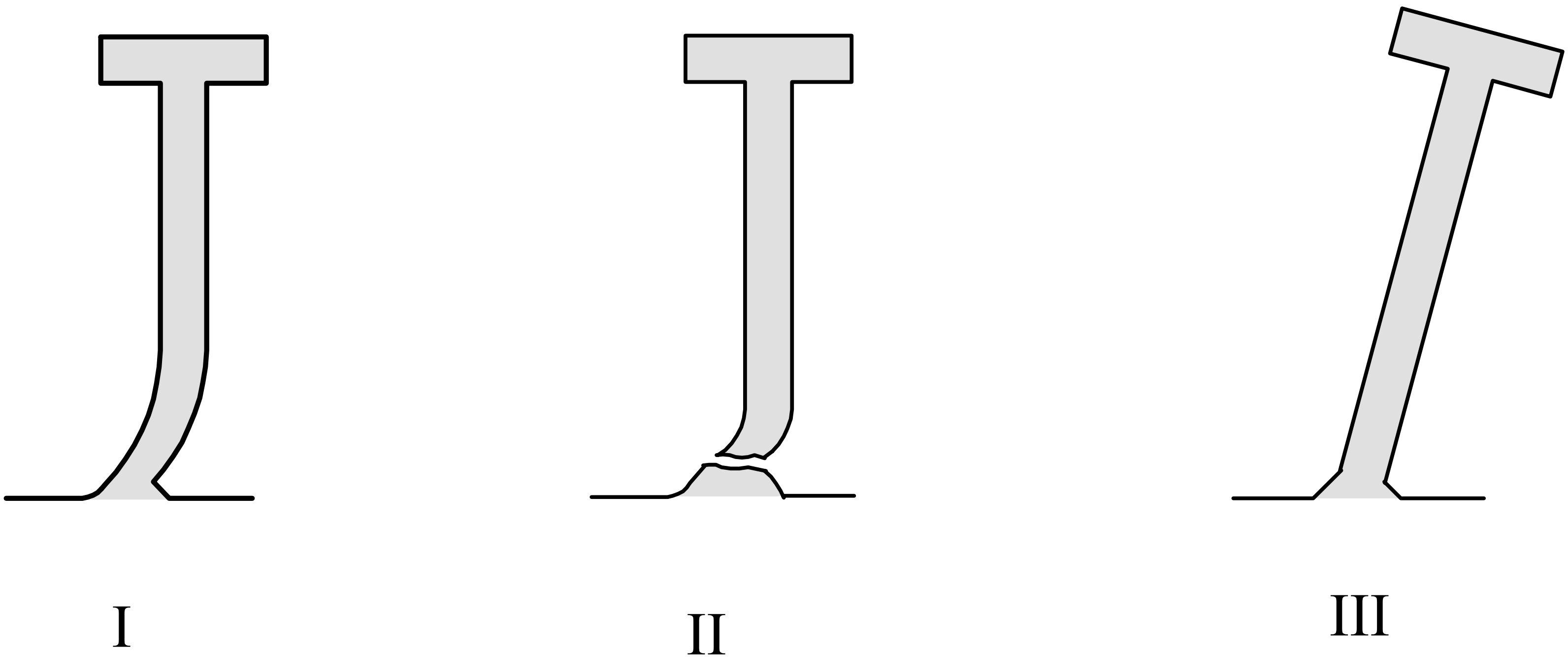
Effect of anchorage



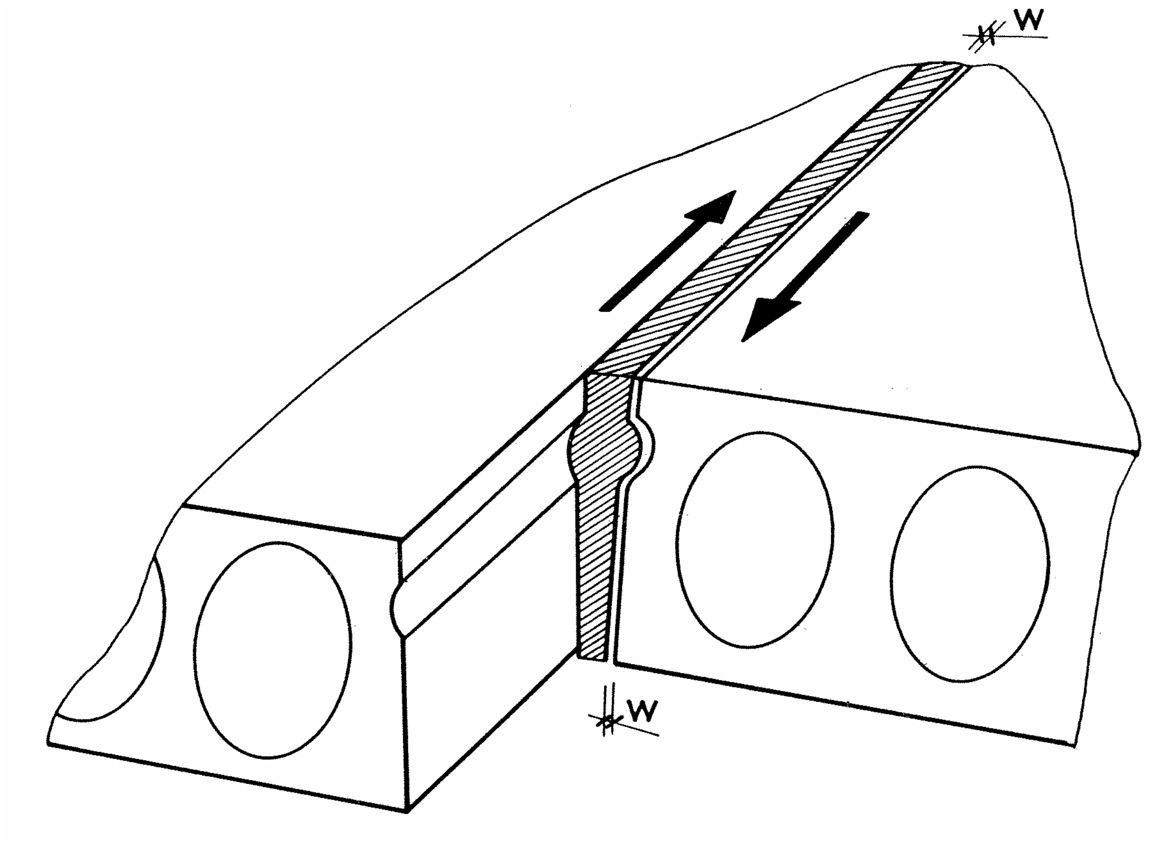
$$V_R = \mu \cdot (\sigma_s A_s) + \phi^2 \sqrt{f_{cc} \cdot f_{s,red}}$$

$$f_{r,red} = f_s - \sigma_s$$

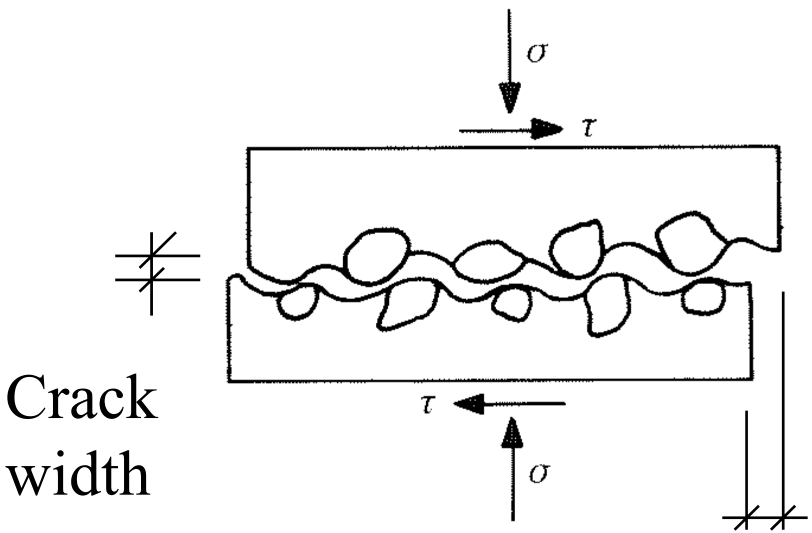
What happened here?

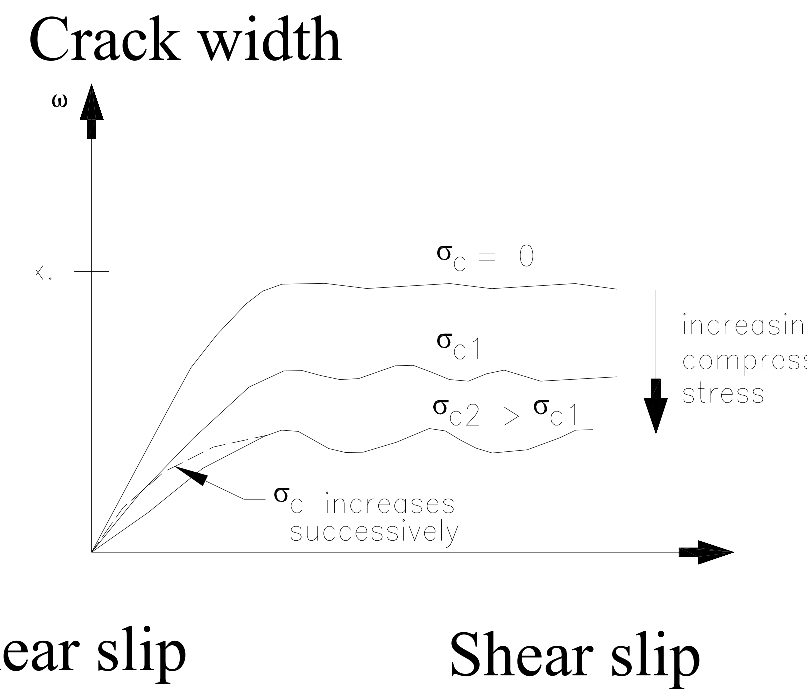


Shear in joints

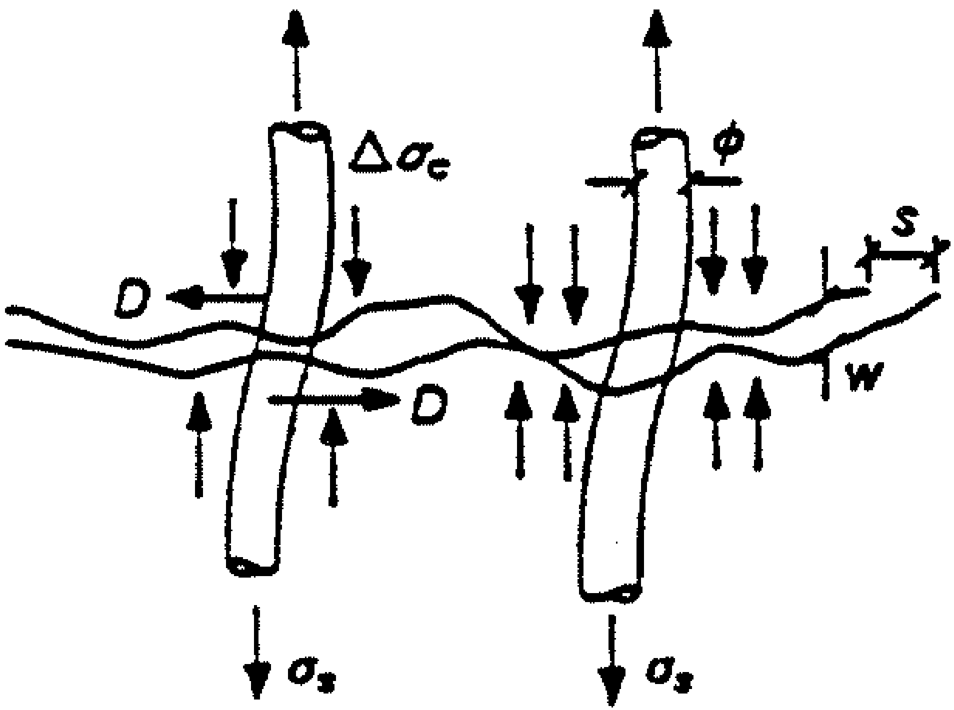


Shear friction

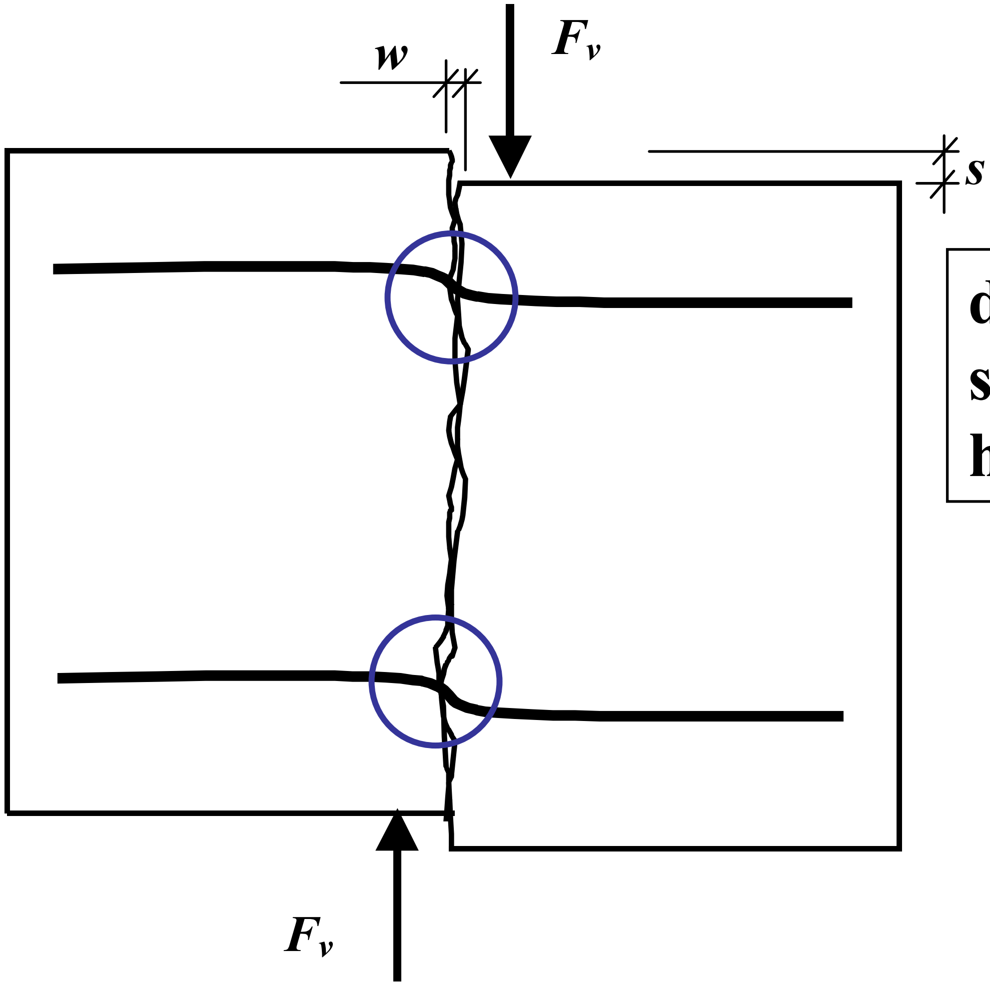




Self-generated friction



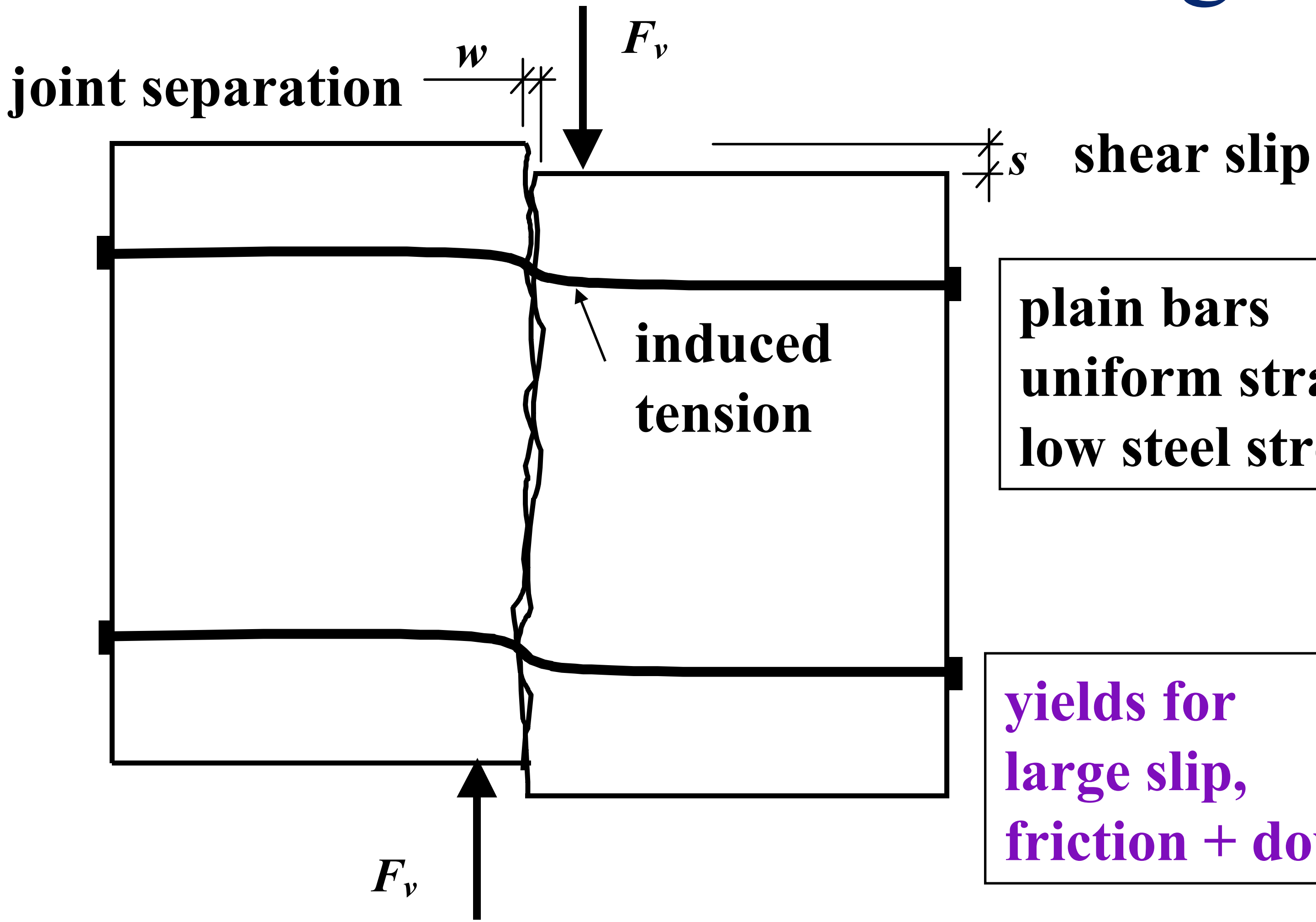
Influence of bond and anchorage



deformed bars
strain localisation
high steel stress

yields for
small slip,
friction dominates

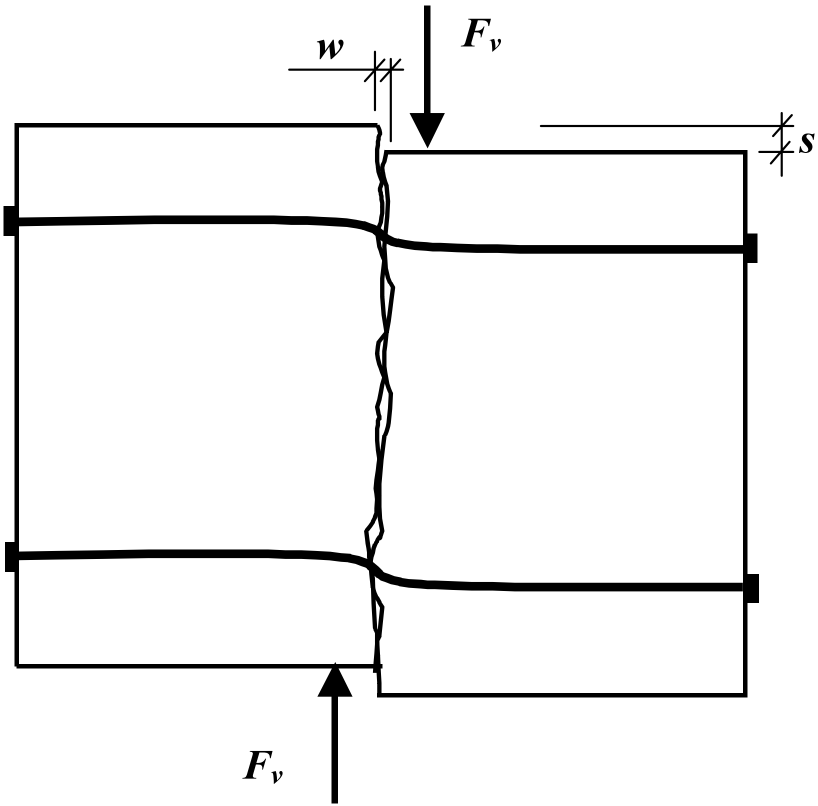
Influence of bond and anchorage



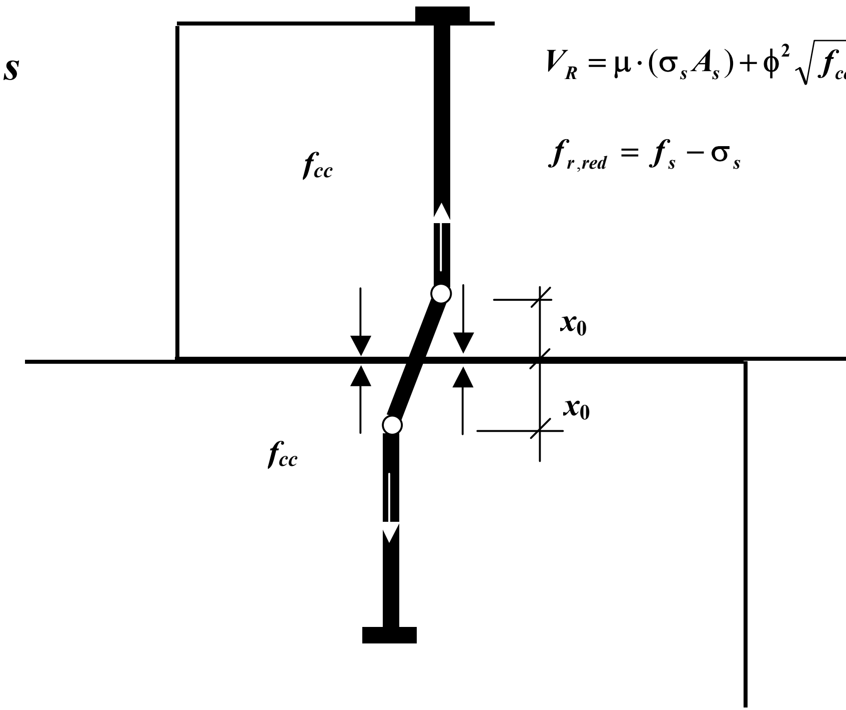
plain bars
uniform strain
low steel stress

yields for
large slip,
friction + dowel

Compare with bolted connection



Shear friction in joint
Plain bars with end anchors

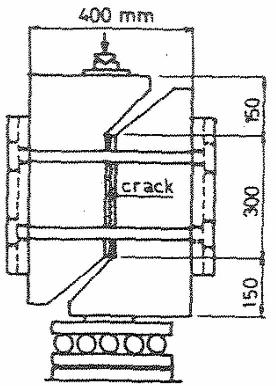


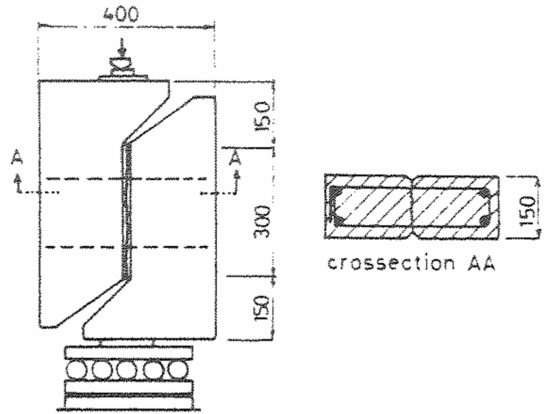
$$V_R = \mu \cdot (\sigma_s A_s) + \phi^2 \sqrt{f_{cc} \cdot f_{s,red}}$$

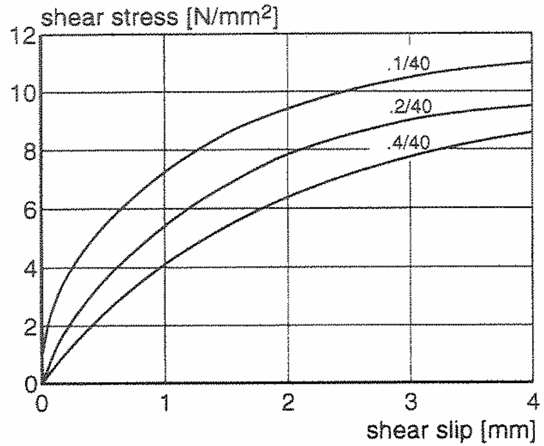
$$f_{r,red} = f_s - \sigma_s$$

Bolted connection
Plain bolt with end anchors

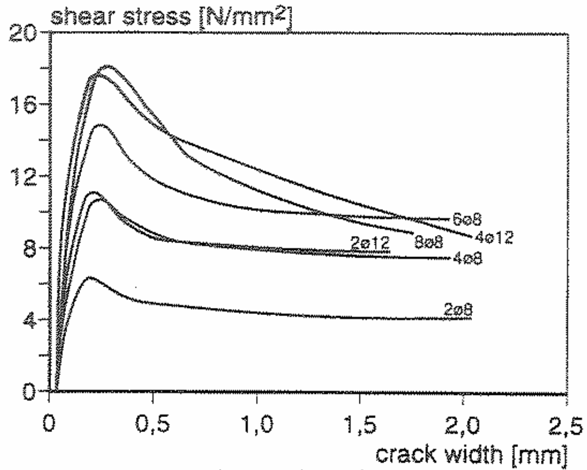
Different responses





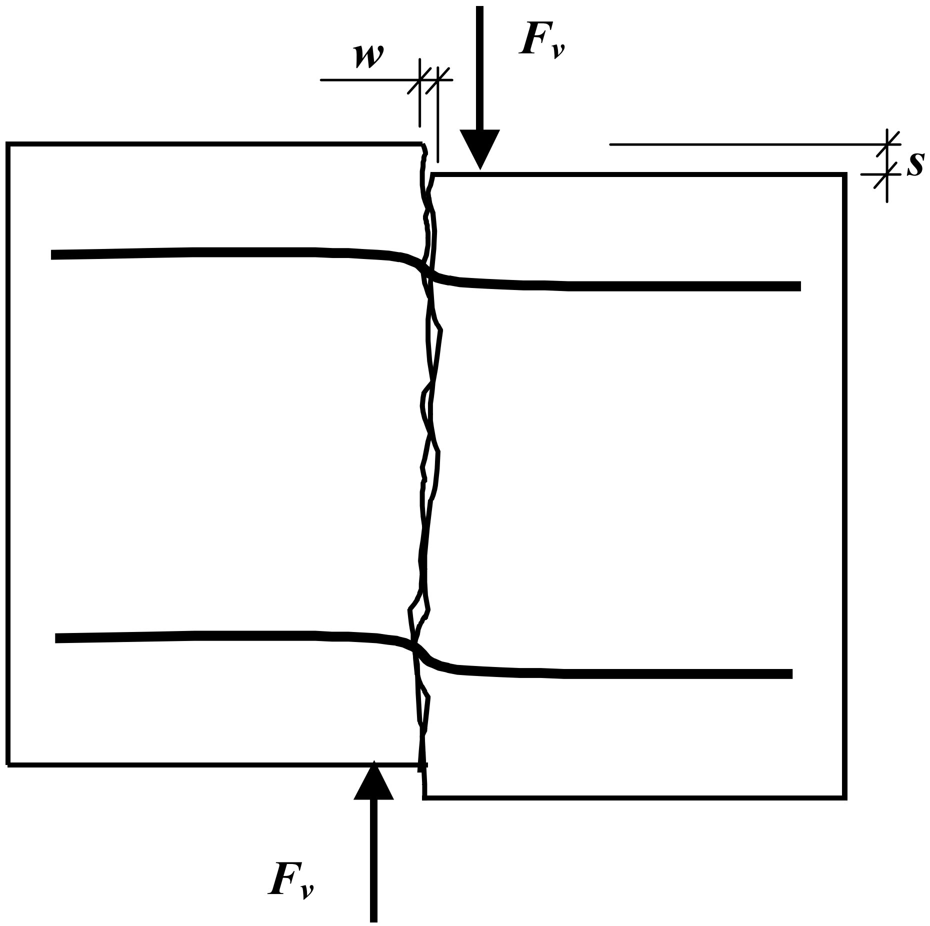


External bars



Internal reinforcement

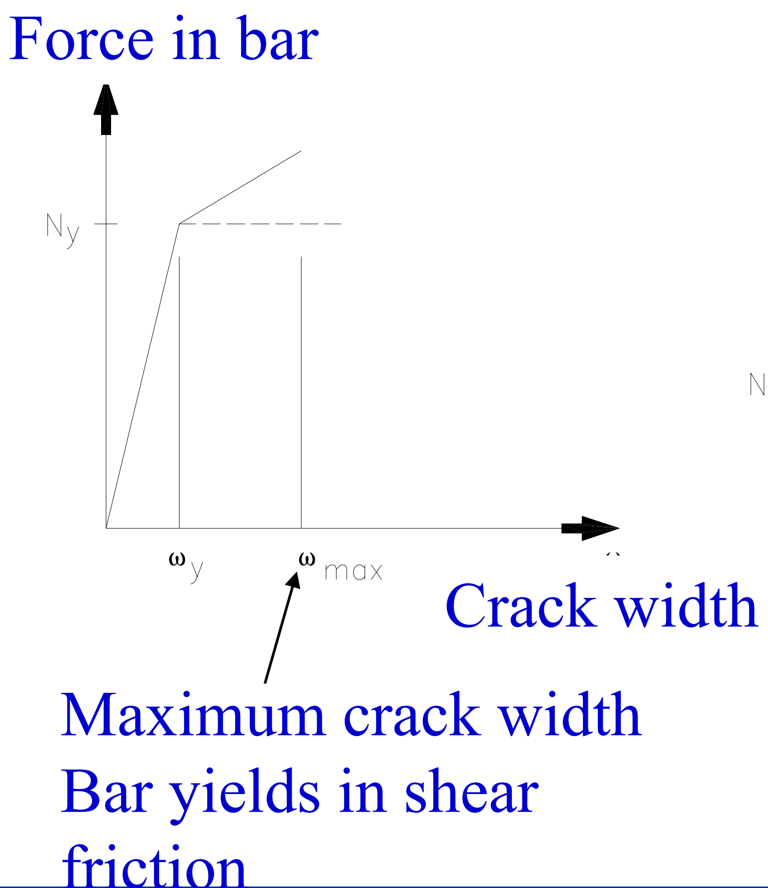
When will the transverse bars yield?

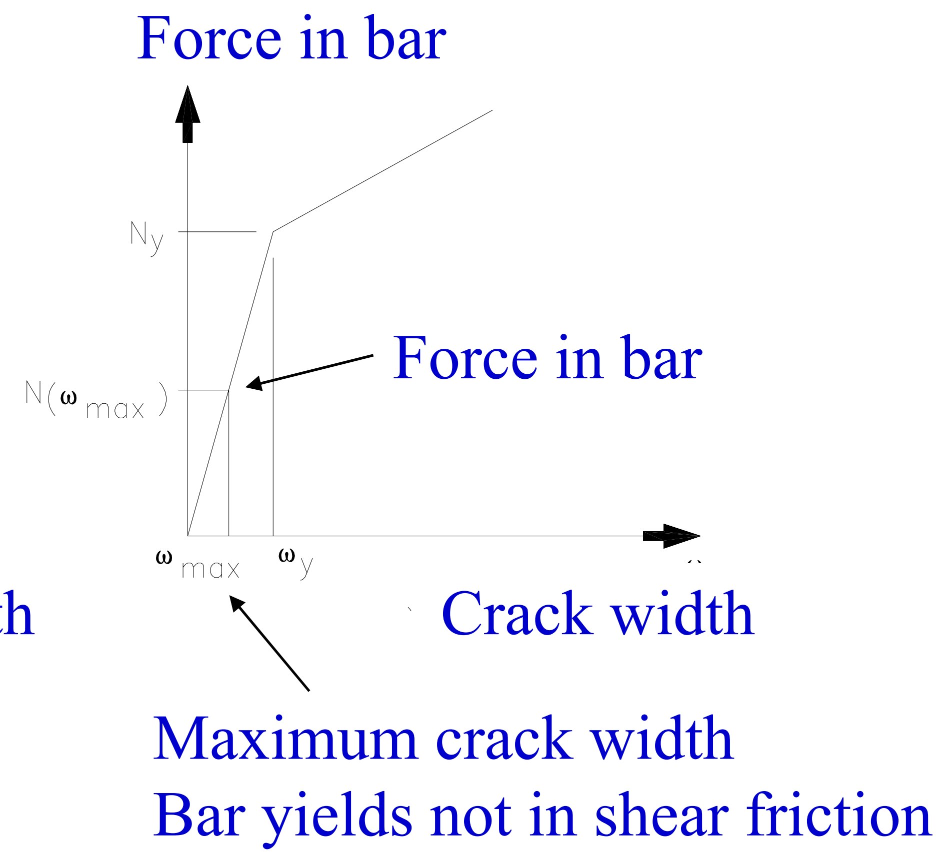


Depends on:

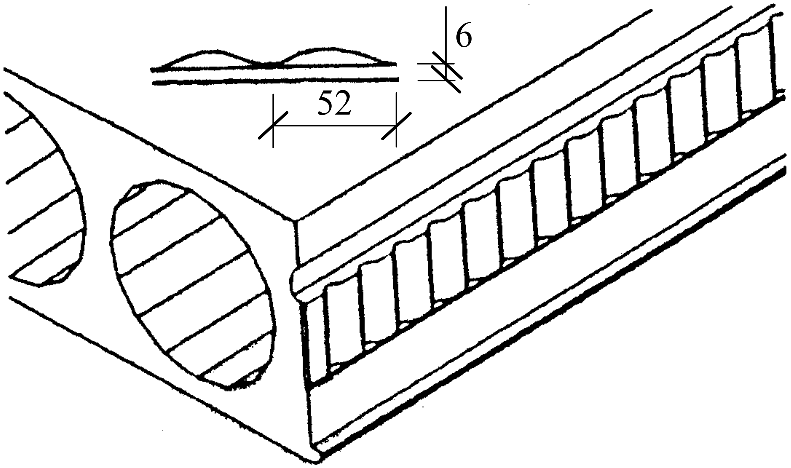
- joint roughness
- bond resistance of transverse bar

Maximum crack width vs. end slip response of transverse bar



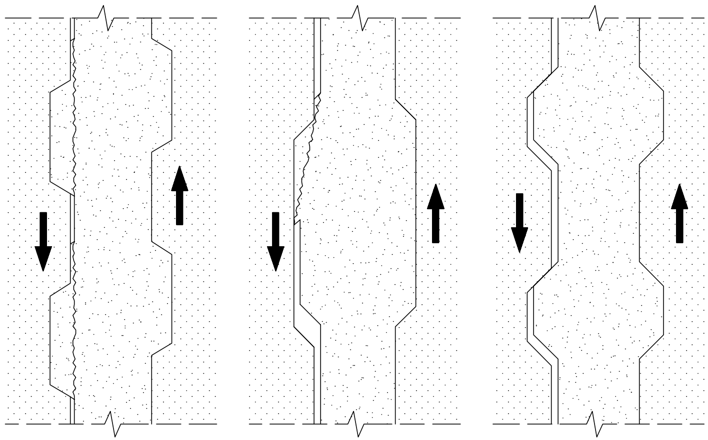


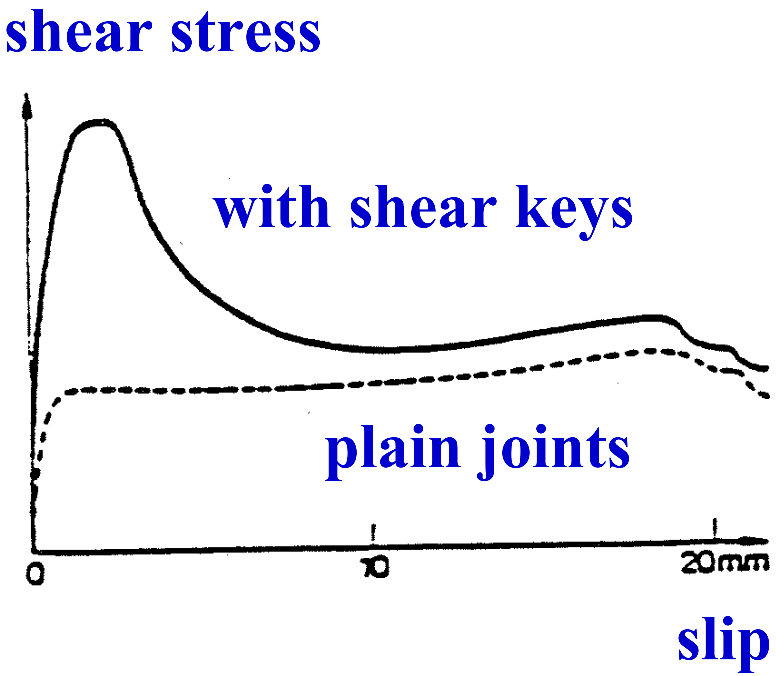
Increased joint separation



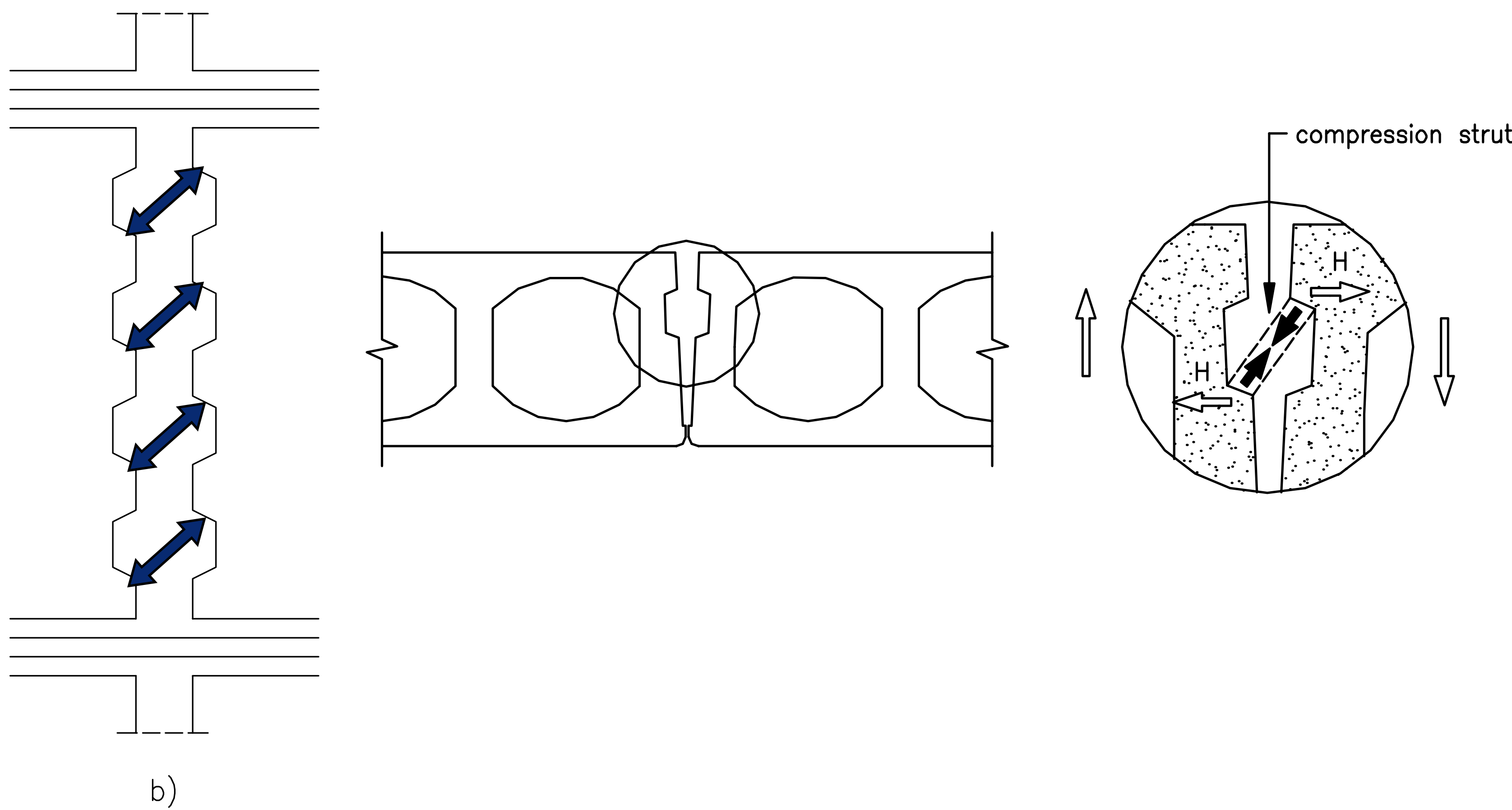
Joint profile with wave-shaped undulations

Joints with shear keys

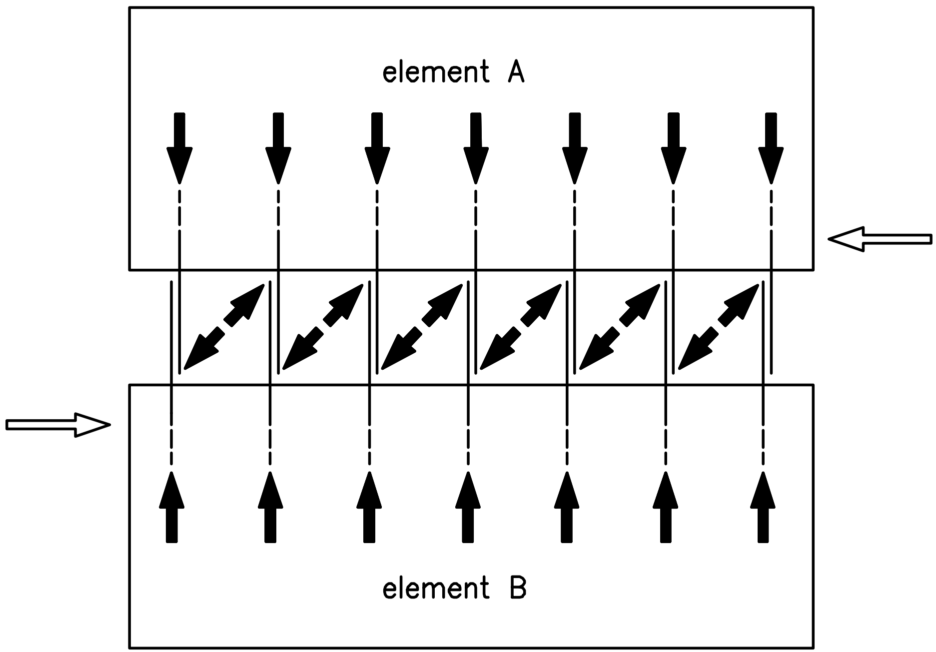


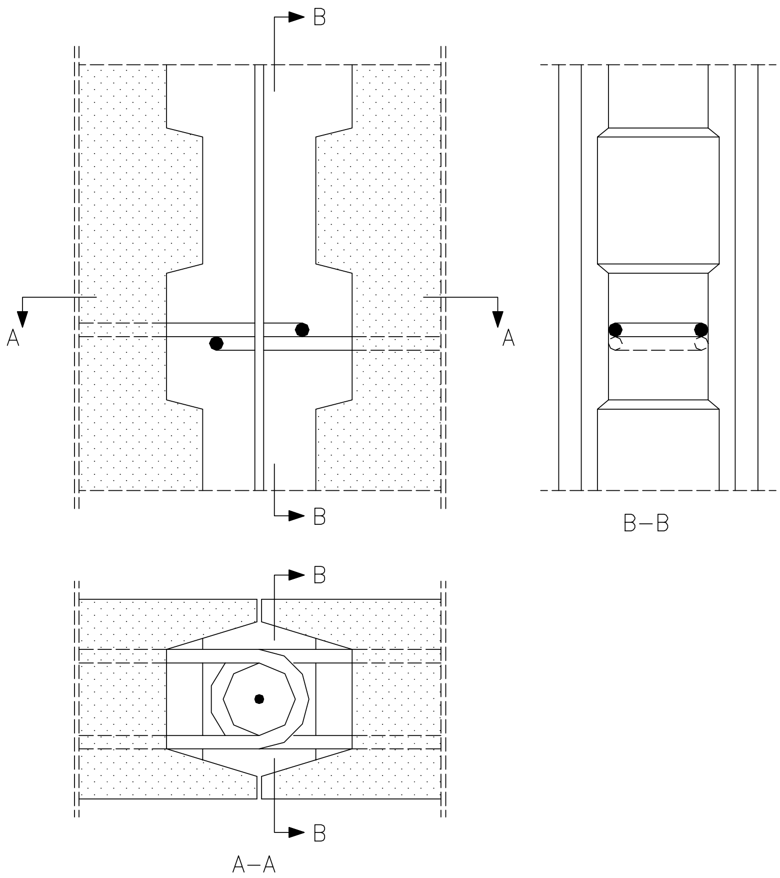


Shear transfer – clamping is needed

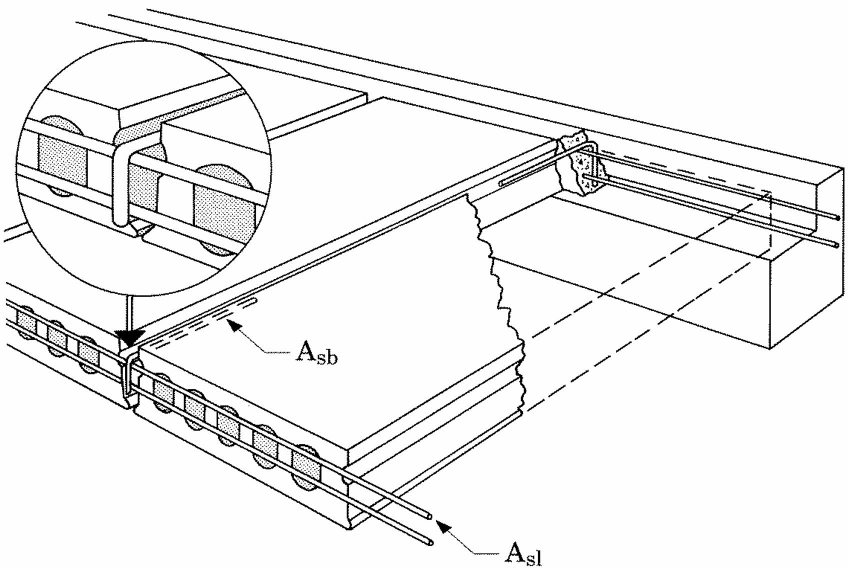


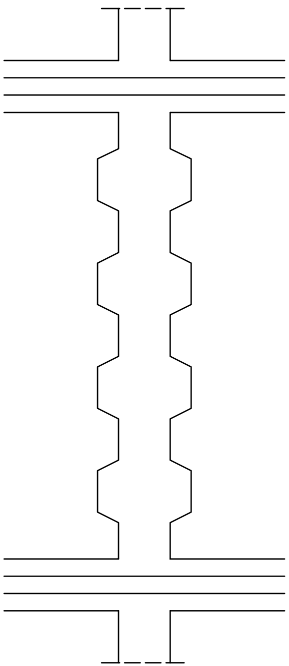
Distributed ties provides clamping





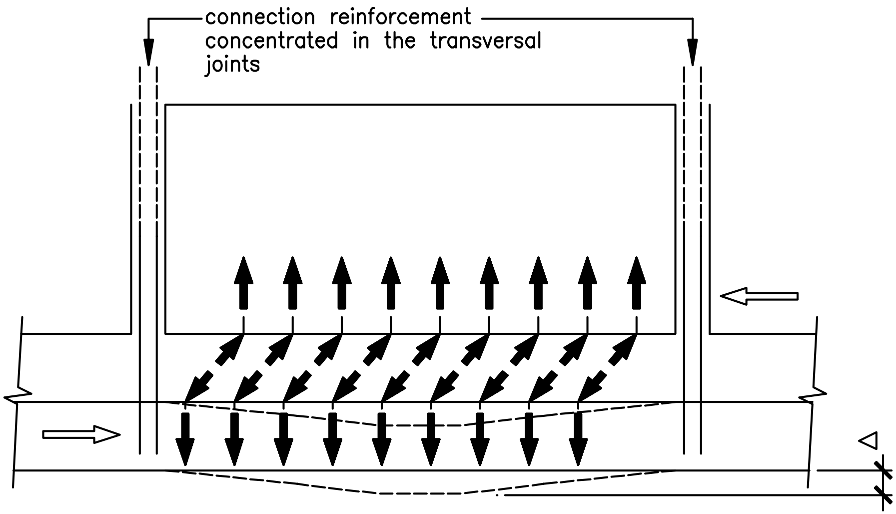
Concentrated ties provide clamping



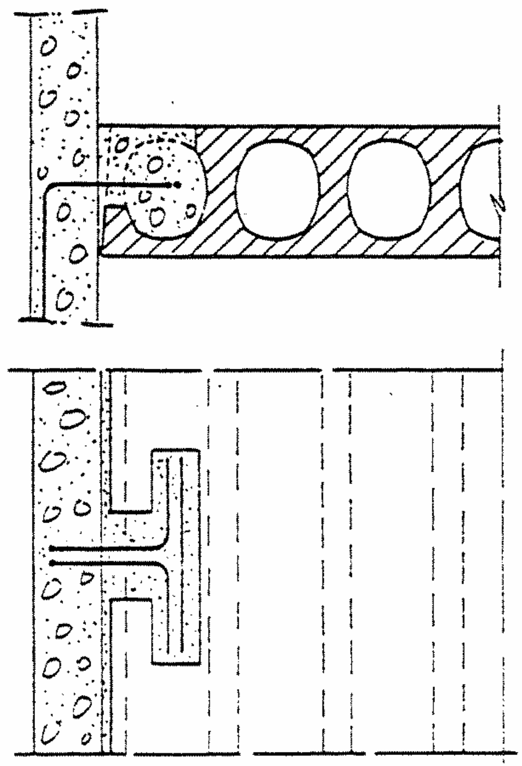


Adequate between elements with high in-plane stiffness that are arranged in the same plane

Distributed ties are needed here

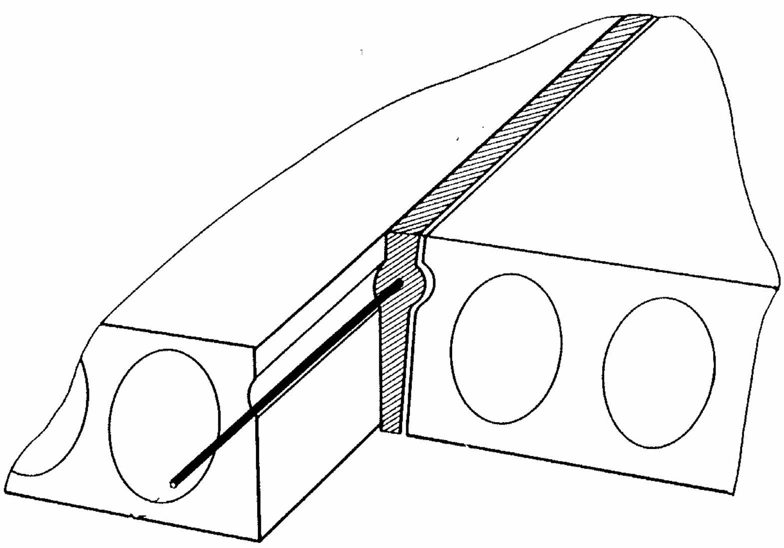


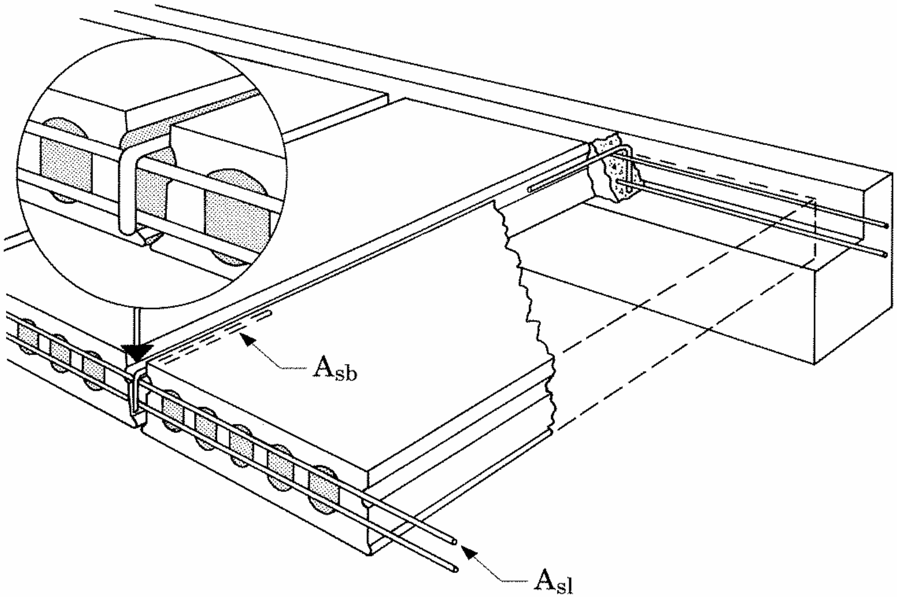
Inclined forces separate the elements arranged at a corner



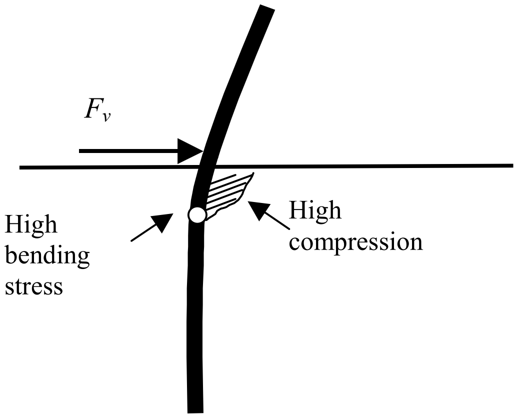
Example of distributed ties between floor and wall

Shear resistance of joints depends on overall design of the subsystem

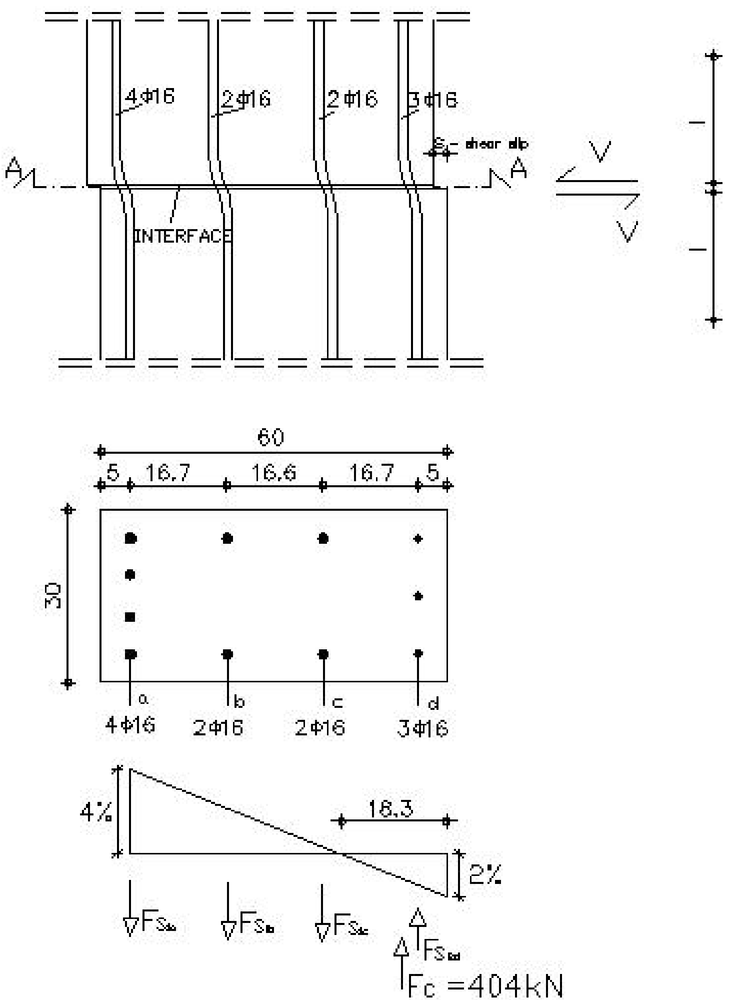




Design examples



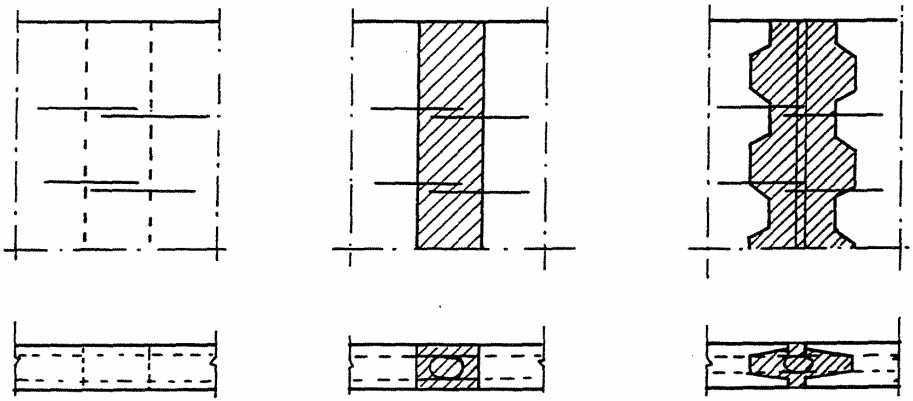
Response of plain dowel



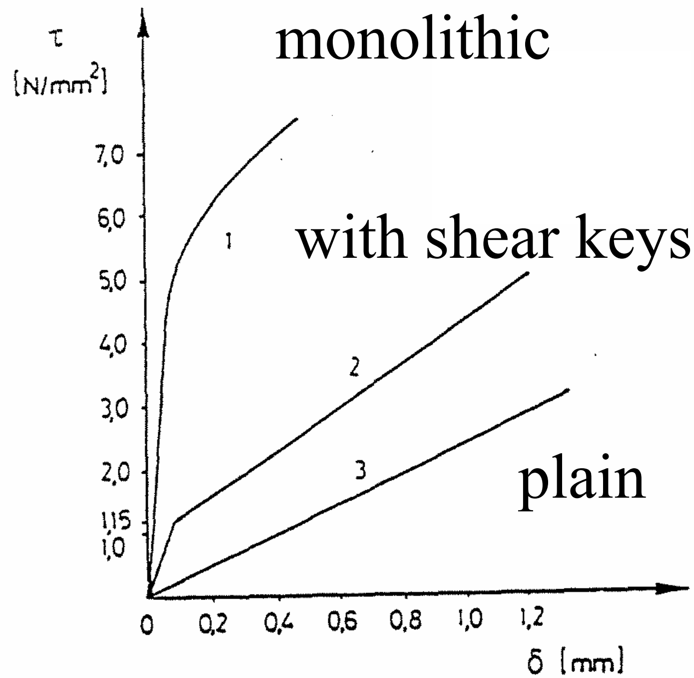
Frictional resistance of concrete interface

Fig.4.21

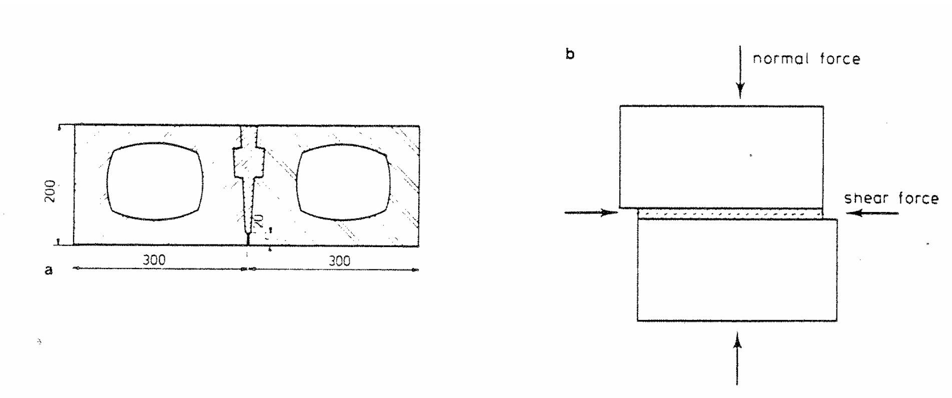
Connections between wall elements



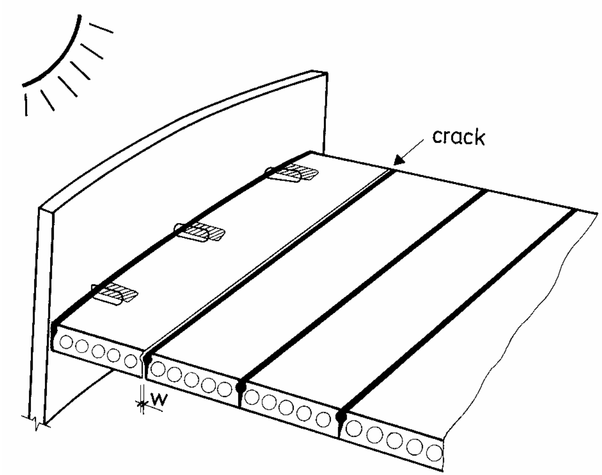
monolithic plain with shear-keys



Connections between floor elements

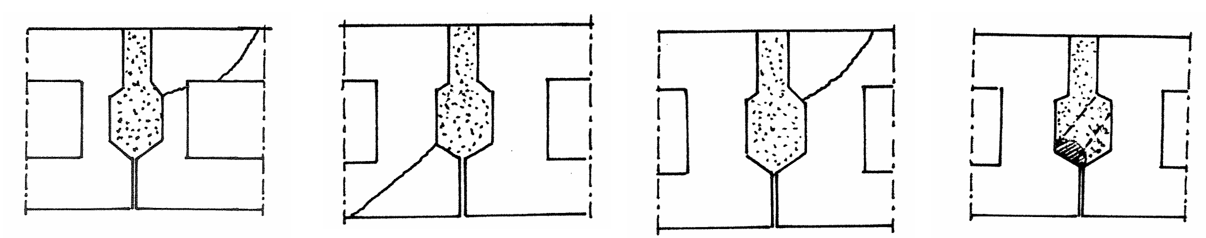


Uncracked joint

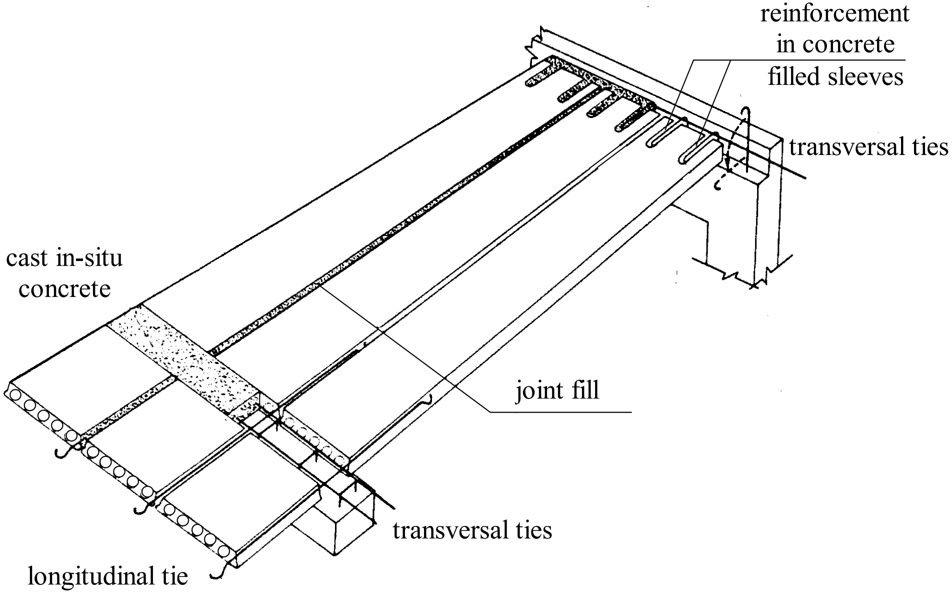


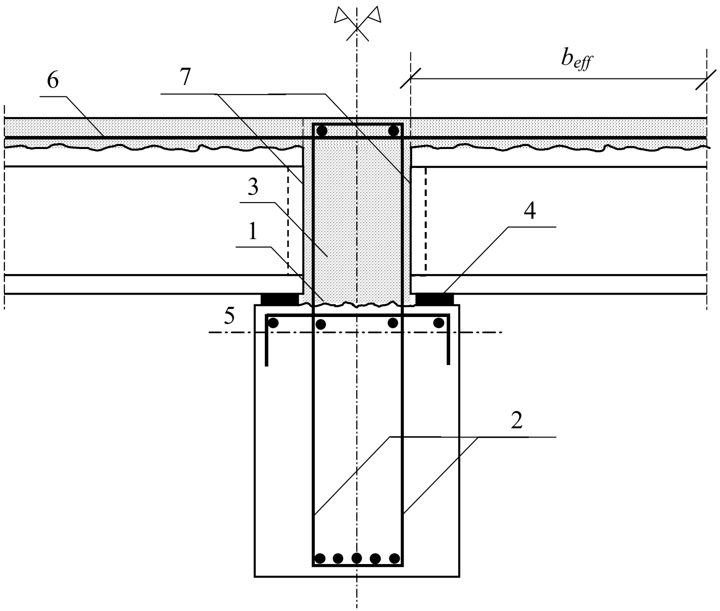
Cracked joints

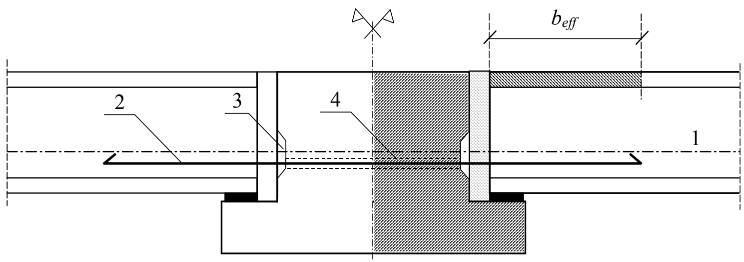
Vertical shear capacity



Applications



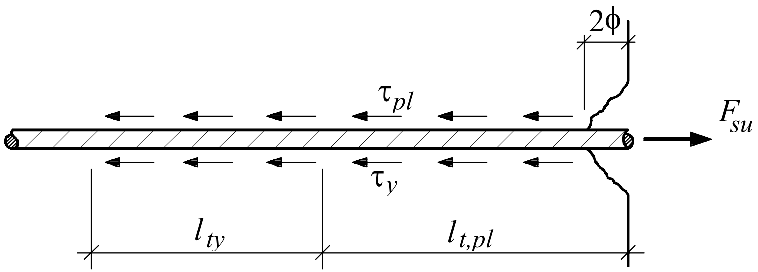




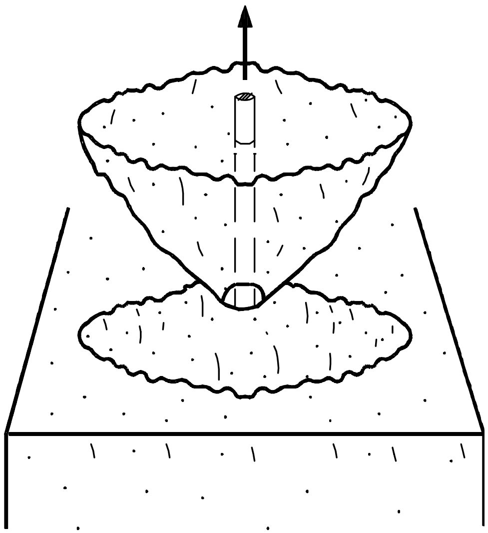
Shear transfer in hollow core floor

Shear transfer in composite beams

Transfer of tension

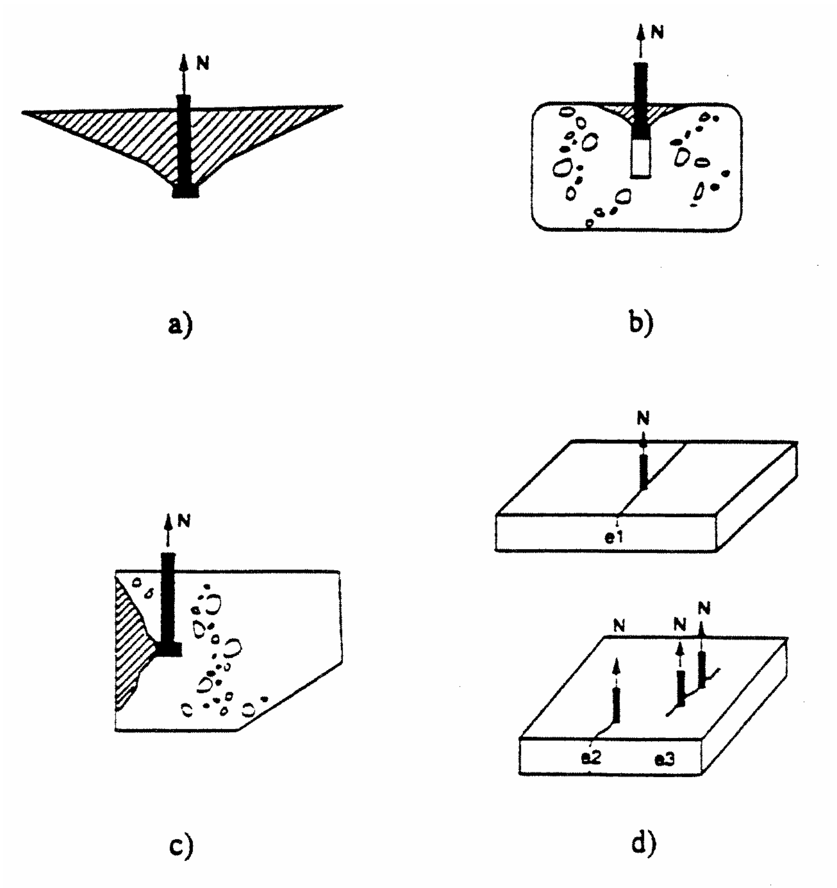


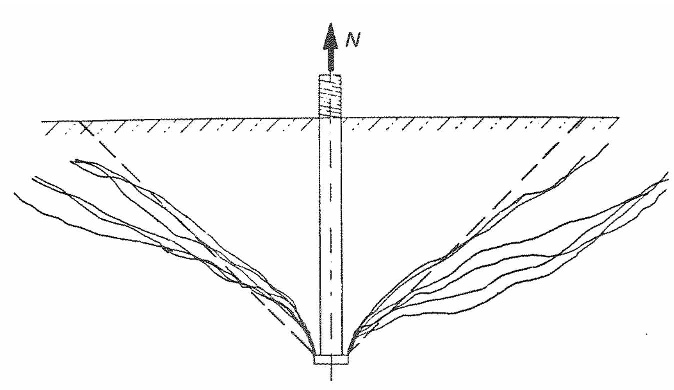
Anchorage with bond



Anchor head

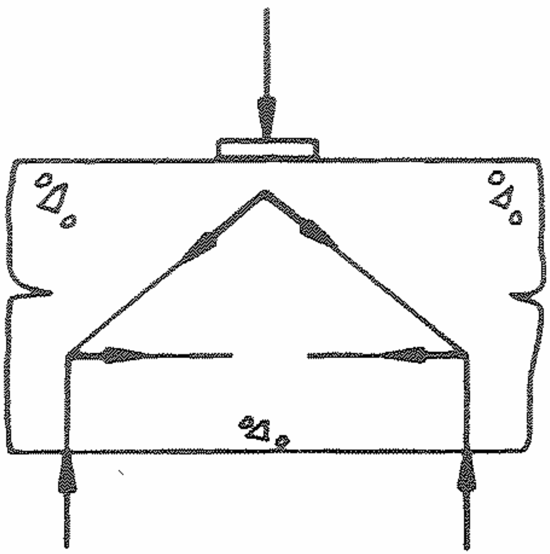
Headed bar



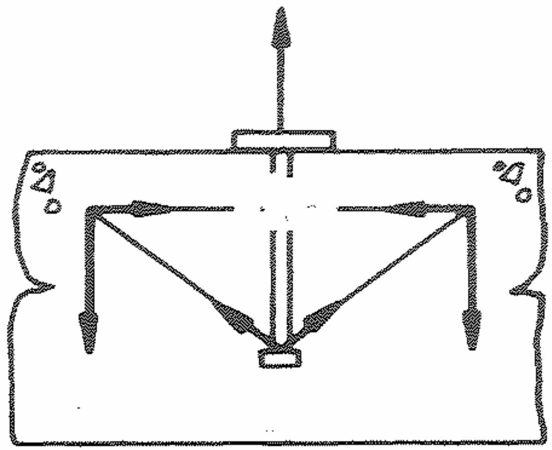


Concrete capacity design approach

Design of connection zone
The force must go further

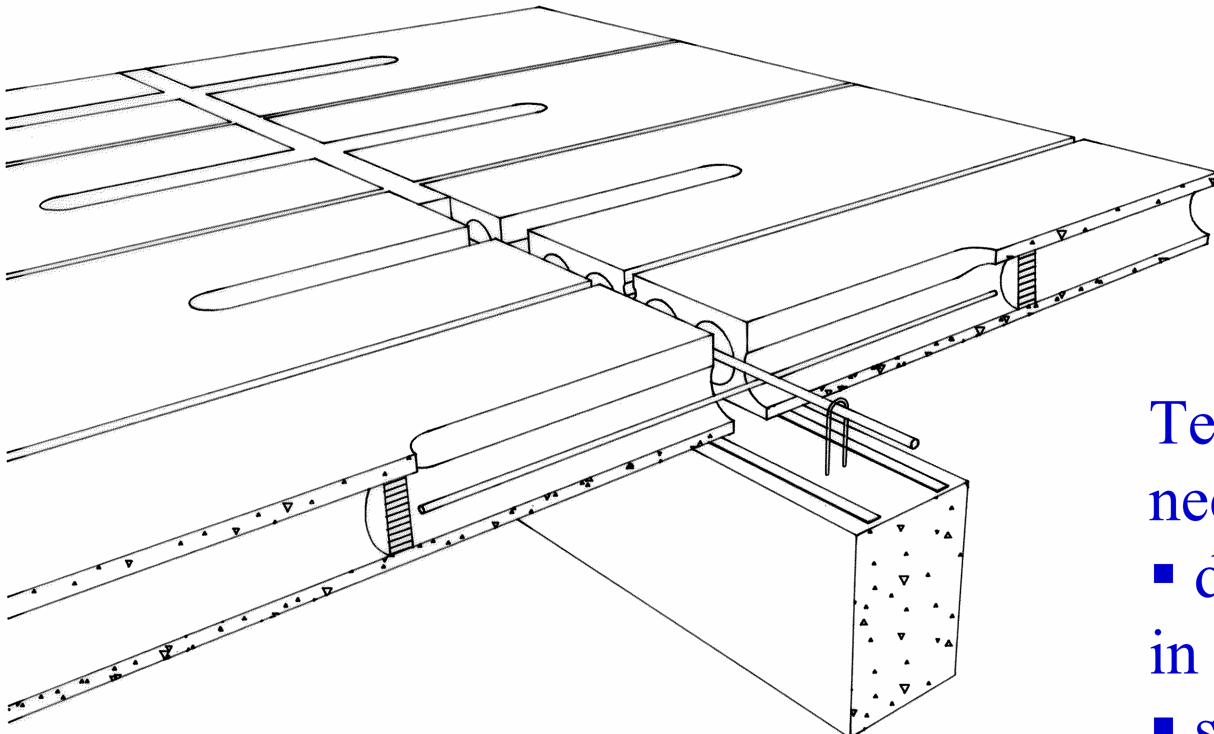


Local compression



Anchorage of headed bar

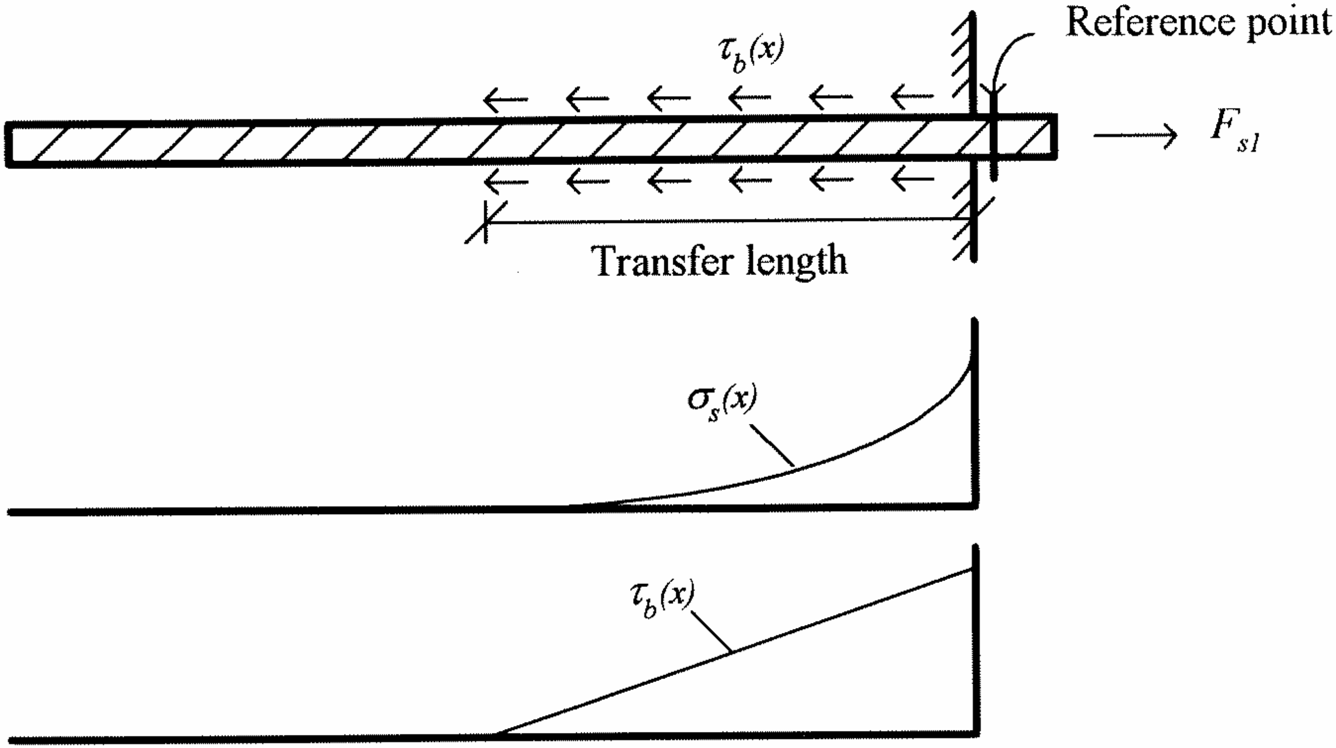
Hollow core floor connection



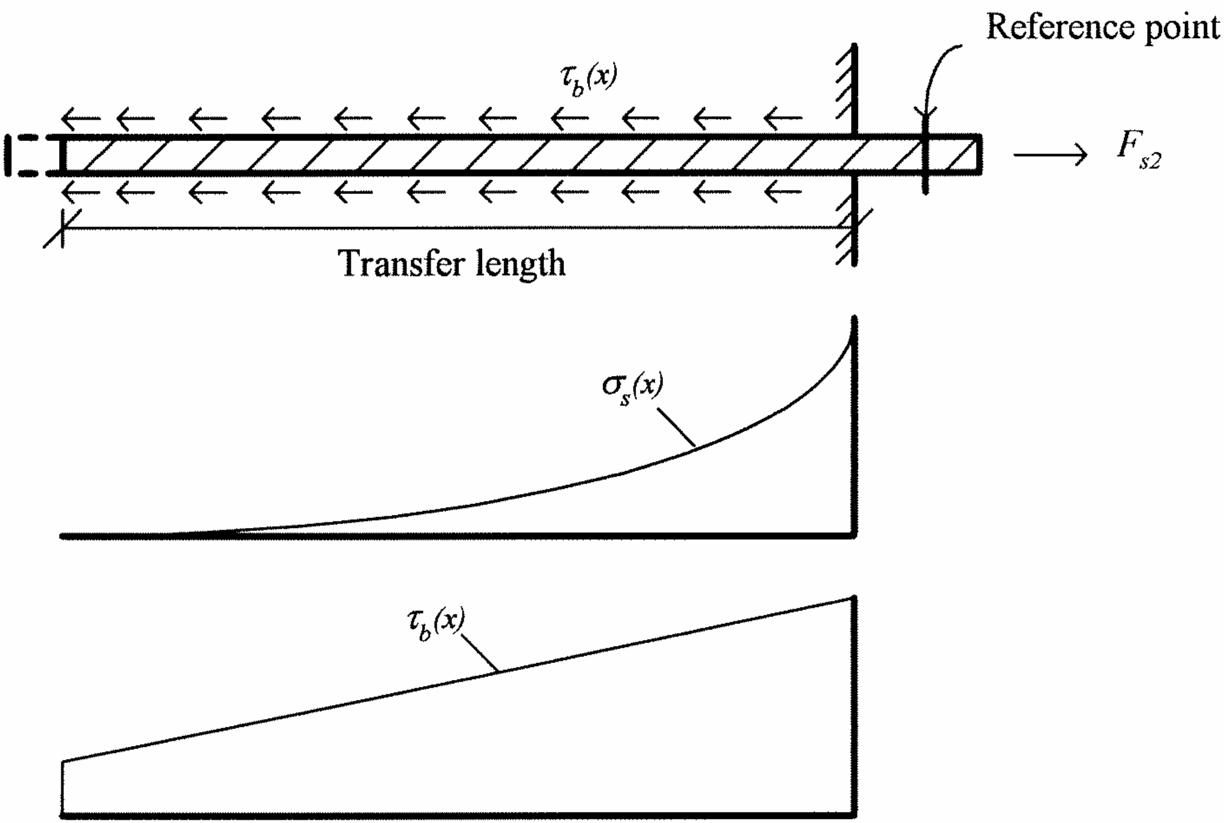
Tensile capacity is needed for:

- diaphragm action in floor
- shear friction resistance of joints

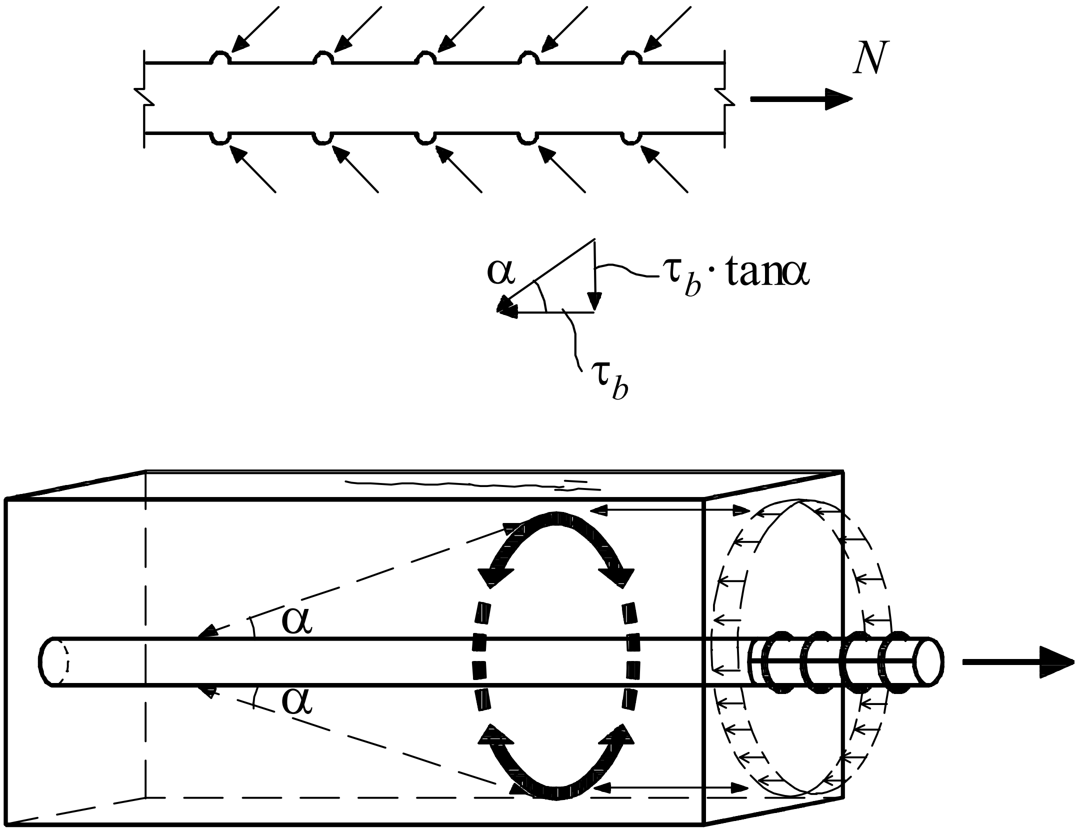
Bond stress development



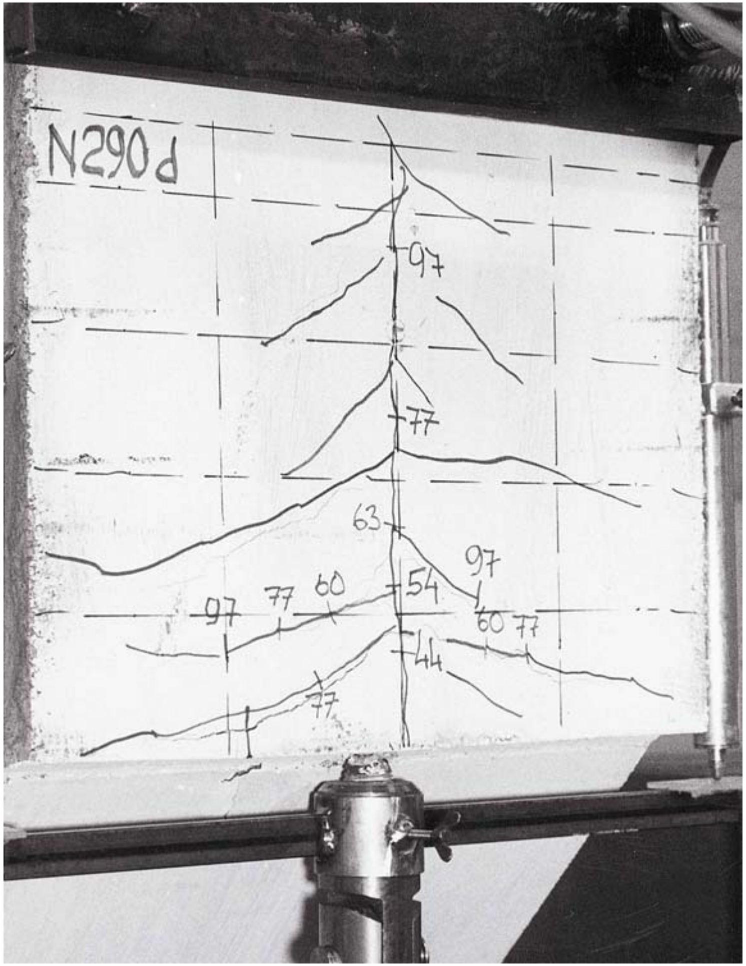
Bond stress development



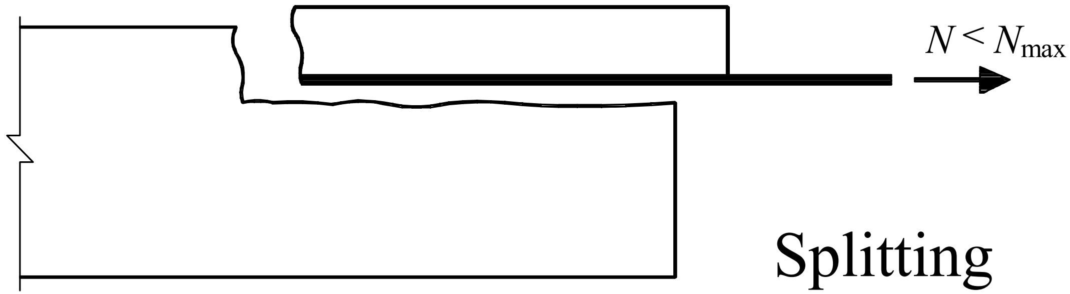
Inclined bond forces



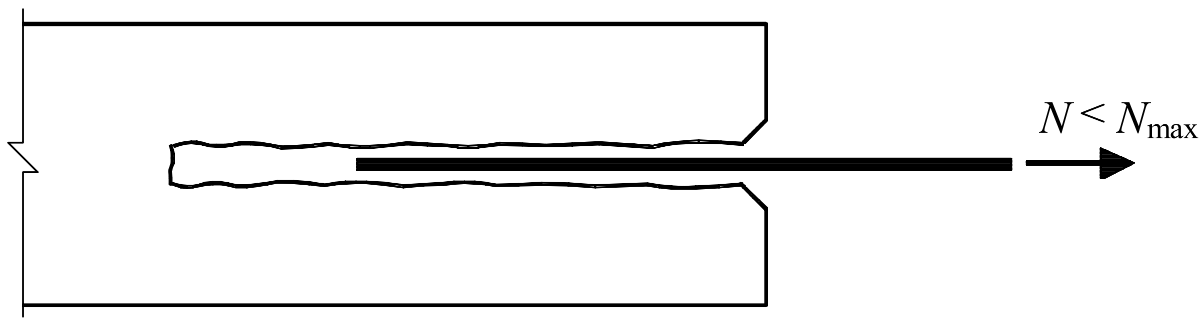
Splitting cracks



Anchorage failures

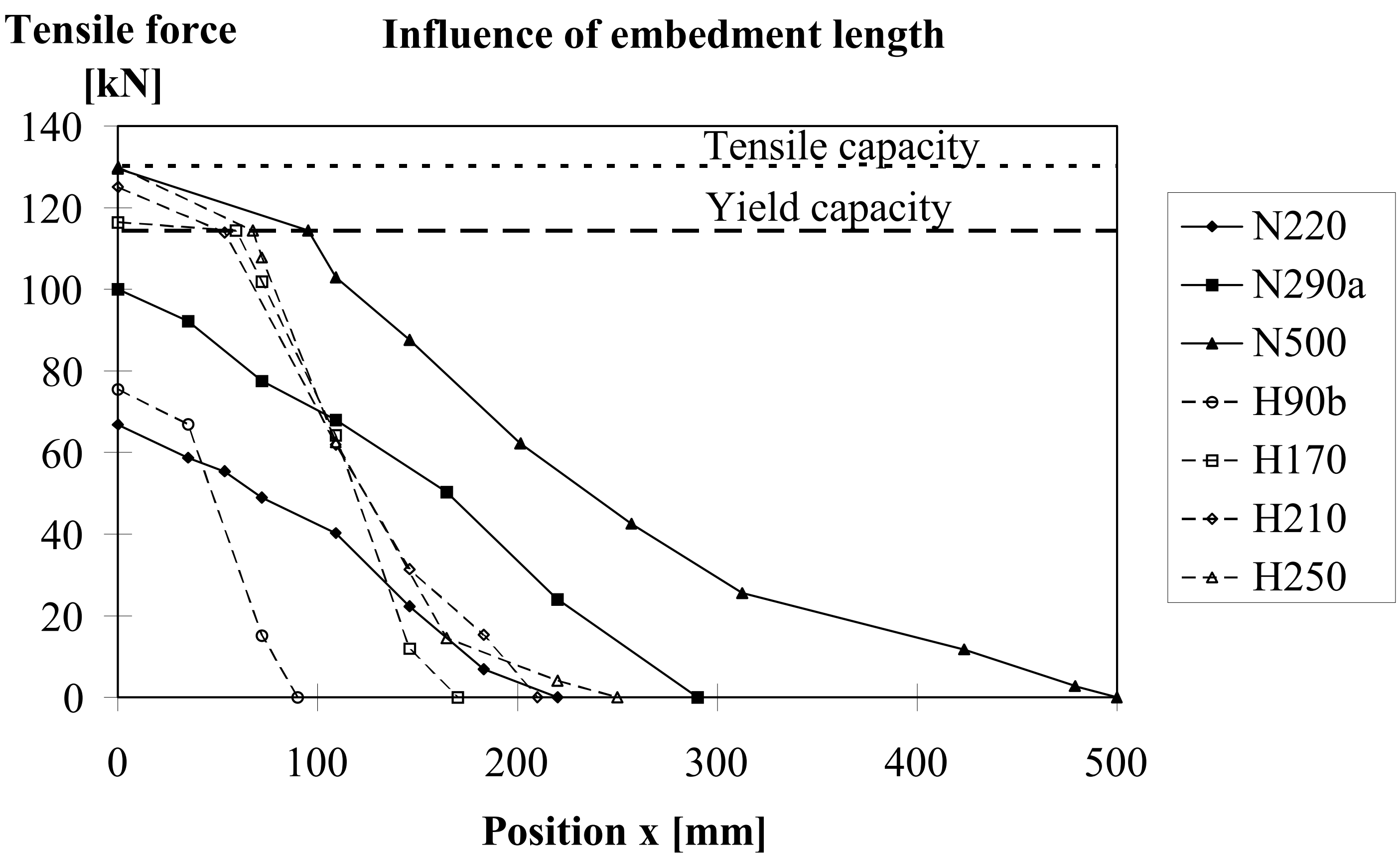


Splitting

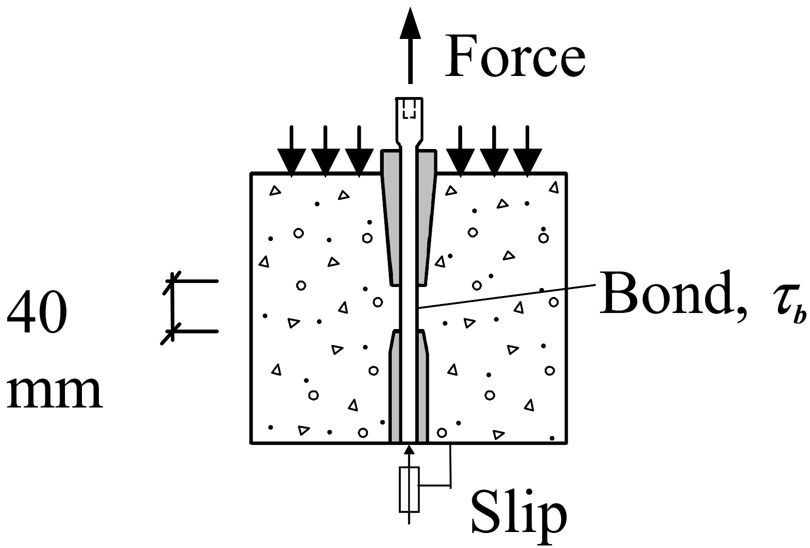


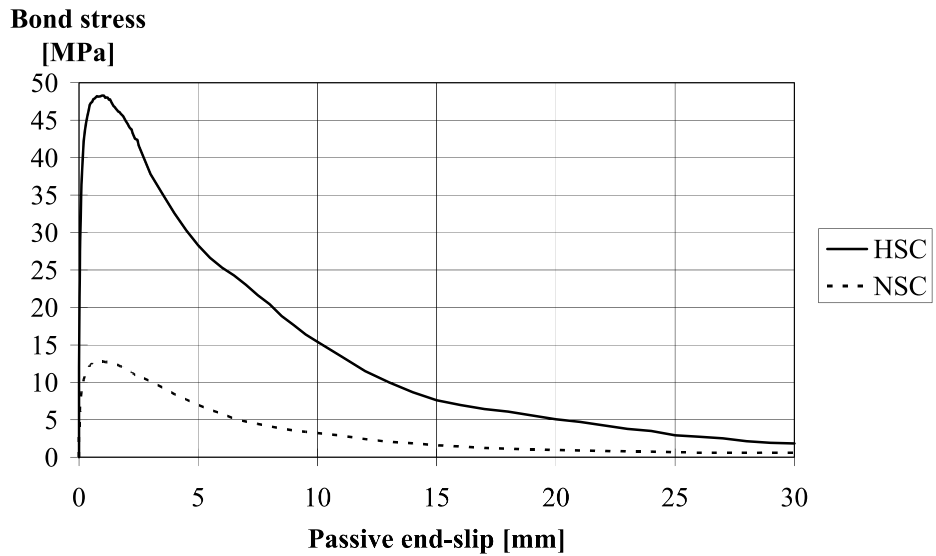
Pull-out

Tensile force development

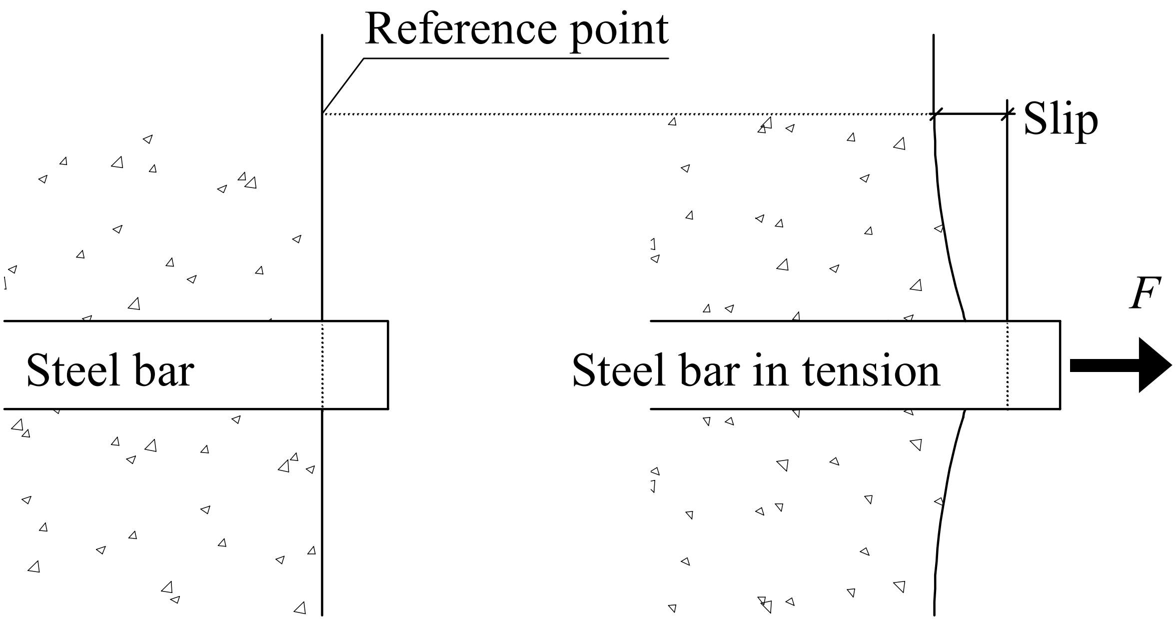


Bond stress - slip relation

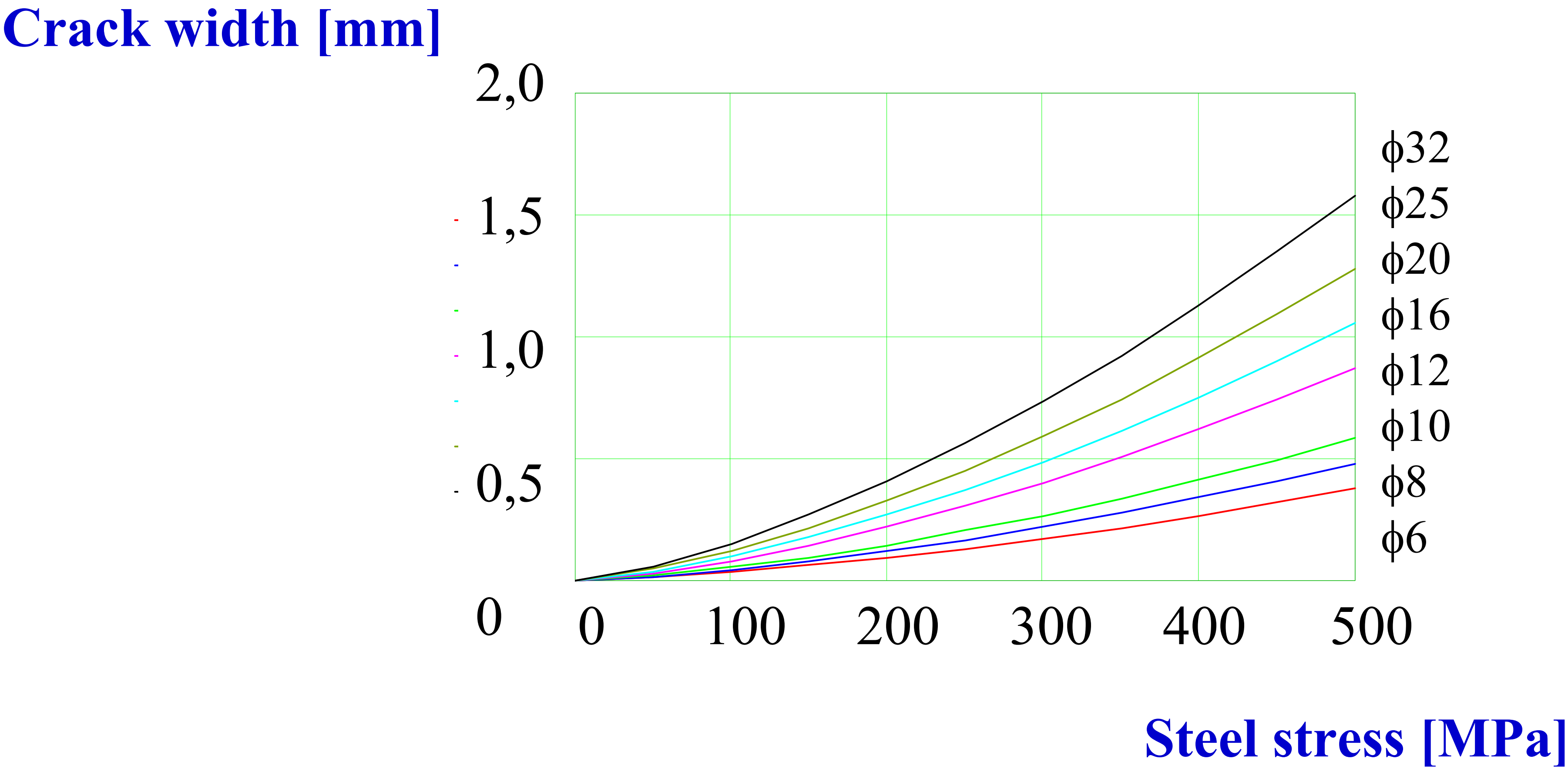




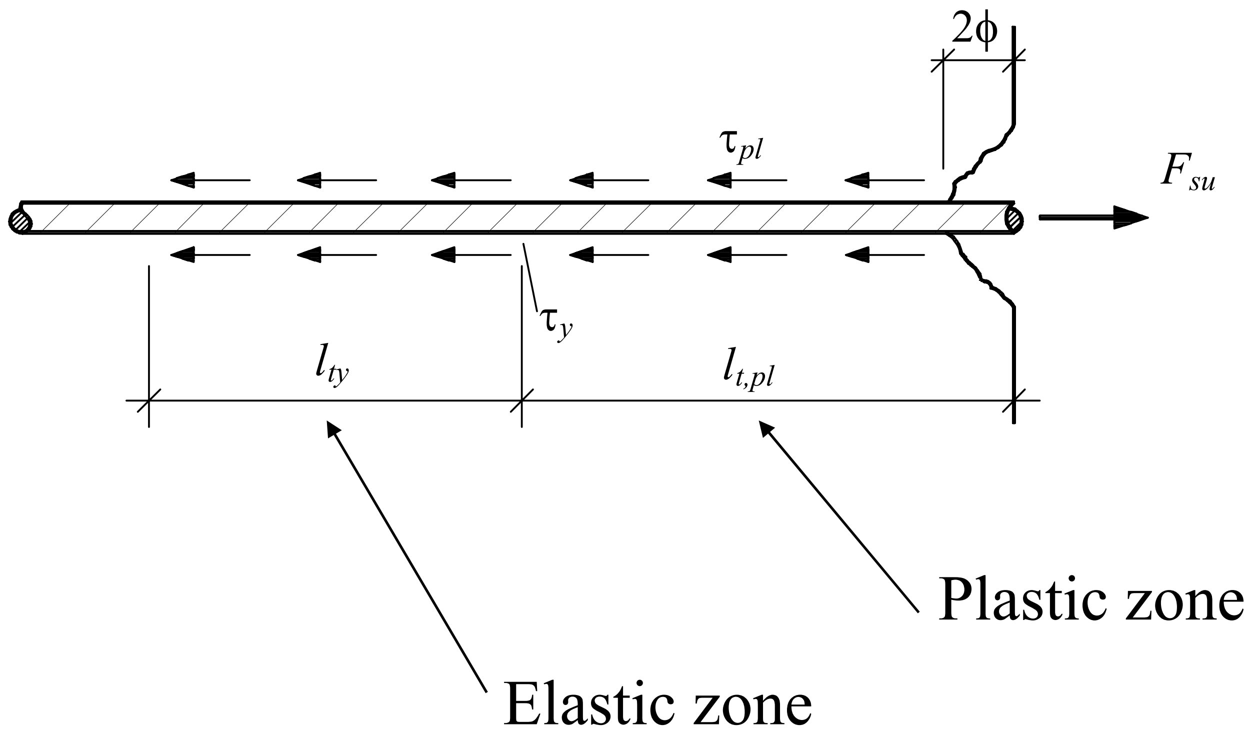
End slip



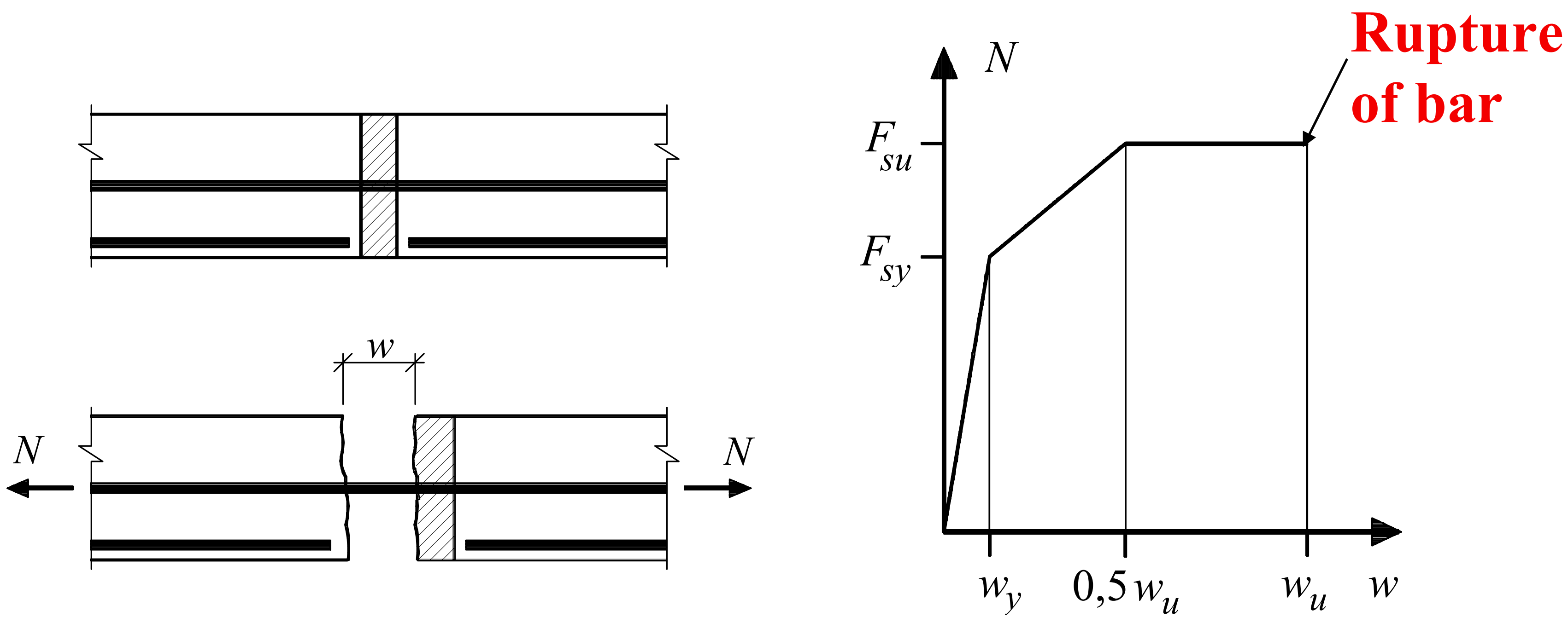
Elastic response



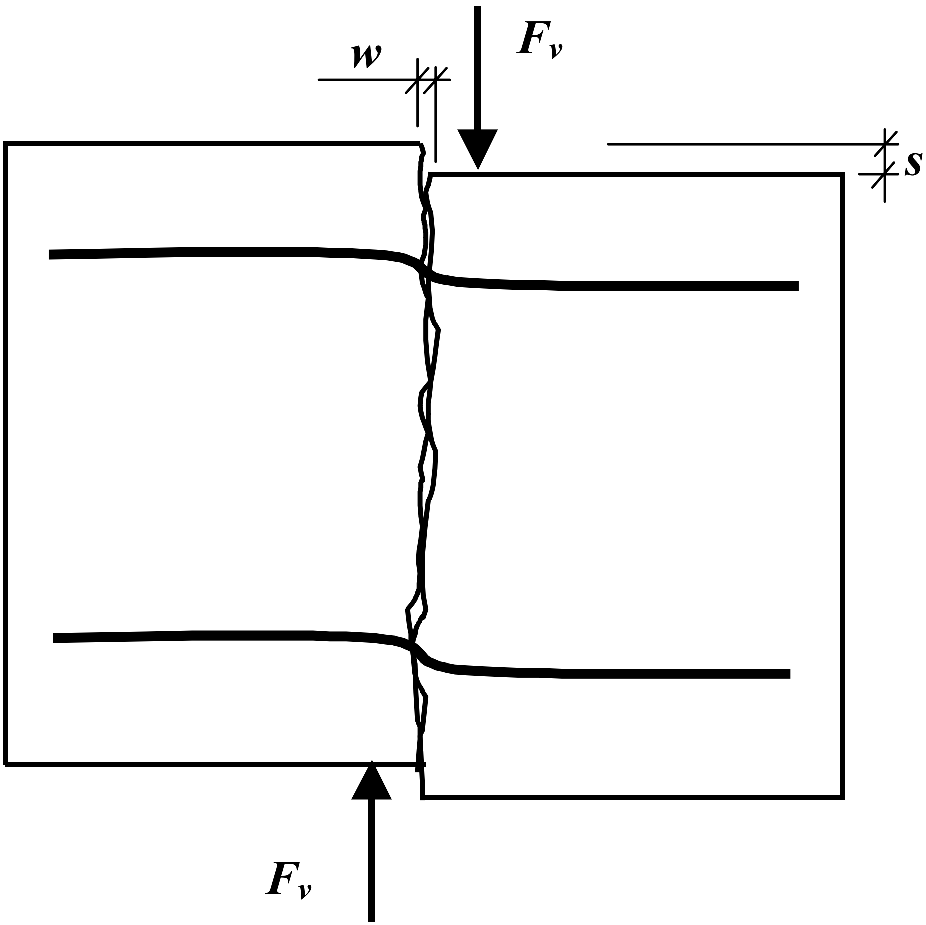
Yield penetration



Response of connections



This information was needed

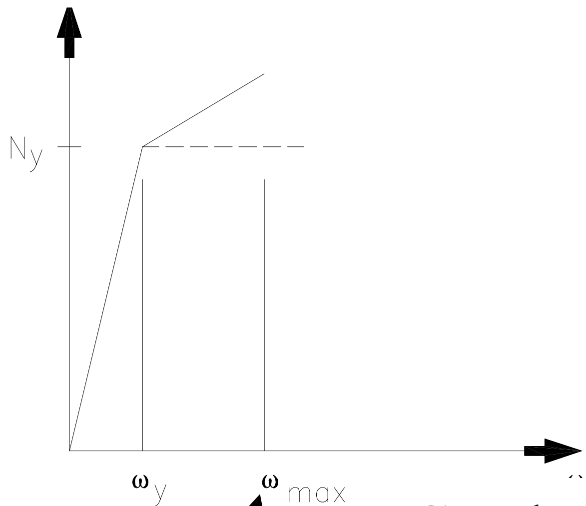


When will the transverse bars yield?

Depends on:
- joint roughness
- bond resistance of transverse bar

Maximum crack width vs. end slip response of transverse bar

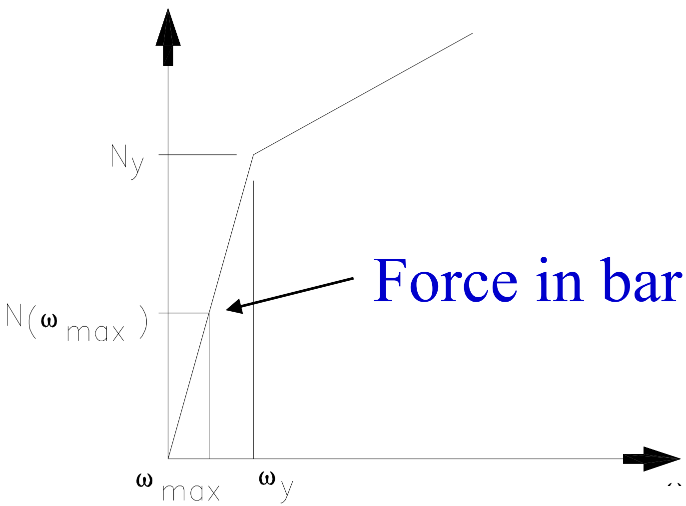
Force in bar



Crack width

Maximum crack width
Bar yields in shear friction

Force in bar

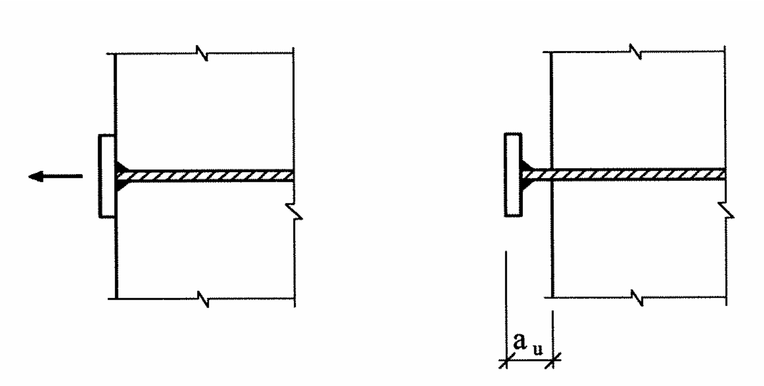


Force in bar

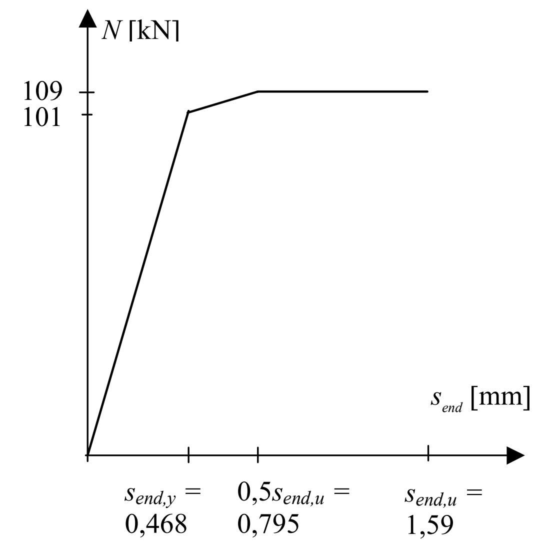
Crack width

Maximum crack width
Bar yields not in shear friction

Examples

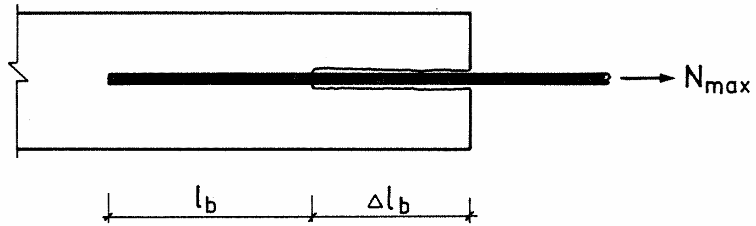


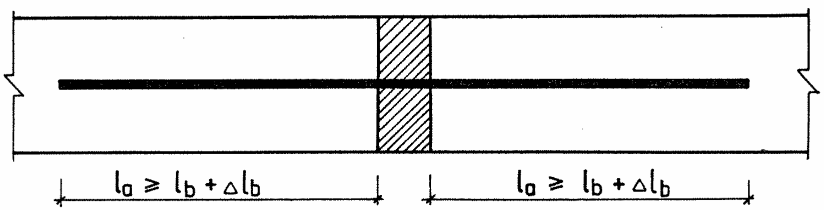
Prediction of end-slip response of anchor bar



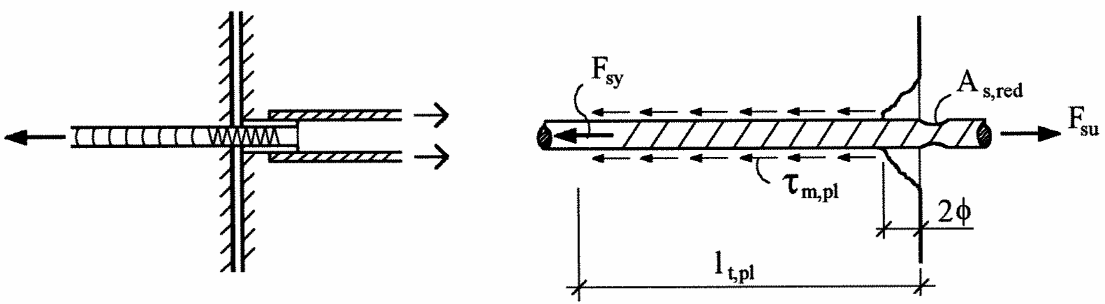
Examples

Design of anchorage allowing for full yield penetration

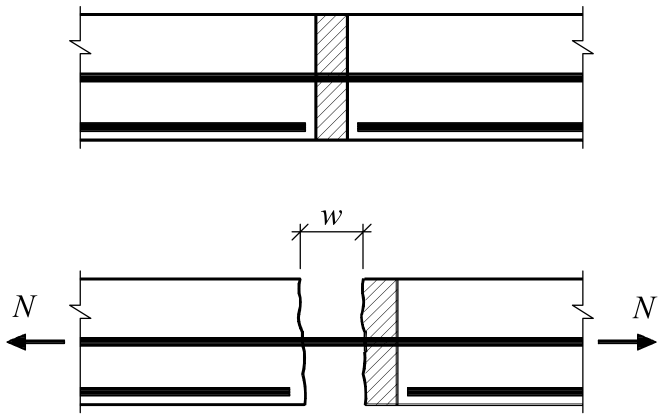




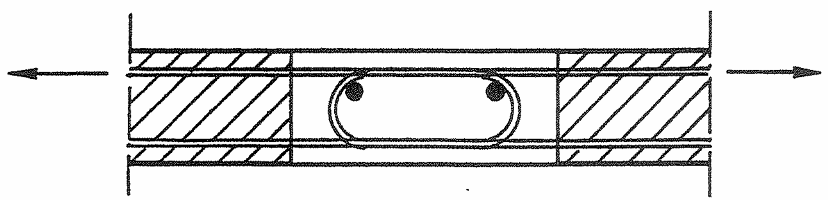
Effect of local weakening



Examples



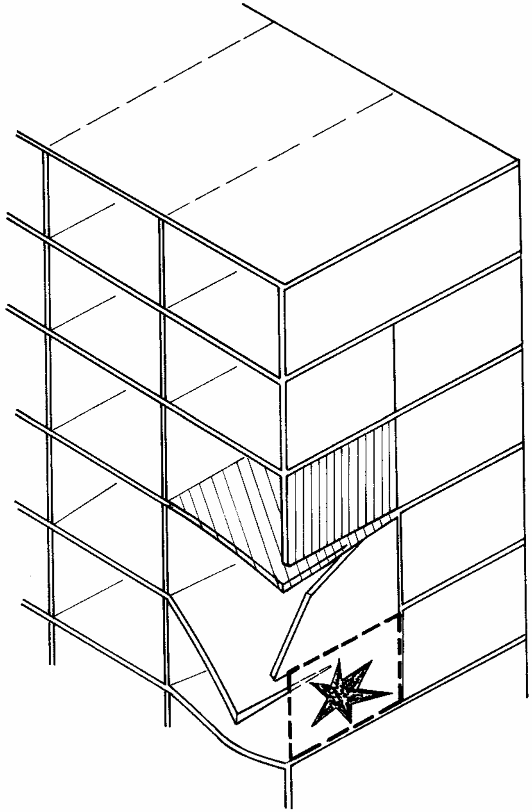
Estimation of tie bar stiffness



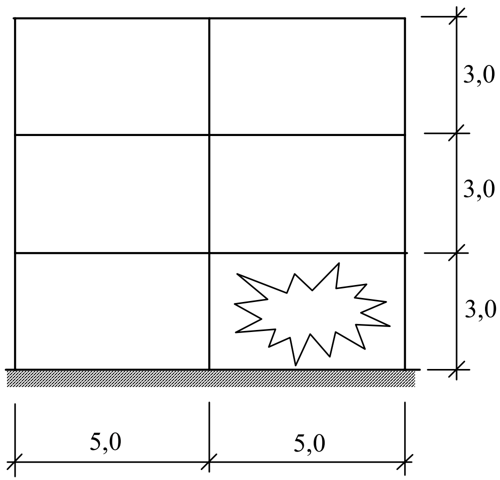
Design of loop connection

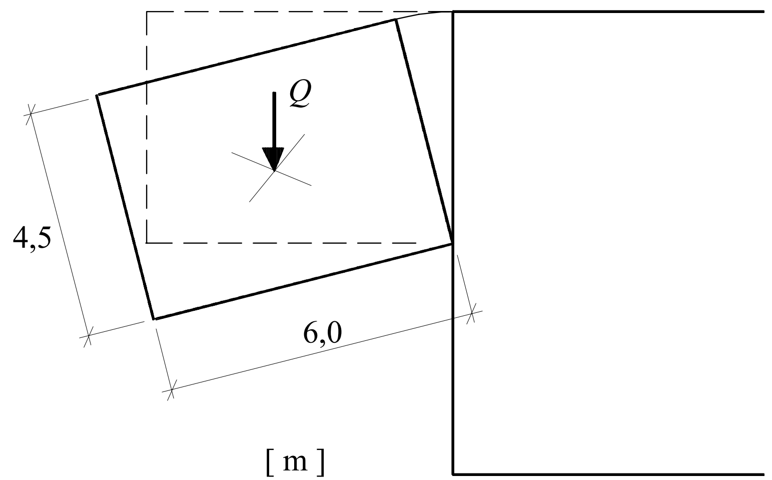
Prevention of progressive collapse

- Withstand accidental loading
- Reducing the risk of accidental loading
- Increase redundancy and prevent propagation of initial damage

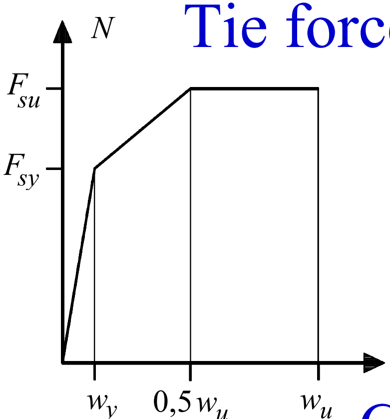


Analysis of collapse mechanisms

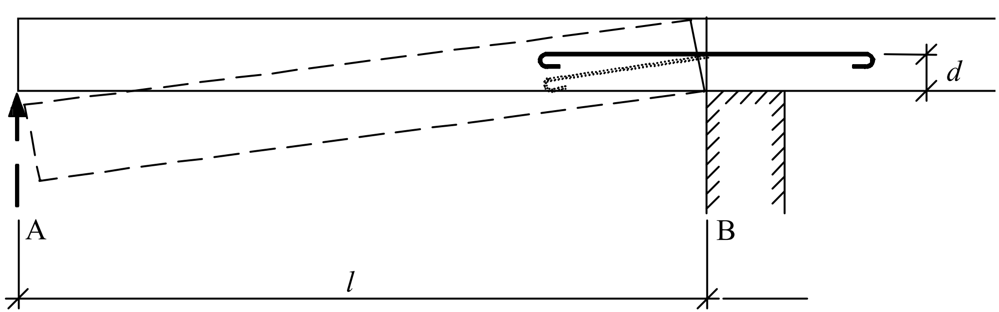




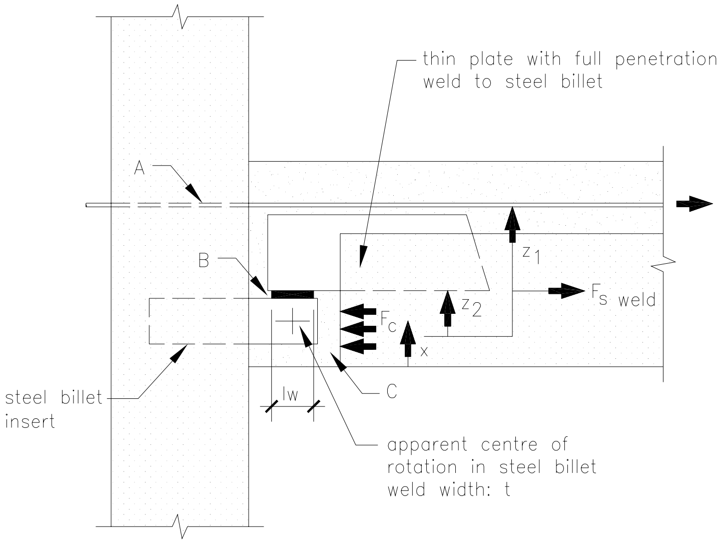
Tie force

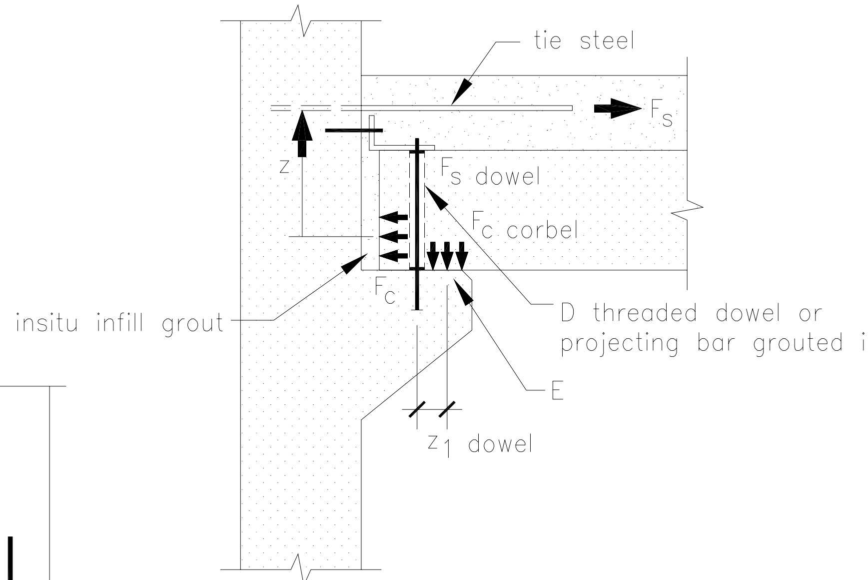


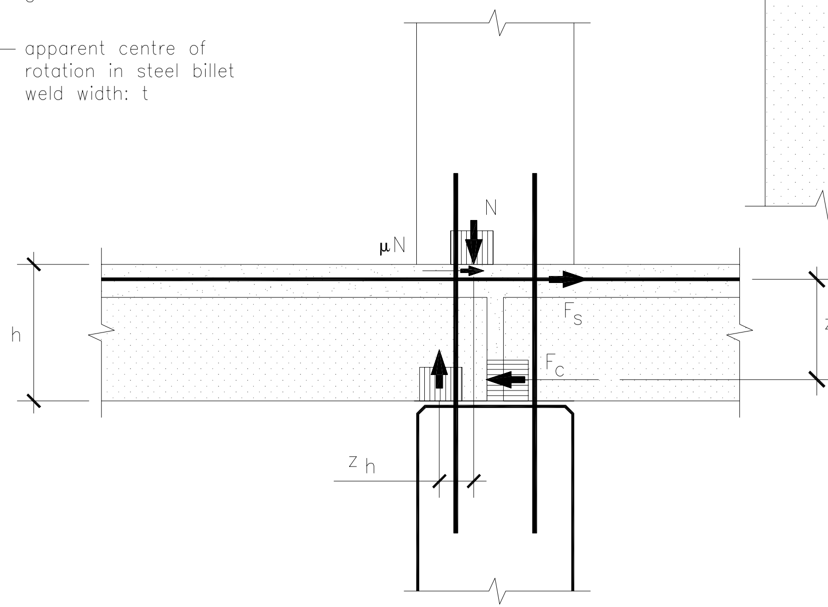
Crack width



Transfer of bending moment

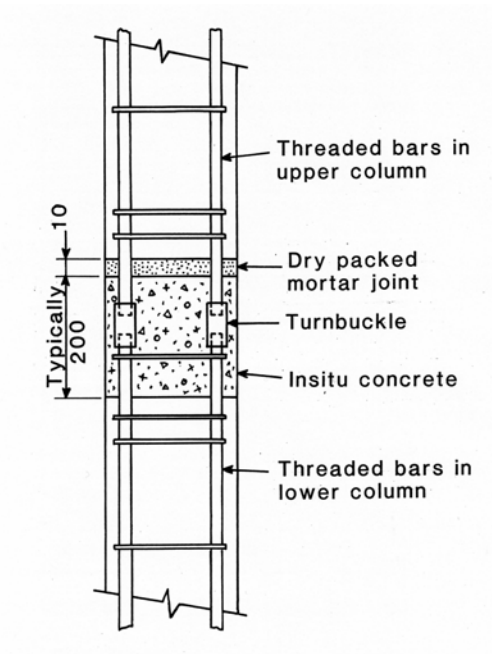




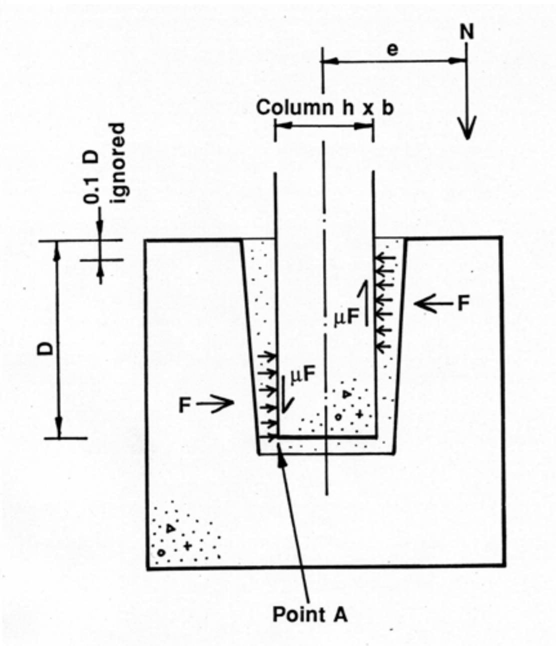


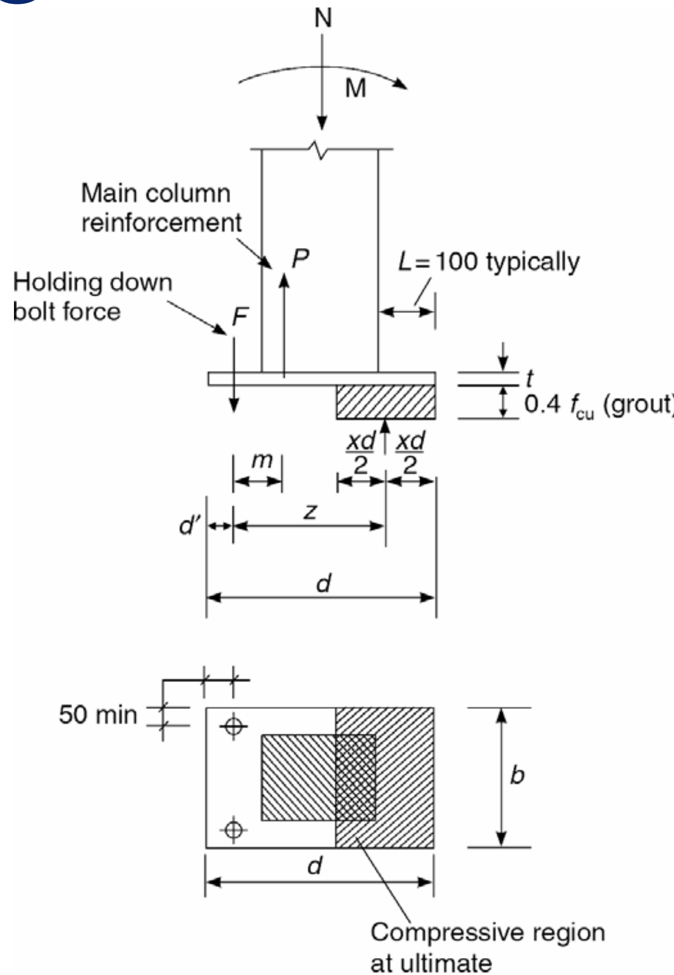
Beam column connections

Transfer of bending moment



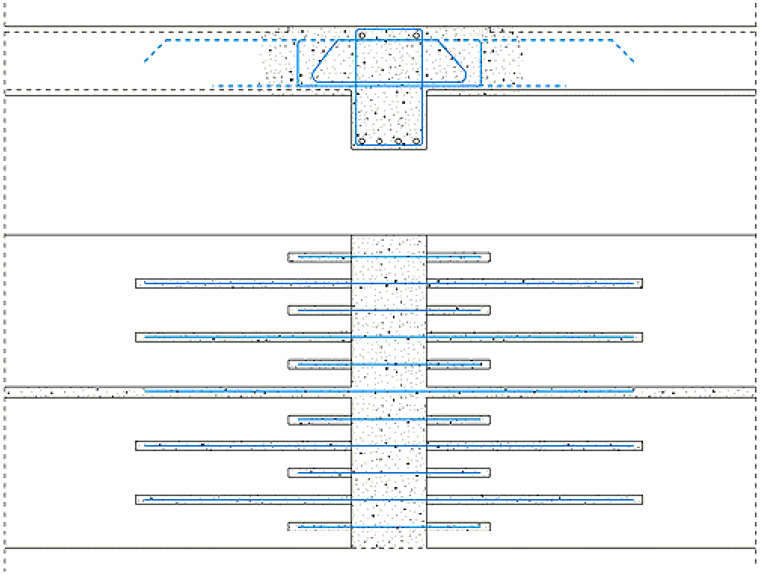
Column splice connection





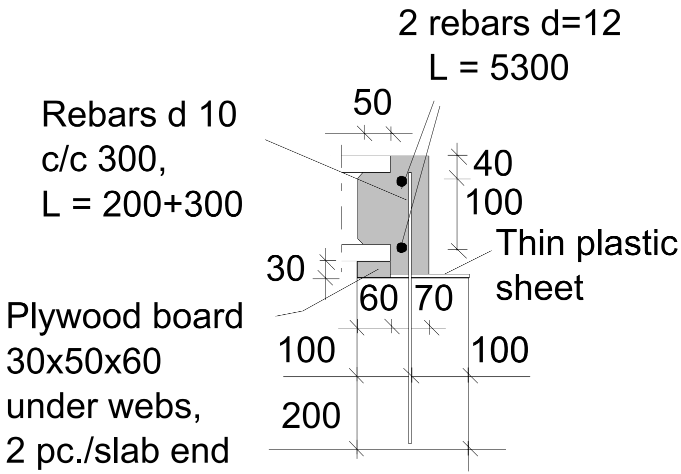
Column base connections

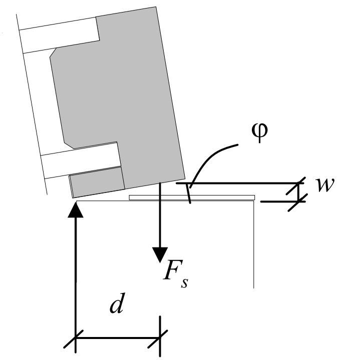
Transfer of bending moment



Floor connections:
no restraint, unintended restraint, full restraint, partial continuity in the service state

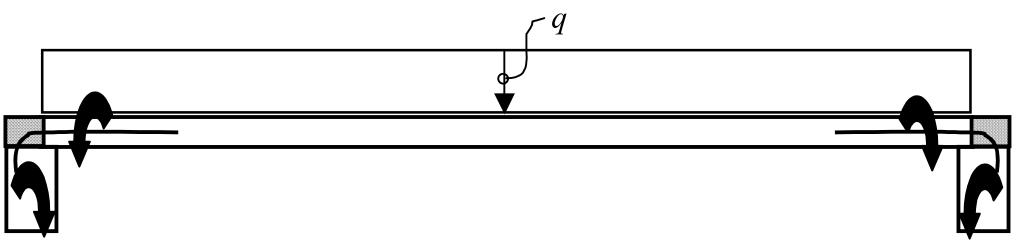
Example

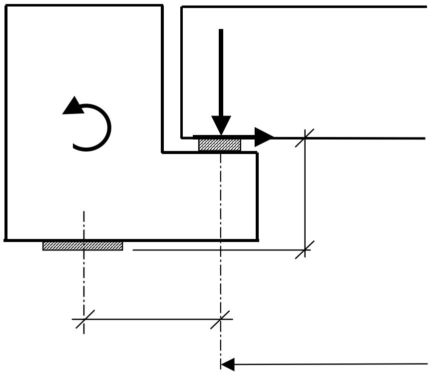




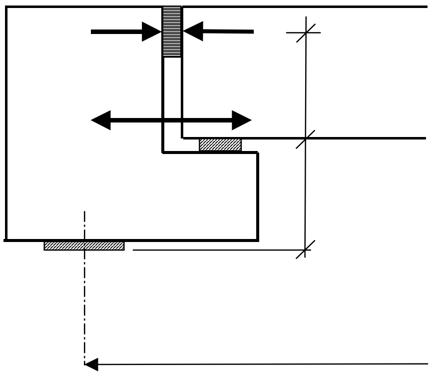
Moment – rotation response of connection at end support

Transfer of torsional moment

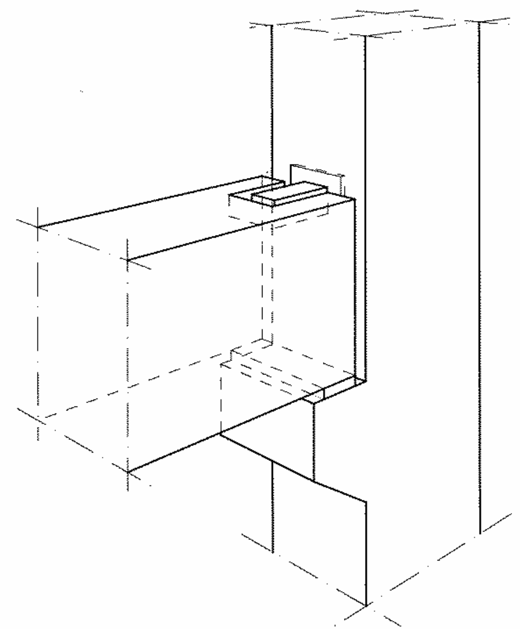




Simply supported



Firmly connected



Torsional restraint at beam support

fib Bulletin on Structural Connections

- Encourage good practice in design of structural connections
- Design philosophy
- Connections ⇔ Structural system
- Understanding of basic force transfer mechanisms