Critical issues in design of connections

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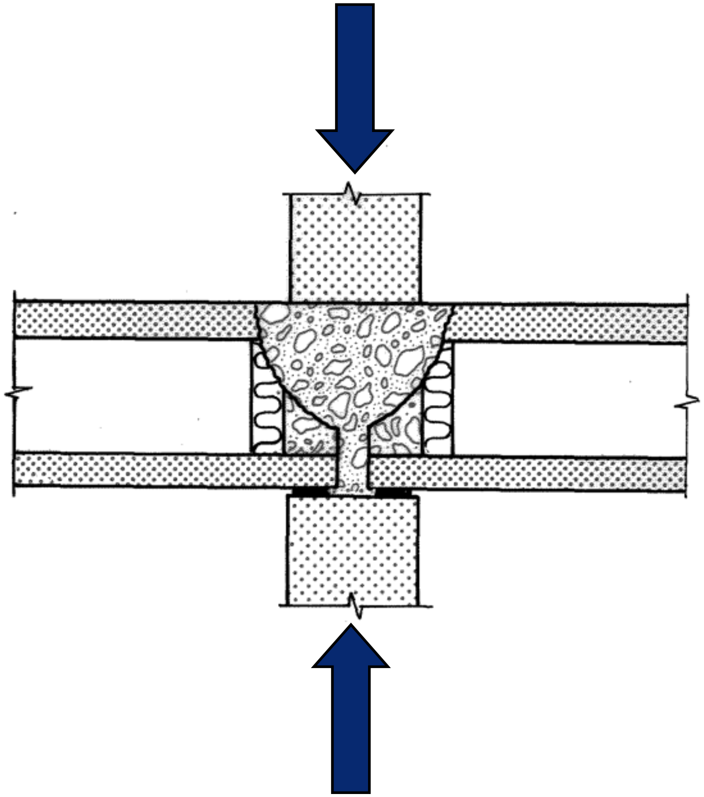
fib – Guide to good practice Precast hollow core floors

- Connections at supports
  - Support
  - Restraint at supports
  - Longitudinal tie bars
  - Tie arrangements at supports – tie beams
  - Strengthening of hollow core units near supports
  - Cantilevering floors
- Connections at longitudinal joints
  - Longitudinal intermediate joints
  - Connections at side joints
  - Grouting of longitudinal joints

Simplified design procedure

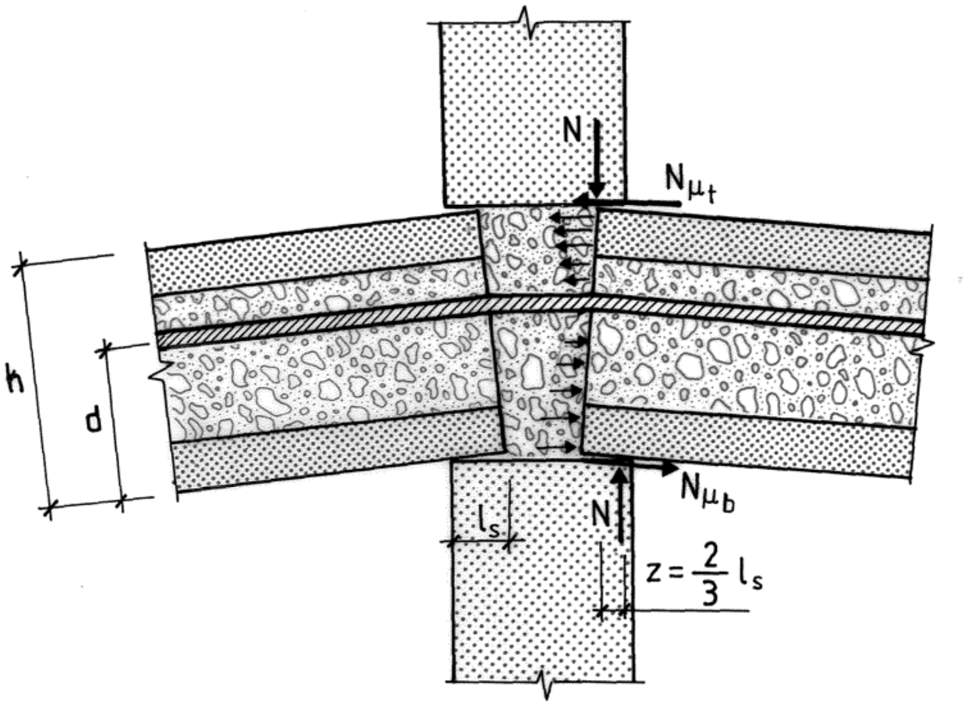
- Capacity of single elements
- Design for one sectional force at the time – no interaction
- Complex interaction between various phenomena
- Interaction between elements within the floor and within connections

Wall/HC floor connection



- The wall load will probably also go through the HC unit and its core filling also in case of soft bearings
- Part of the wall load will spread transversally into the HC unit (compatibility) – splitting effects
- Combined effect of wall load and restraint moment
- Important to avoid cracks in unfavourable locations

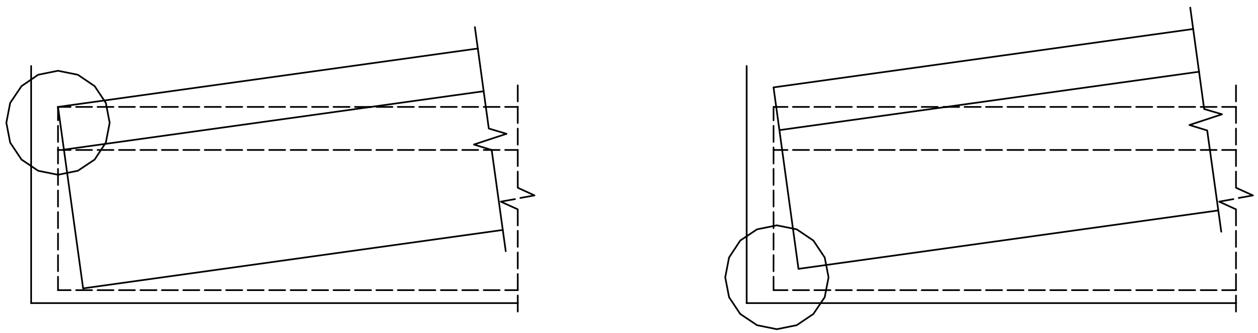
Unintended restraint – HC-floor



- Clamping
- Friction
- Bond to joint (before cracking of joint face)
- Tie bar (after cracking of joint face)

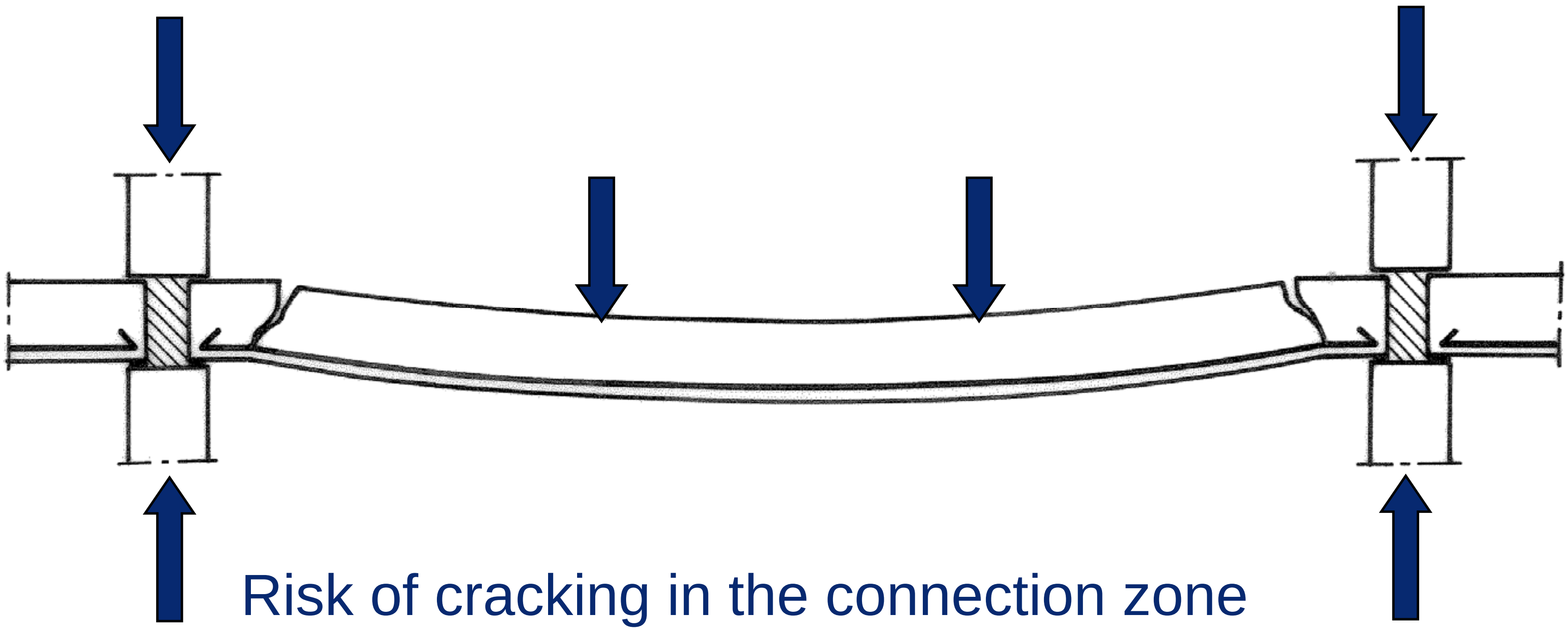
Bond strength ≈ tensile strength

Need for movements?



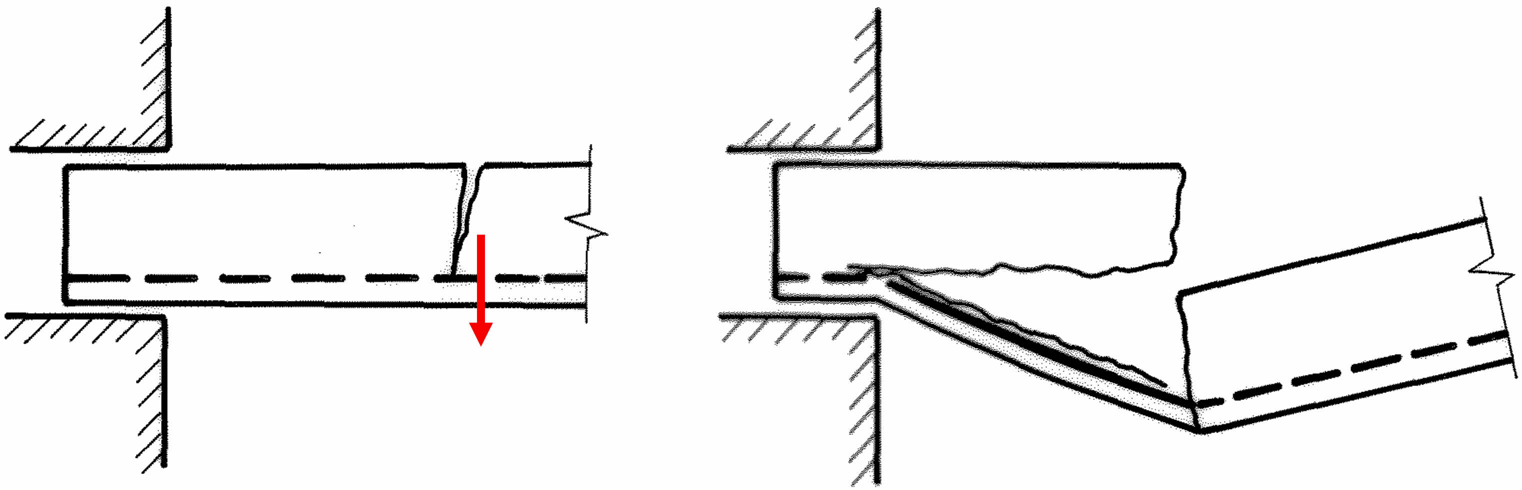
Shortening
Positive rotation
Negative rotation

Negative moment - cracking



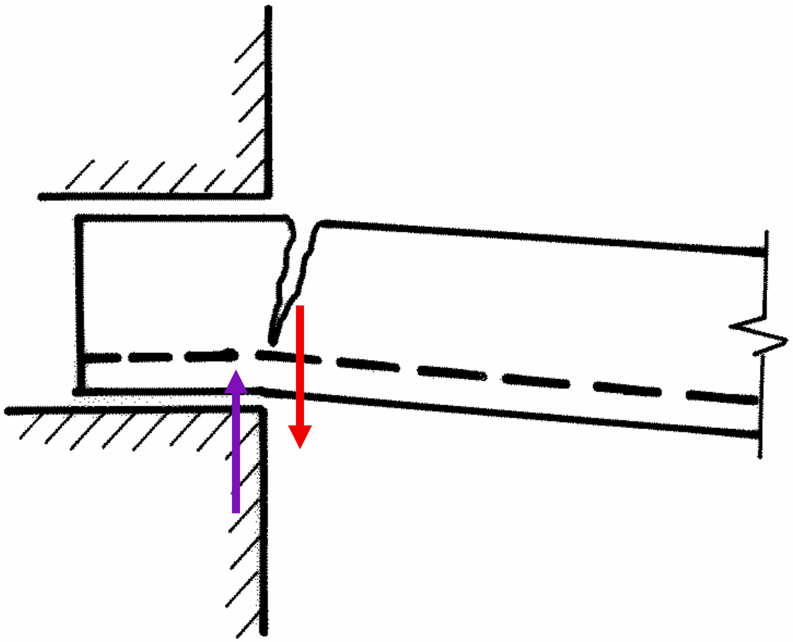
Risk of cracking in the connection zone also due to transfer of compression.
Interaction compression – flexural restraint
Restraint cracks may appear early

Unfavourable crack position



Low shear capacity
No support for dowel action

Preferred crack location



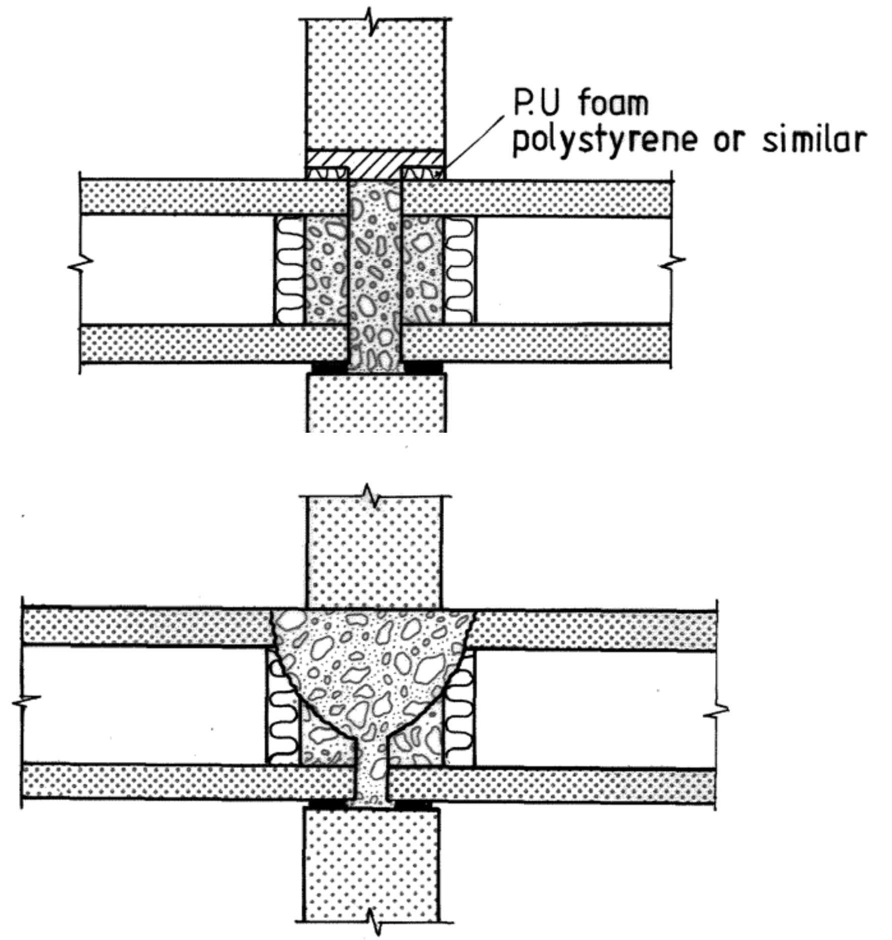
Support for dowel action in both directions

Reduced shear capacity of cracked section

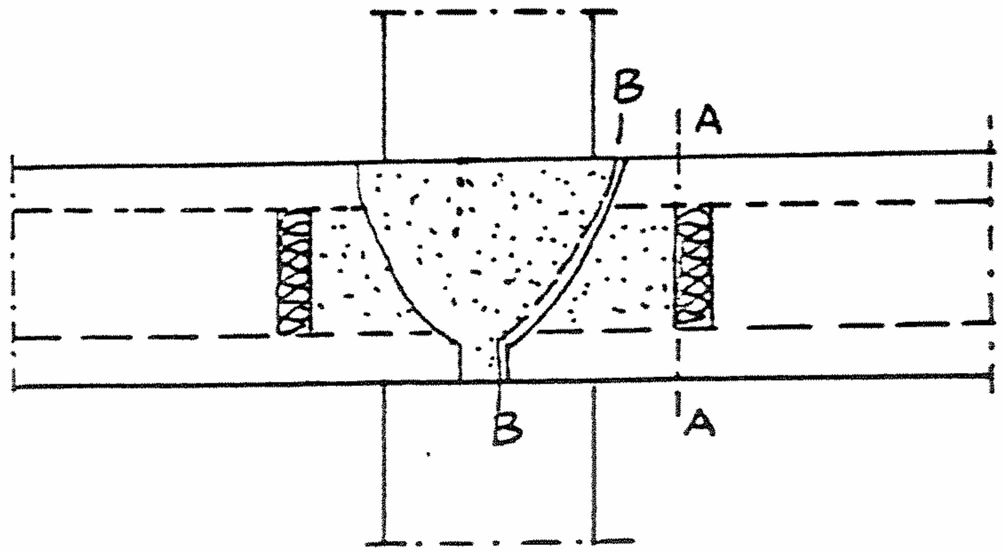
Prevent/reduce restraint moment

FIP Recommendations 1988:

- avoid crack inducements in critical zone, core filling
- vertical load distribution between floor elements
- limit the restraint, see Figs.
- when needed strengthen the floor by tie bars
- proper anchorage of tie bars

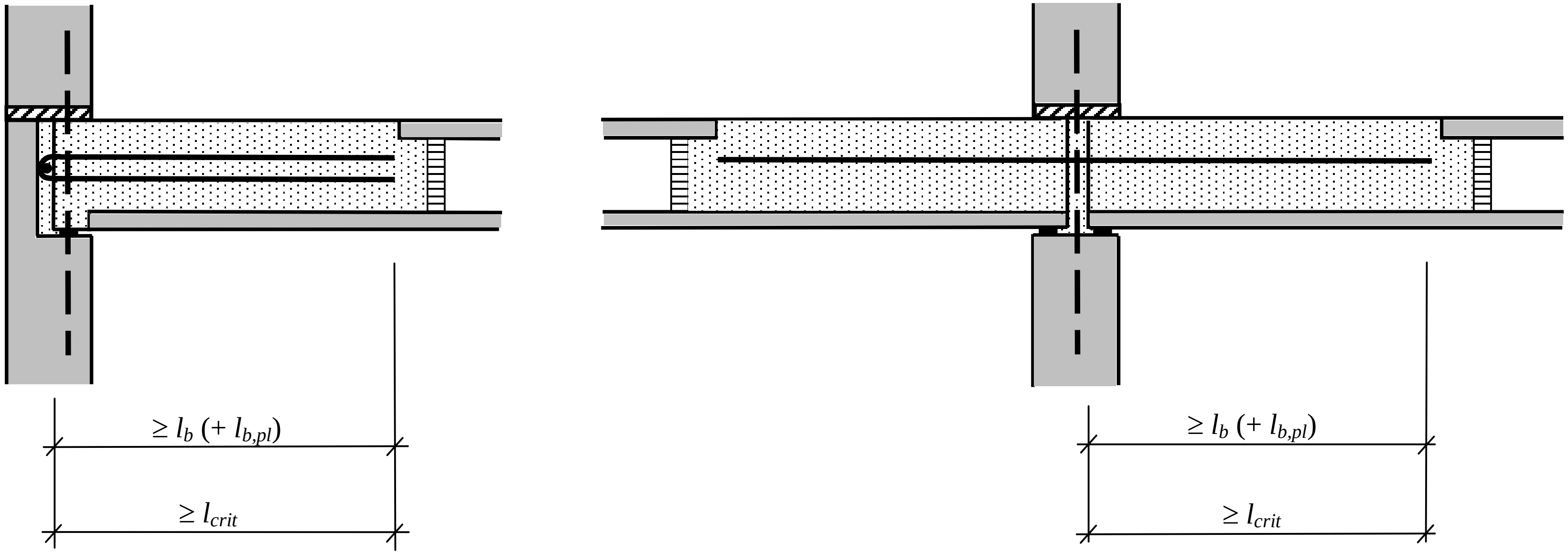


Idea of notched ends



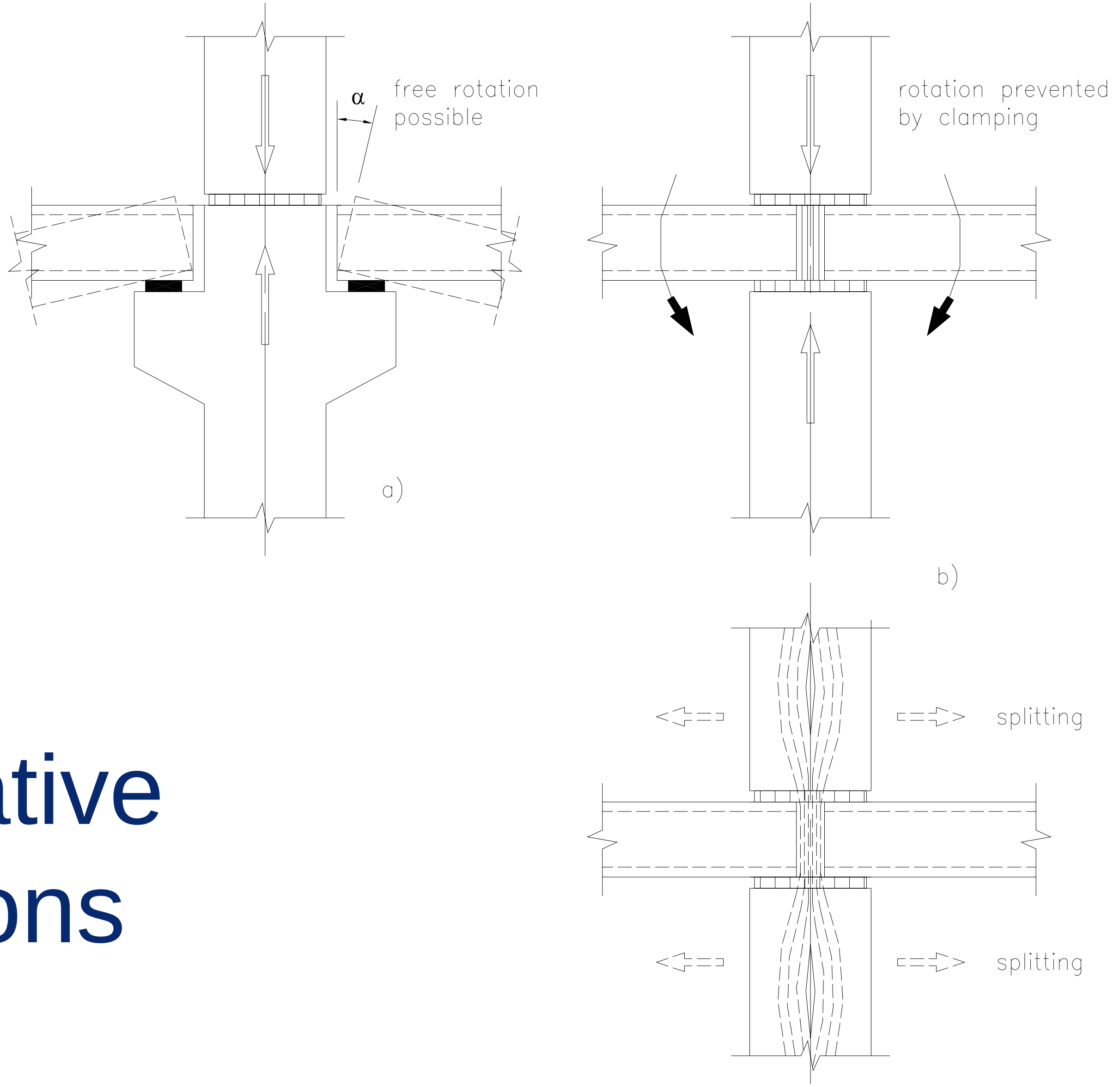
Weak section - avoid cracks in unfavourable positions
In practice the crack will not be that perfect
Crack propagates inside the support, which is good

Strengthening of HC-floor

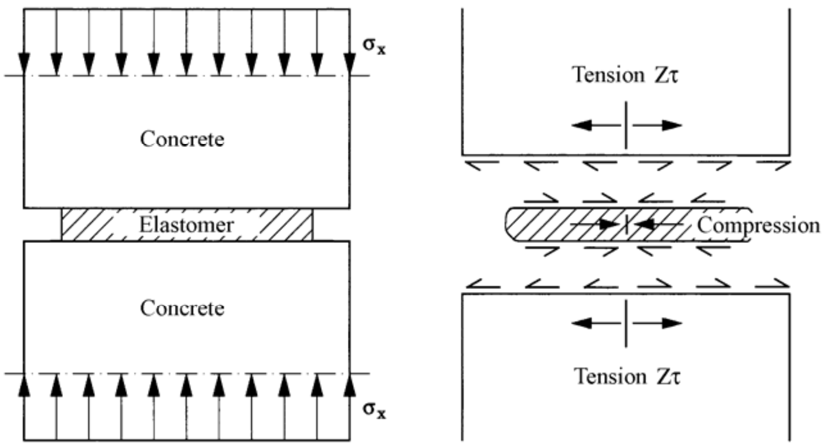


Tie bars in cores or grouted joints,
full anchorage in critical zone
Limit the tie force, keep any cracks together

Alternative solutions

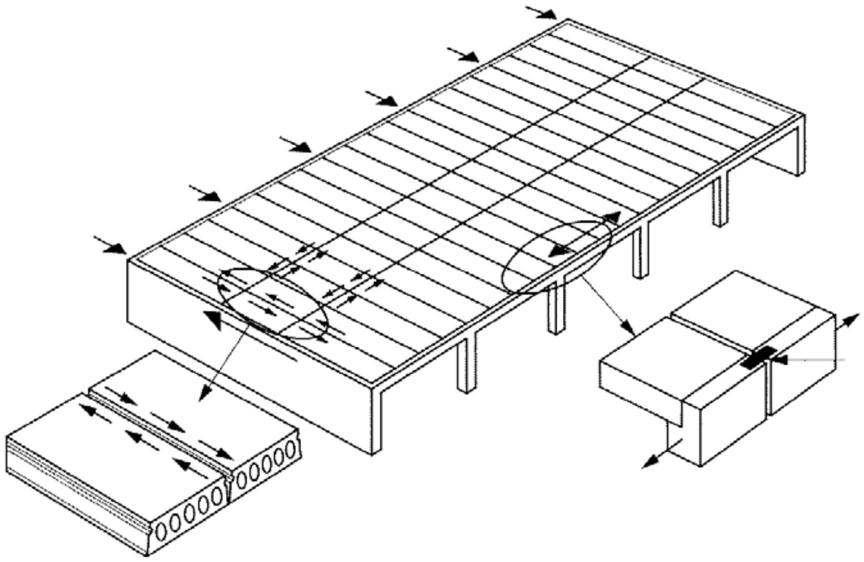


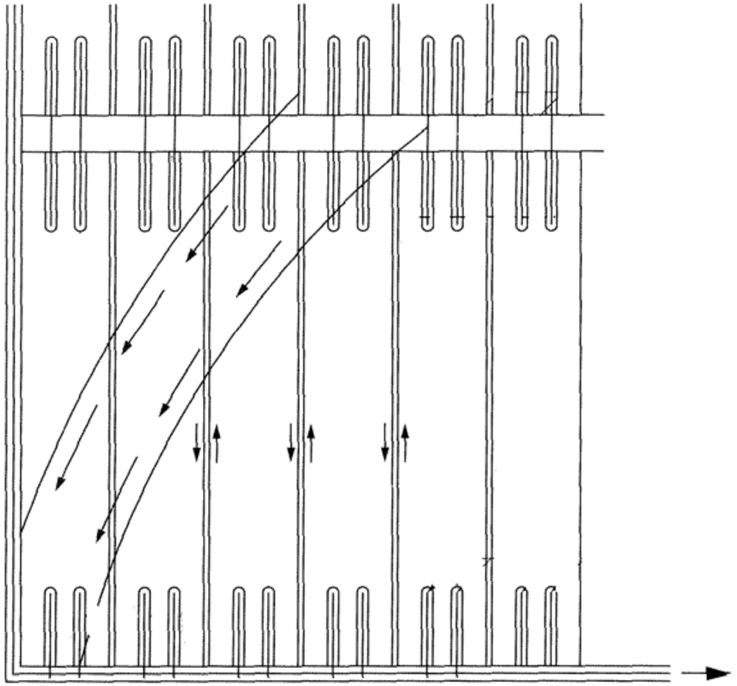
Neoprene bearing



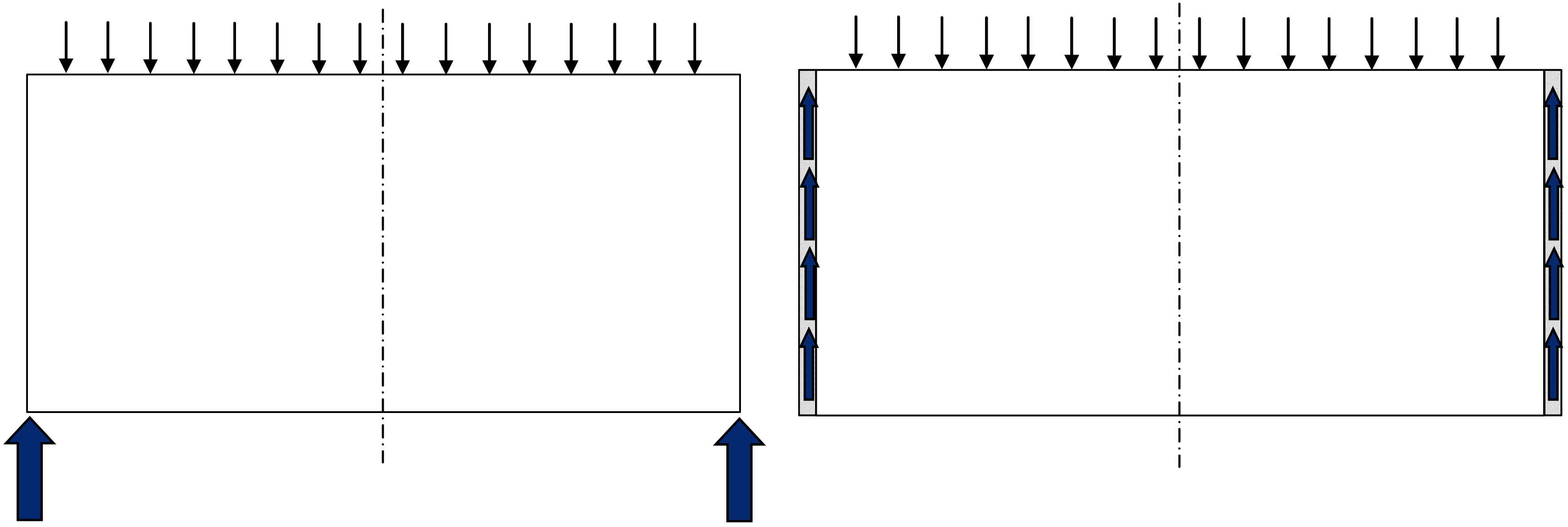
- Transverse tension – provokes cracks along strands and anchorage failure
- The tie beam along the element end and concrete fill in the cores are important to prevent those cracks

Diaphragm action of HC floor



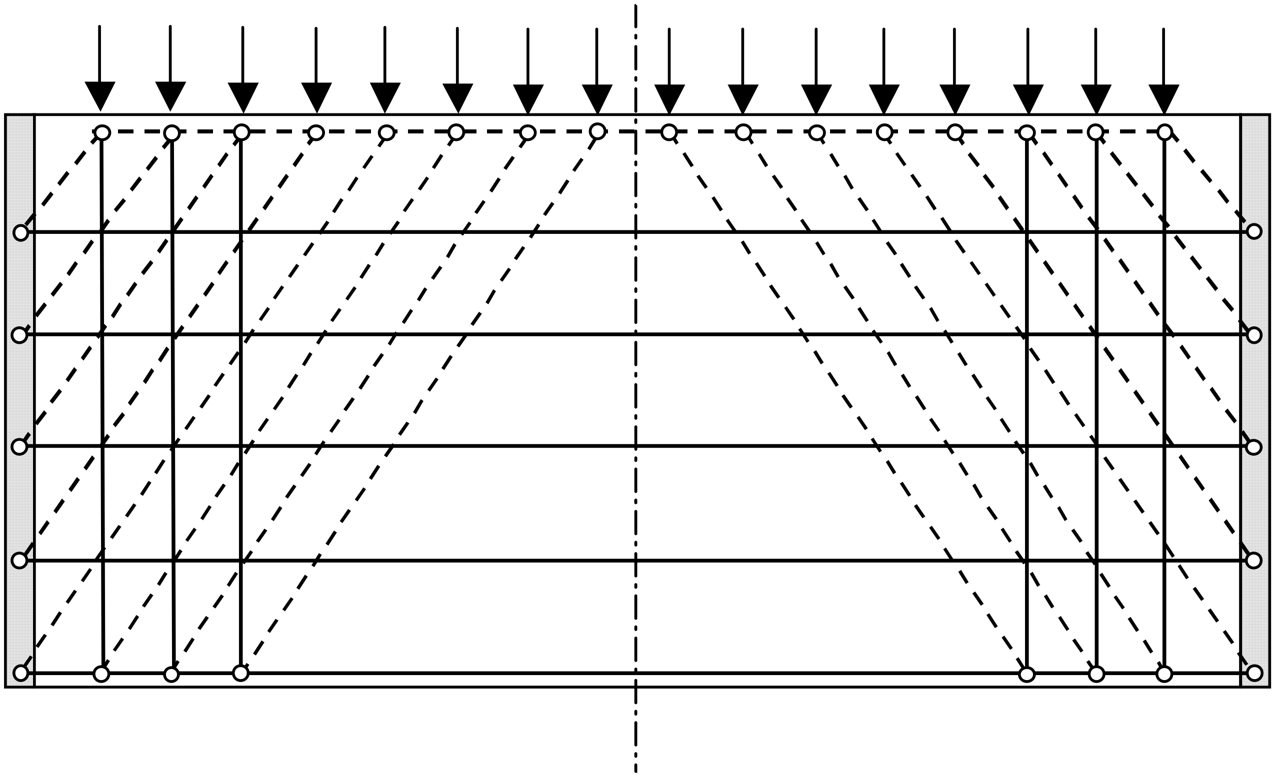


Different support conditions

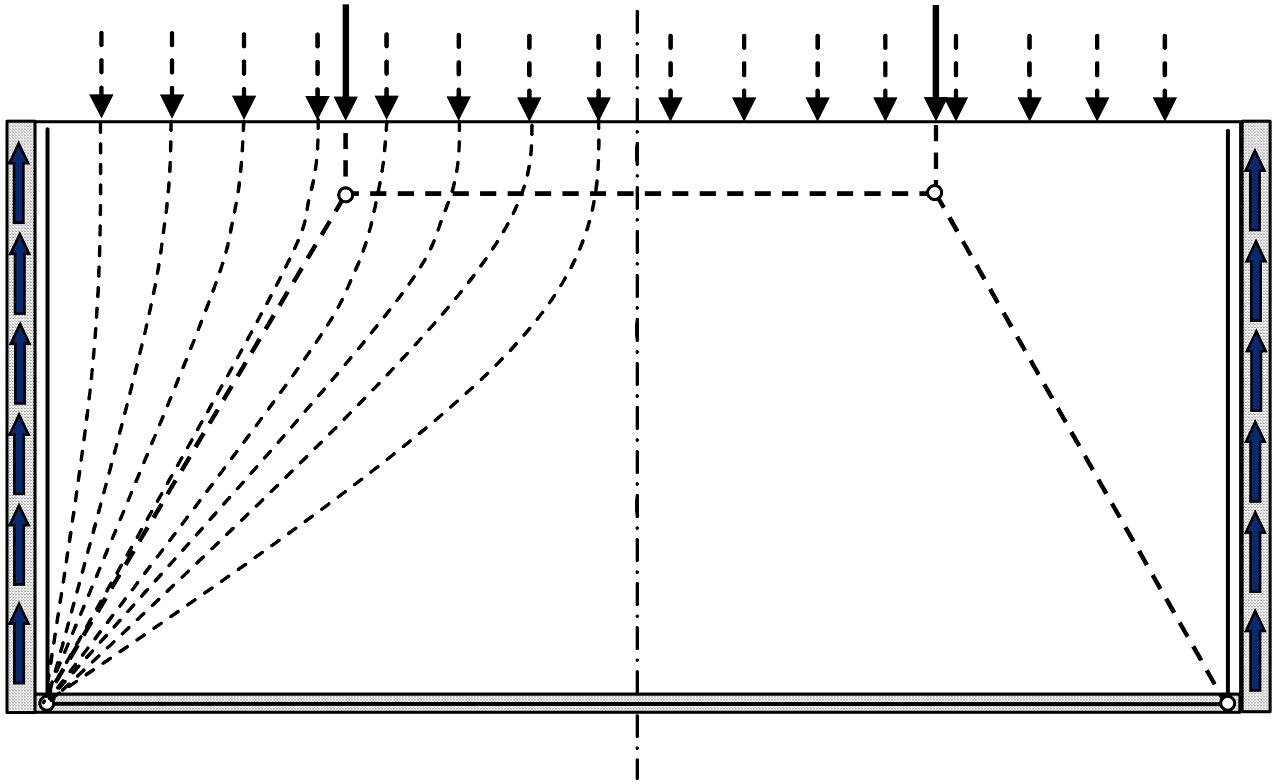


The beam analogy is not fully applicable

Load transferred the shortest way

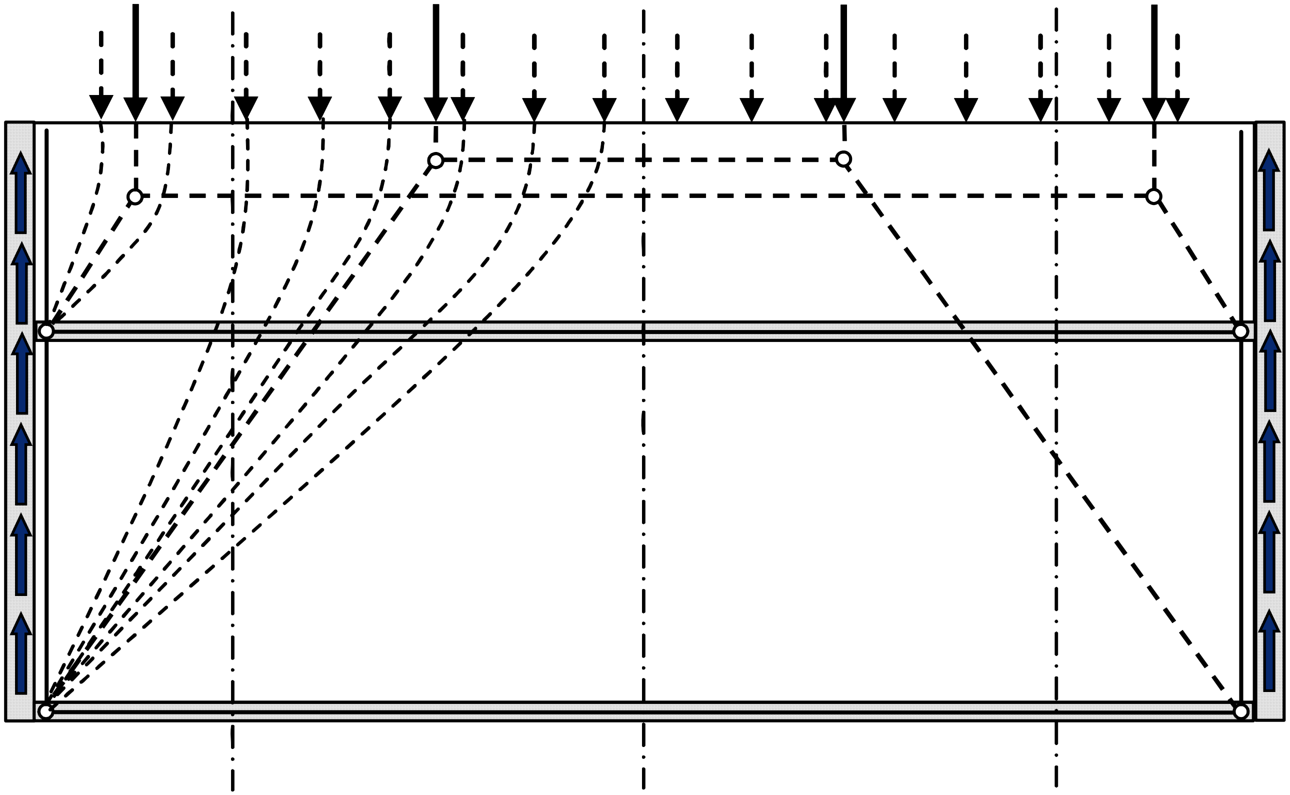


In HC floors transverse steel is placed in transverse joint only



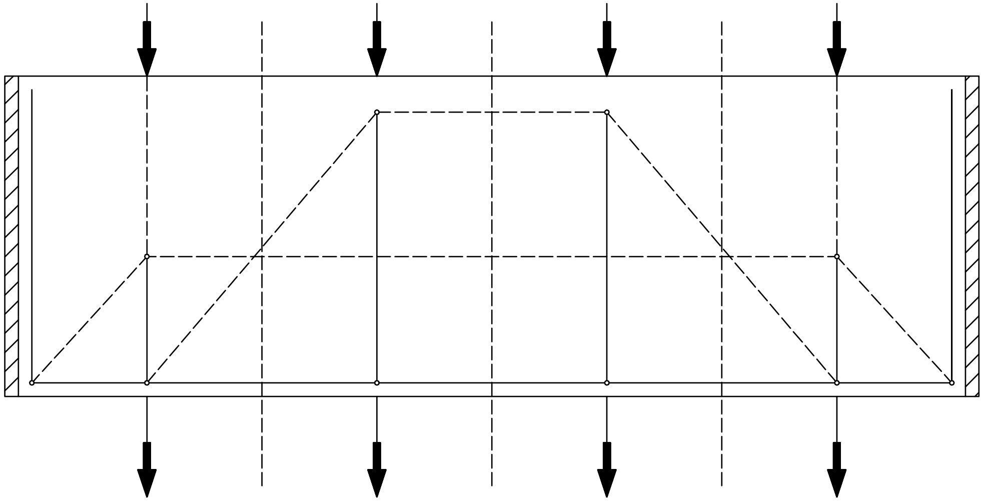
Suspension is needed along the edges

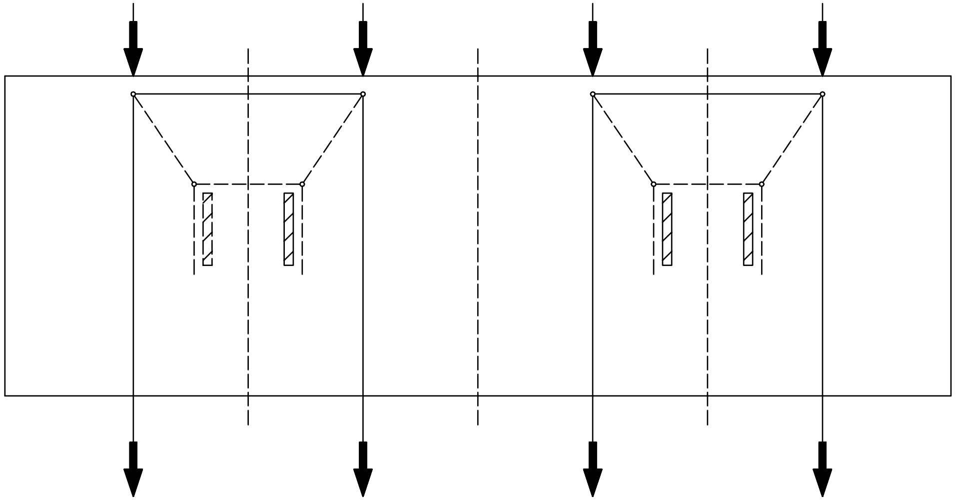
Model with intermediate joint



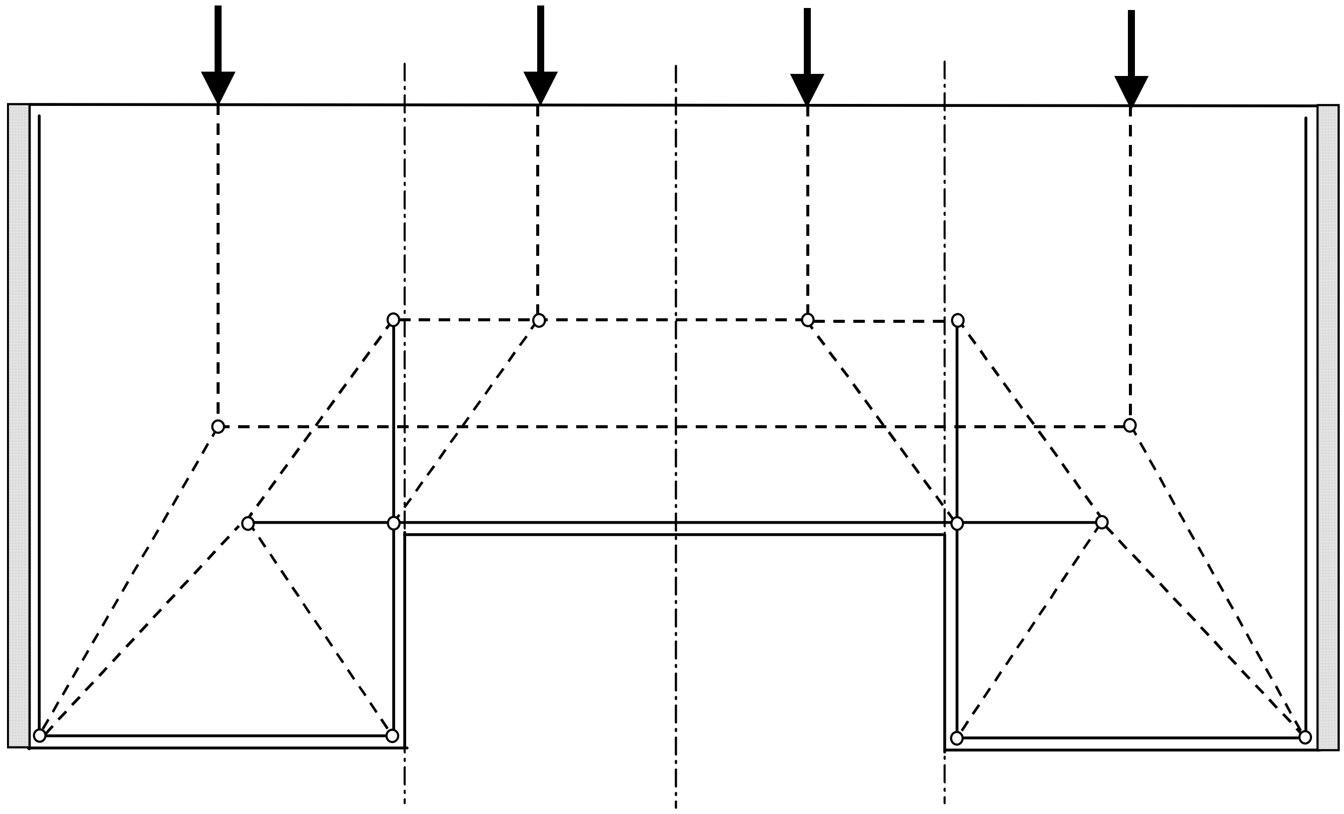
Suspension is needed along the edges

Strut and tie models

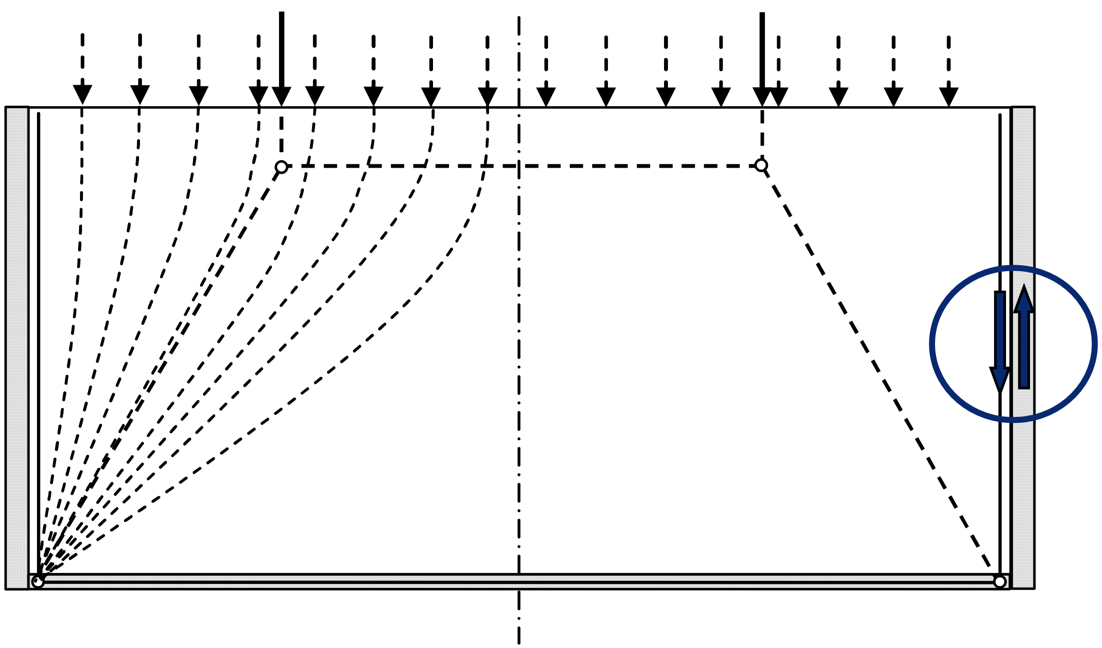

a)

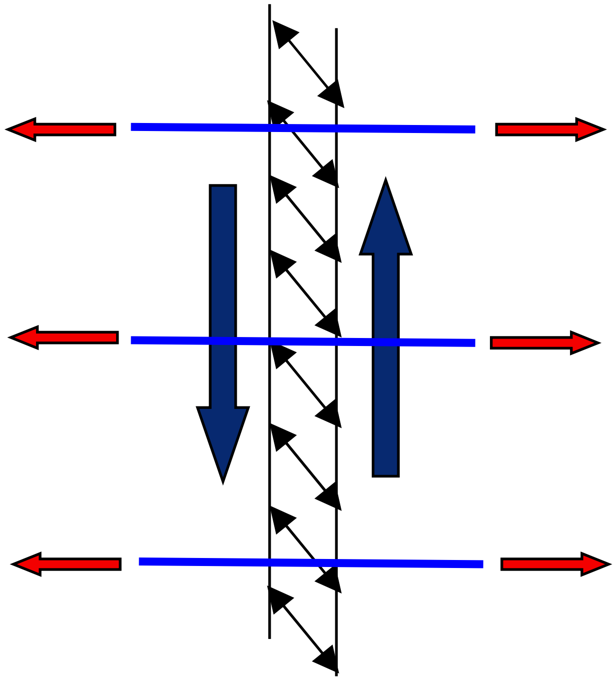

b)

Strut and tie models



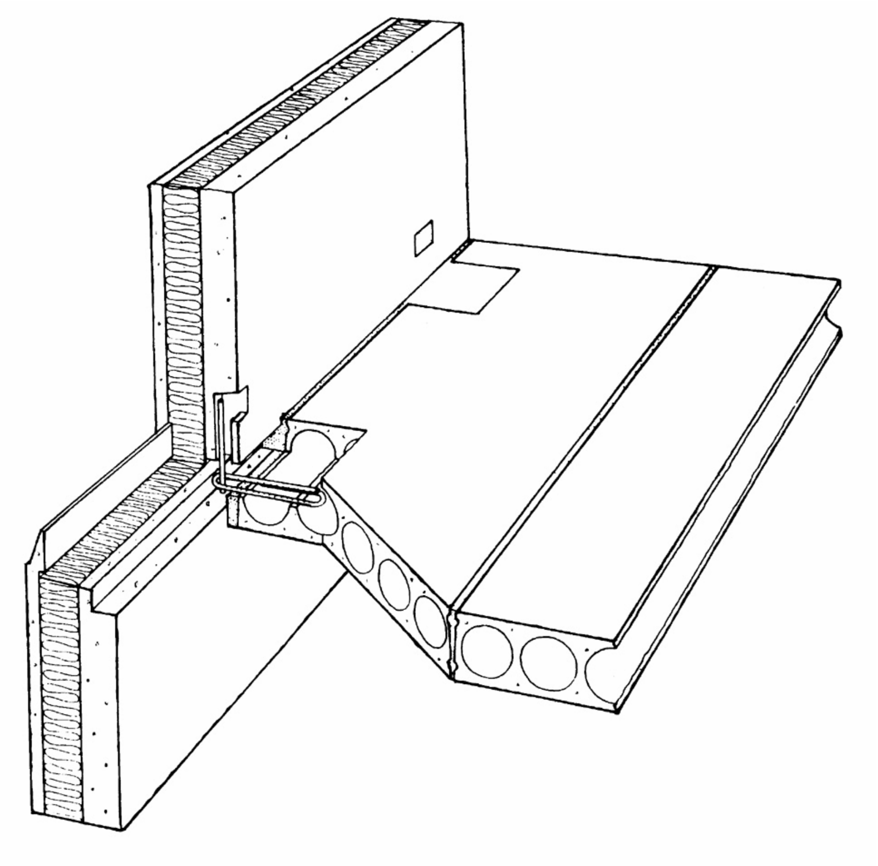
Distributed shear transfer by friction





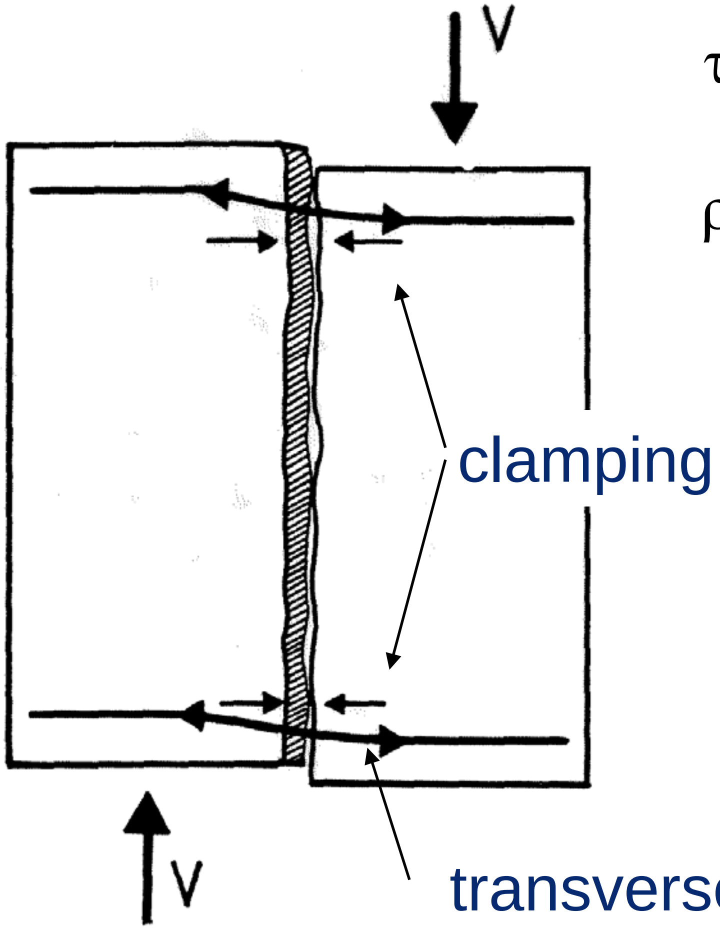
$$\tau_{Rdj} = k_T \tau_{Rd} + \mu\left(\sigma_N + \rho \cdot f_{yd}\right) \leq 0{,}5 \nu f_{cd}$$

Shear transfer by friction



It is not the steel detail that is loaded in shear, but the steel detail make friction possible

Design for shear friction

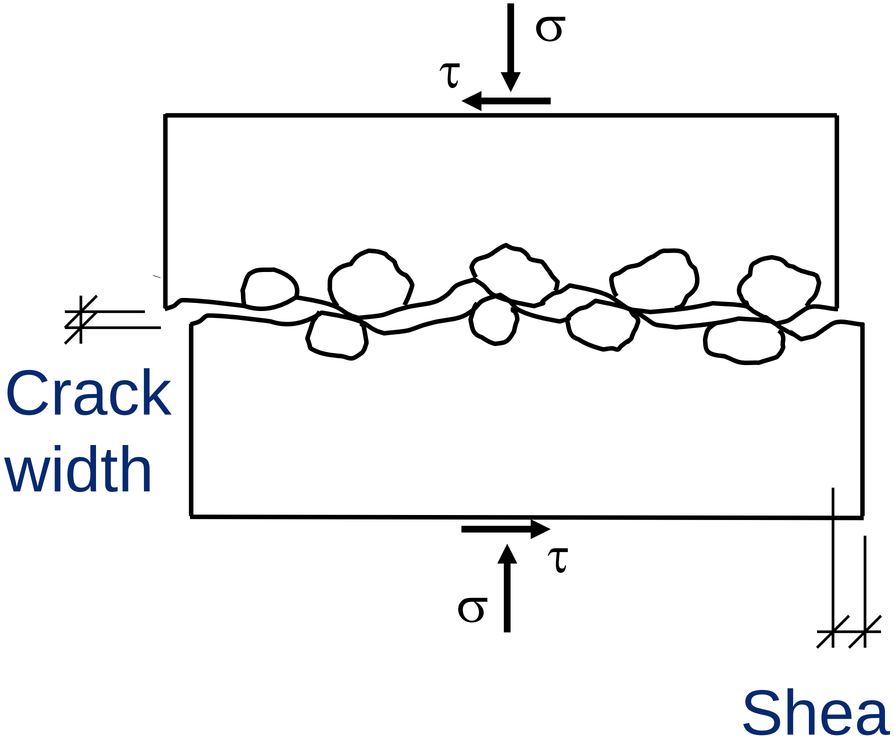


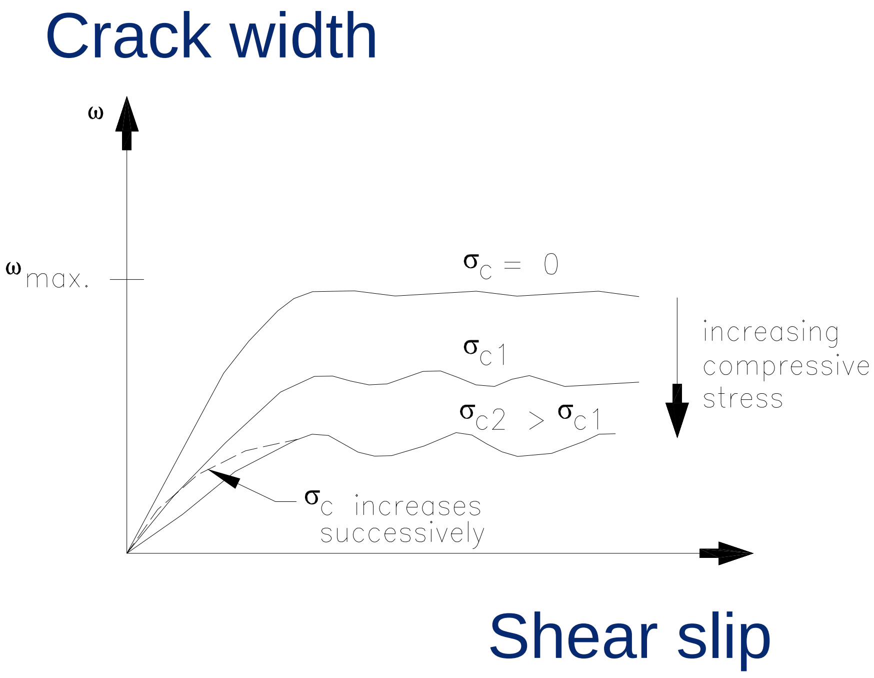
$$\tau_{Rdj} = k_T \tau_{Rd} + \mu\left(\sigma_N + \rho \cdot f_{yd}\right) \leq 0{,}5\nu f_{cd}$$

$$\rho = \frac{A_s}{A_j}$$

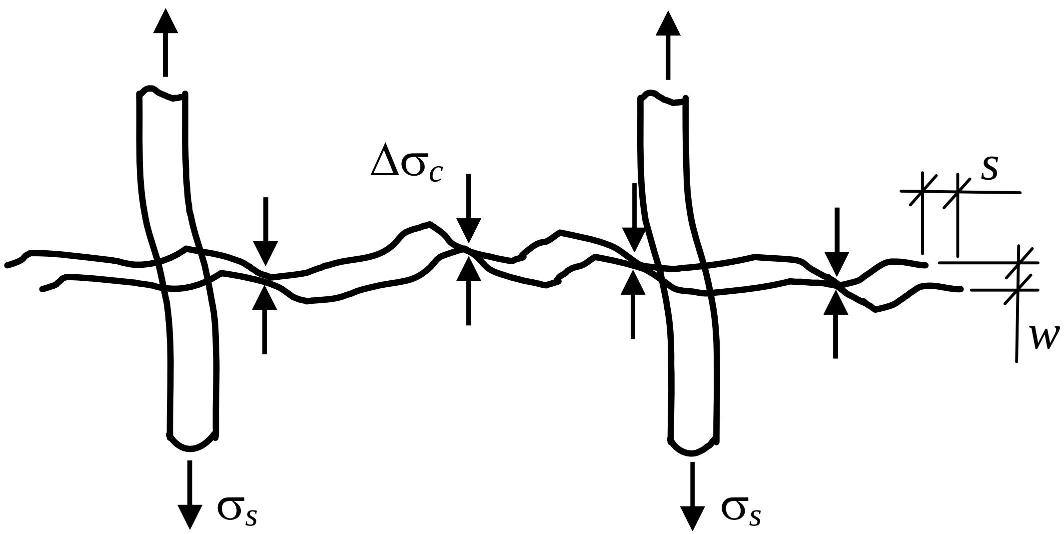
Will the steel always yield?

Influence of joint roughness





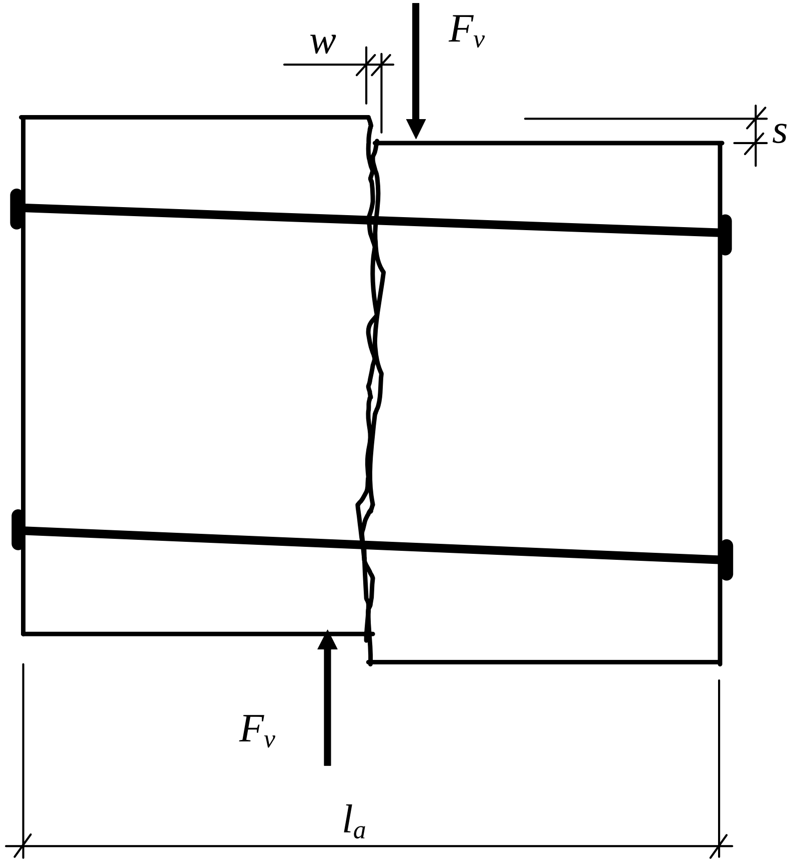
Self-generated friction



$$\tau_{Rdj} = k_T \tau_{Rd} + \mu\left(\sigma_N + \rho \cdot f_{yd}\right) \leq 0{,}5 \nu f_{cd}$$

$$\rho = \frac{A_s}{A_j}$$

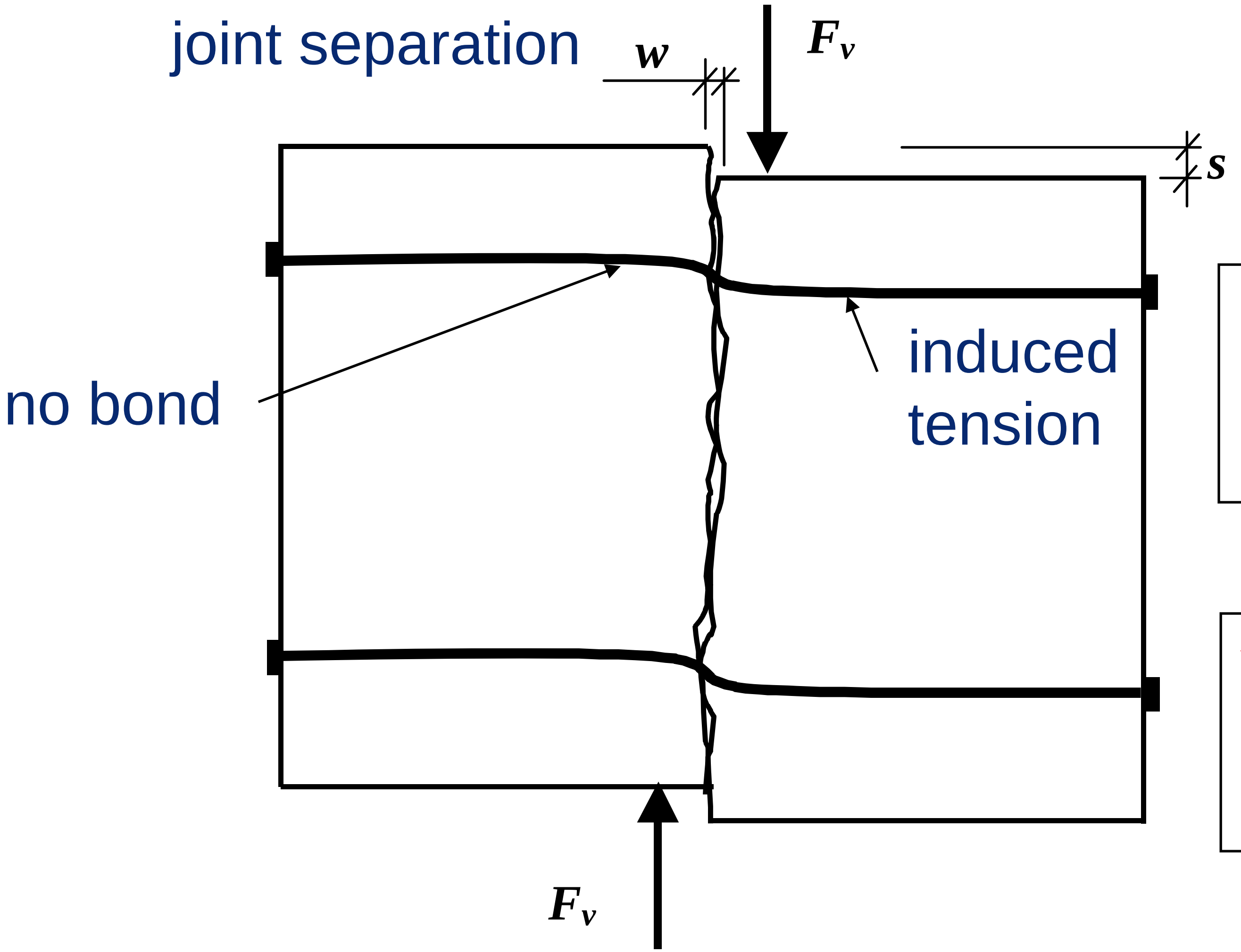
External bars – small steel stress



When the maximum crack opening w_{max} is reached, the steel has not yet started to yield

$$\sigma_s < f_{yd}$$

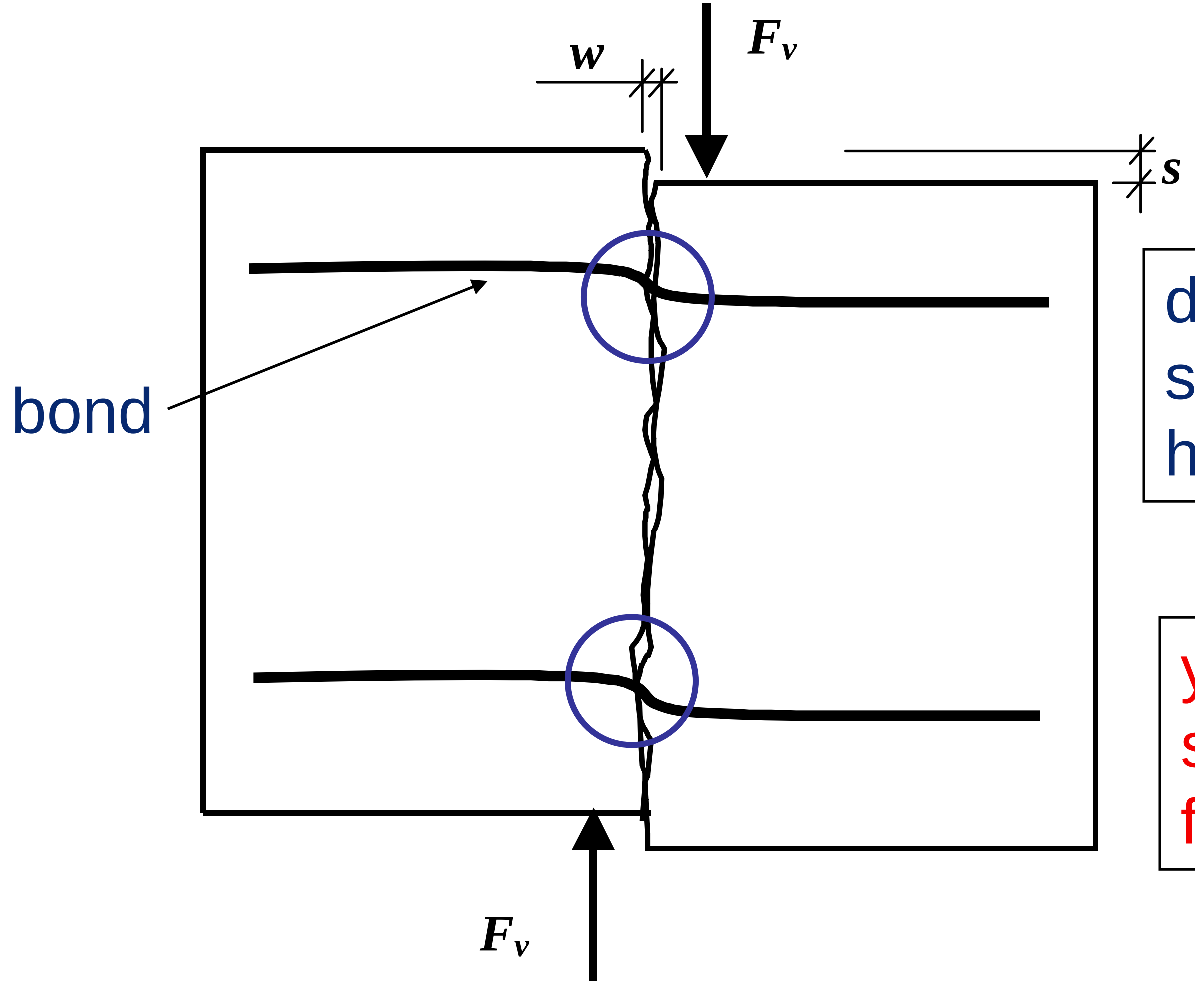
Influence of bond and anchorage



plain bars
uniform strain
low steel stress

yields for
large slip,
friction + dowel

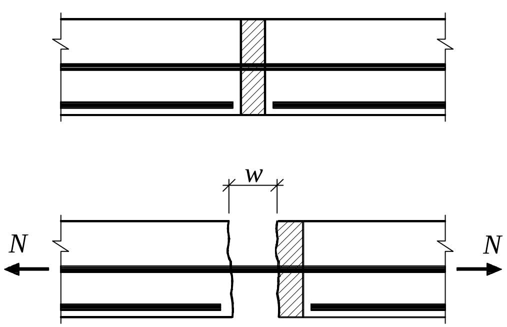
Influence of bond and anchorage

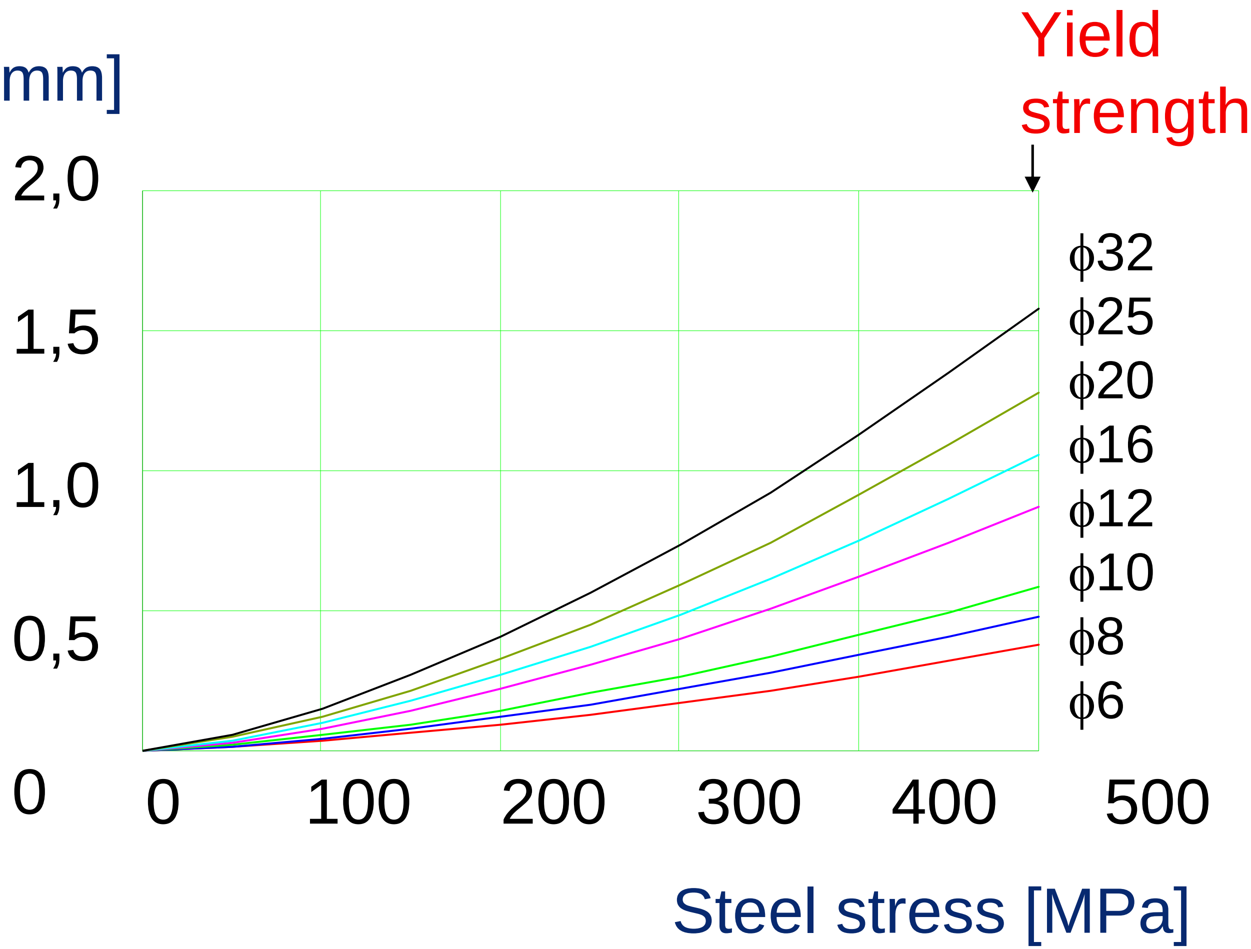


deformed bars
strain localisation
high steel stress

yields for
small slip,
friction dominates

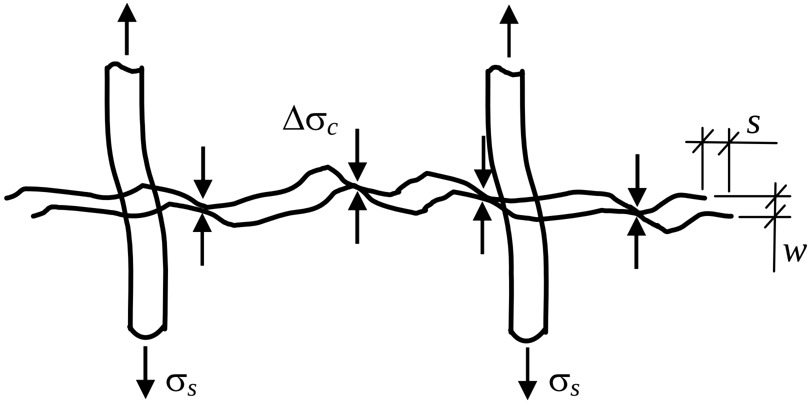
Pull-out resistance



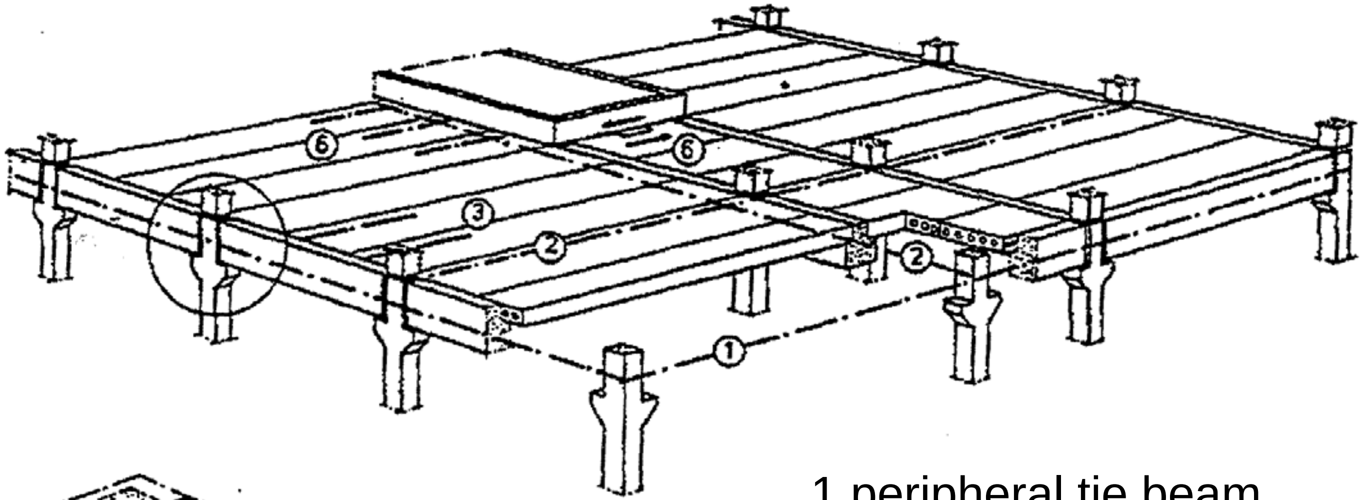


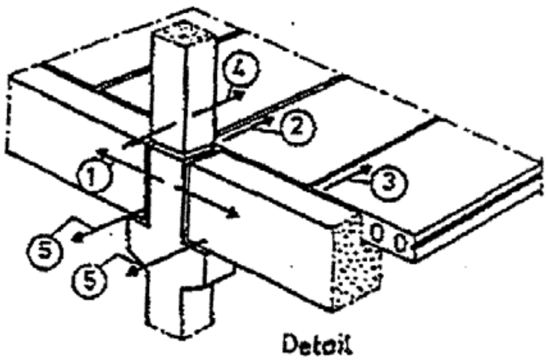
Conclusion

- Aim at distributed shear transfer by friction
- Detail the connection such that the transverse steel is forced to yield for a small shear slip along the joint



Design for robustness

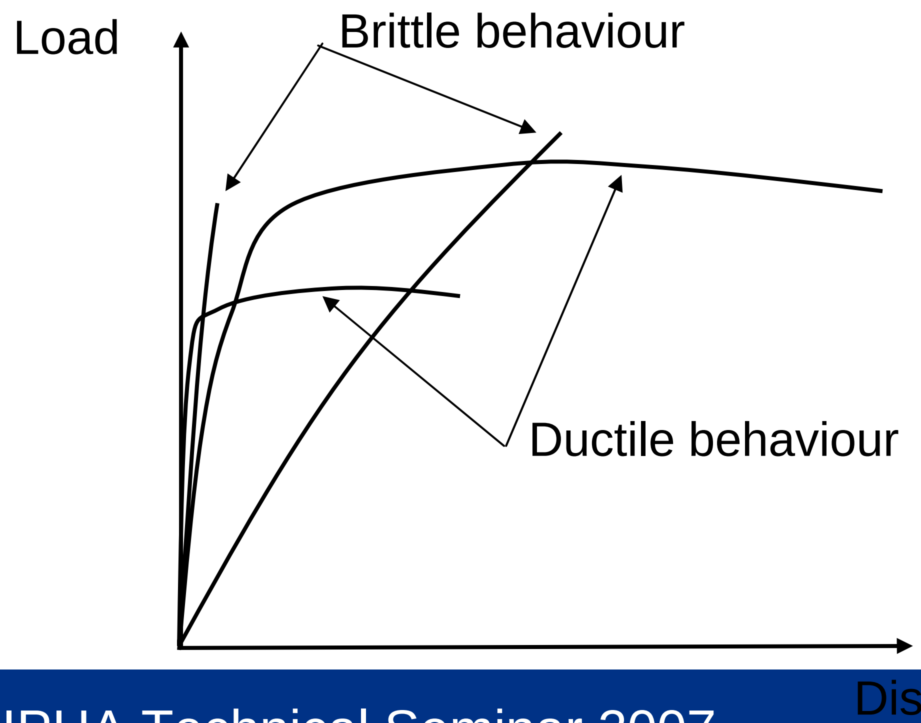




1 peripheral tie beam
2 internal floor tie
3 floor elements to edge beam
4 upper column to lower column
5 beam to column
6 floor to stabilising core

What is meant by ductility?

Ductility = the ability of a structural member, a structural connection or a structural material to undergo large plastic deformations without significant loss of force capacity

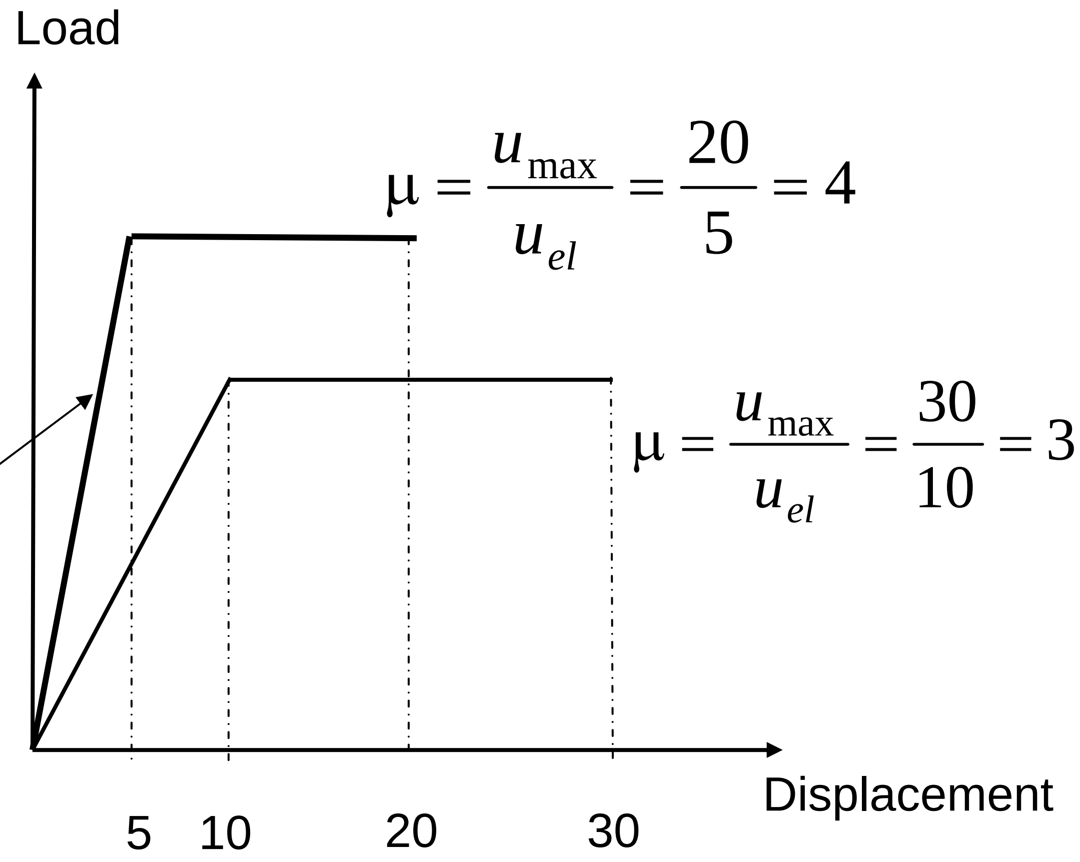


Don’t mix up deformation capacity and ductility. Ductility refers to the shape of the load-displacement diagram, not the absolute value of deformation

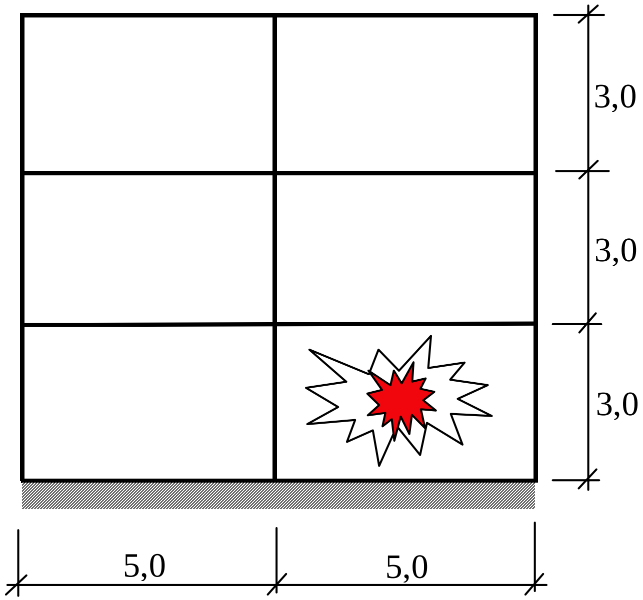
Ductility factor

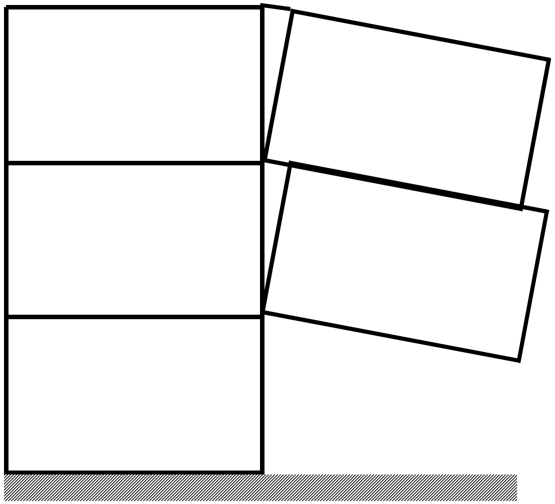
$$\mu = \frac{u_{\max}}{u_{el}}$$

Less deformable
but more ductile



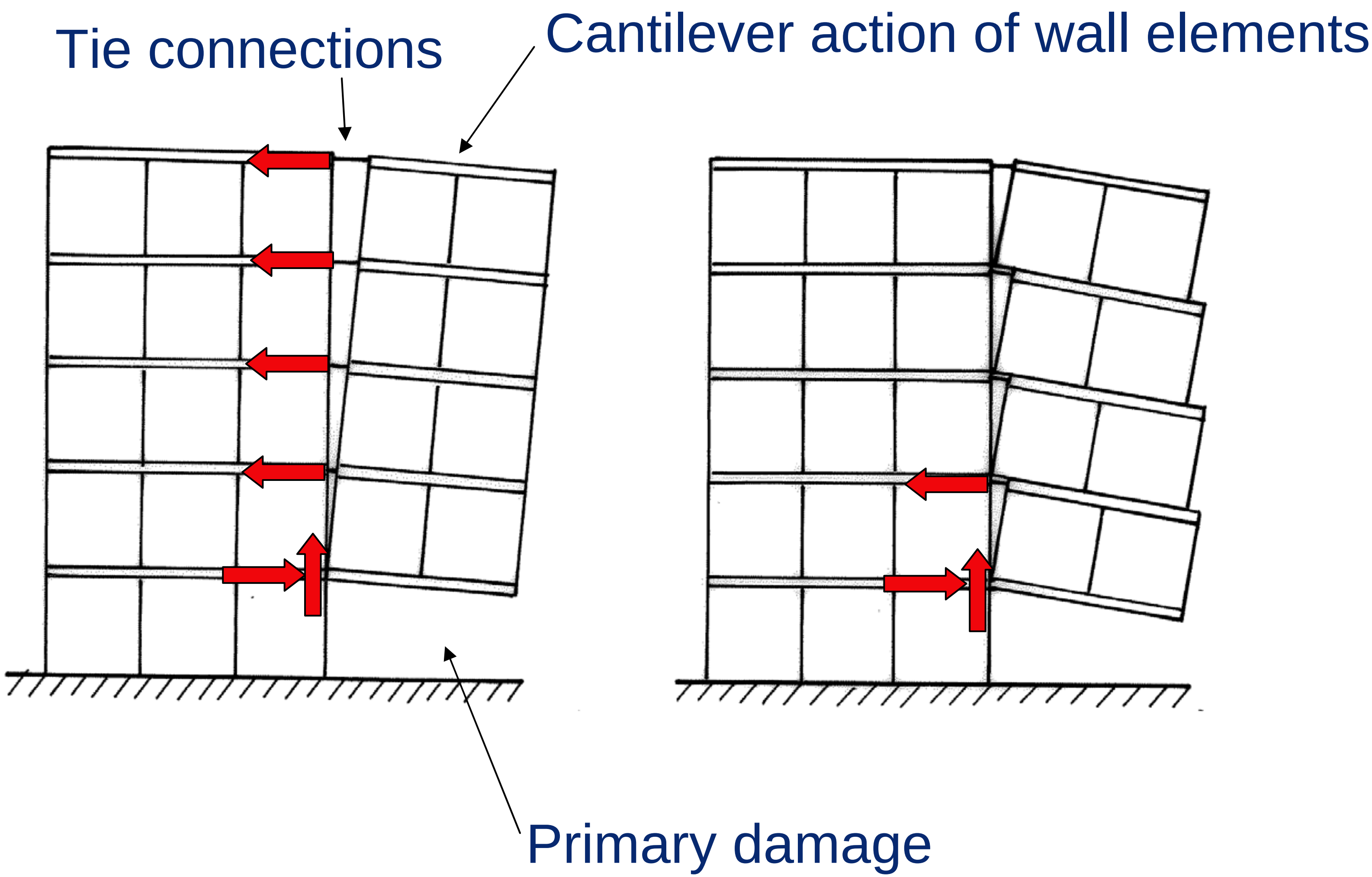
Analysis of various damages and possible alternative force paths





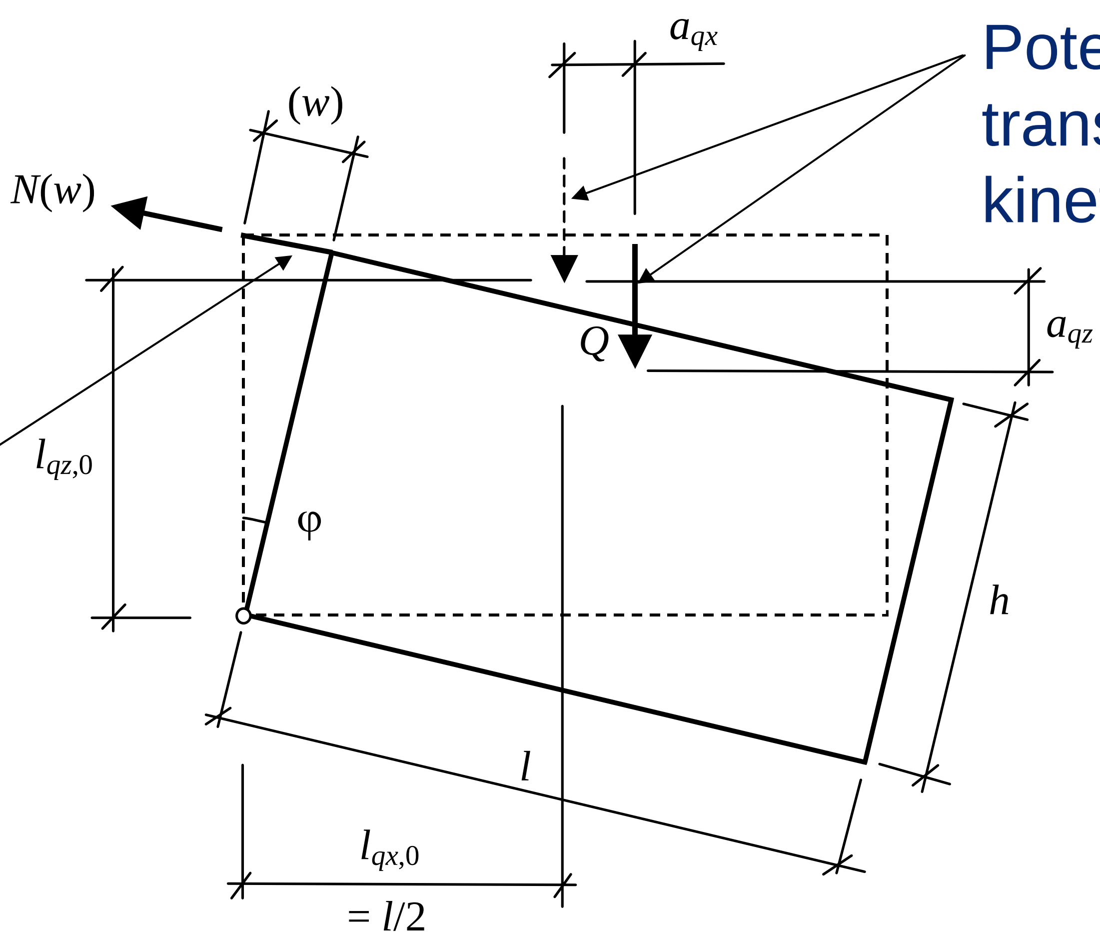
New local equilibrium of a cantilever system with large displacements. Spread of collapse is prevented.

Alternative ways to bridge the local damage



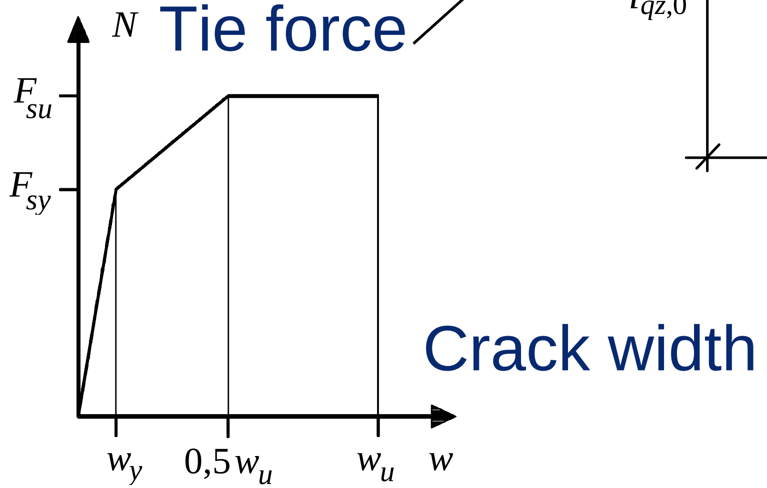
Dynamic problem – no equilibrium in the start

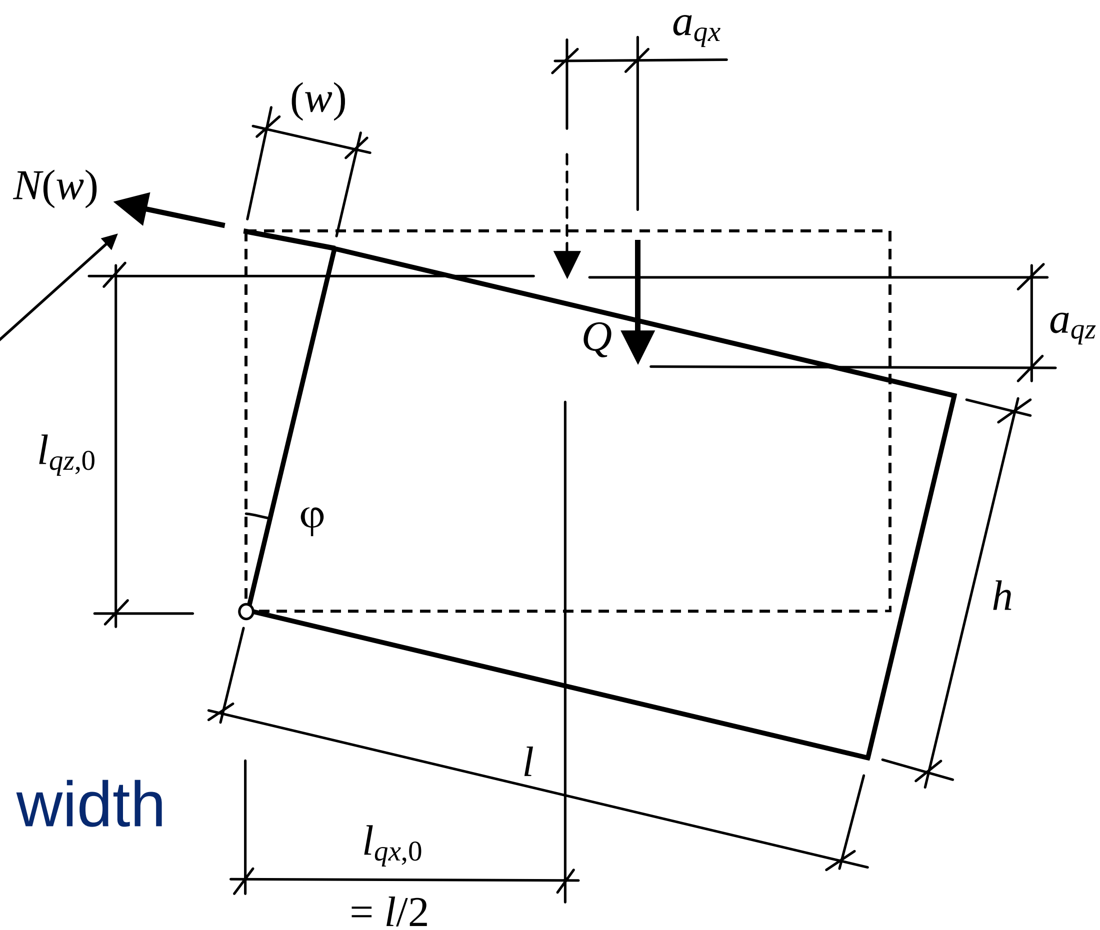
Energy consumed as strain energy



Potential energy transformed to kinetic energy

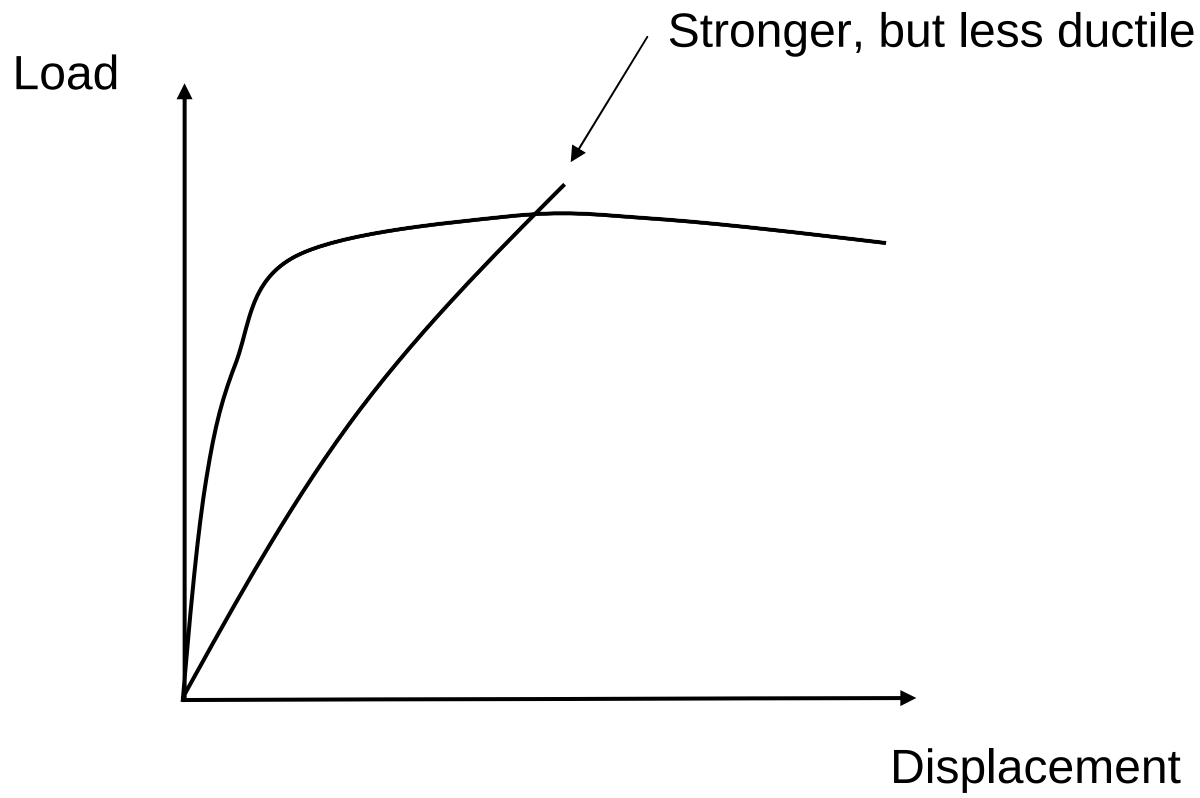
To find a new equilibrium in a deflected state



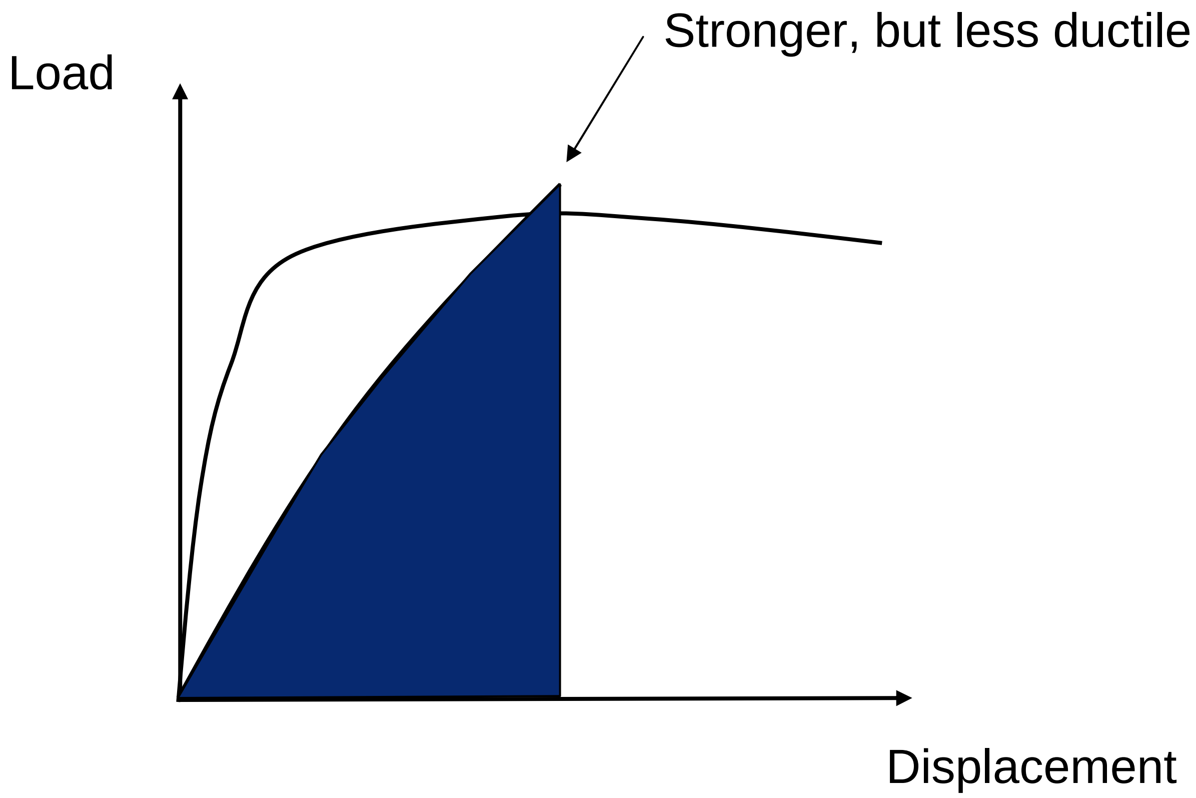


If the loss of potential energy can be absorbed as strain energy, static equilibrium can be achieved (deflected state)

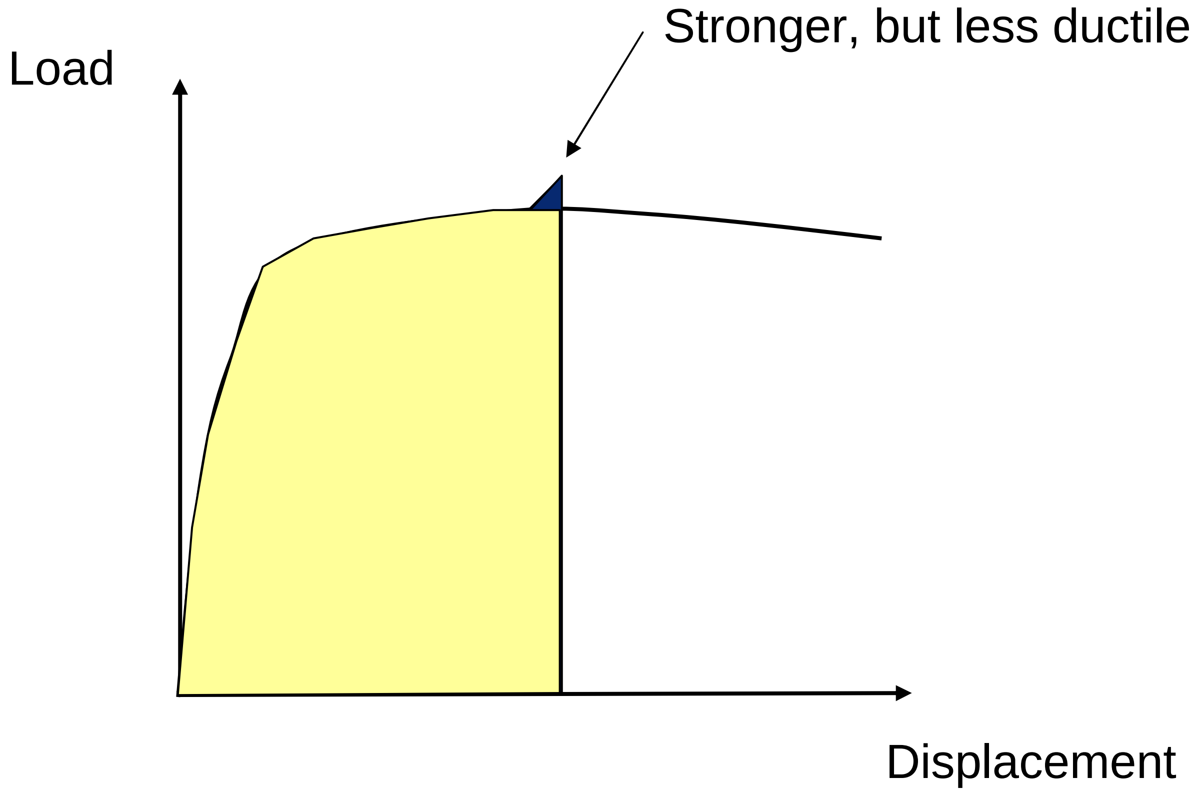
Ductile tie connections are favourable



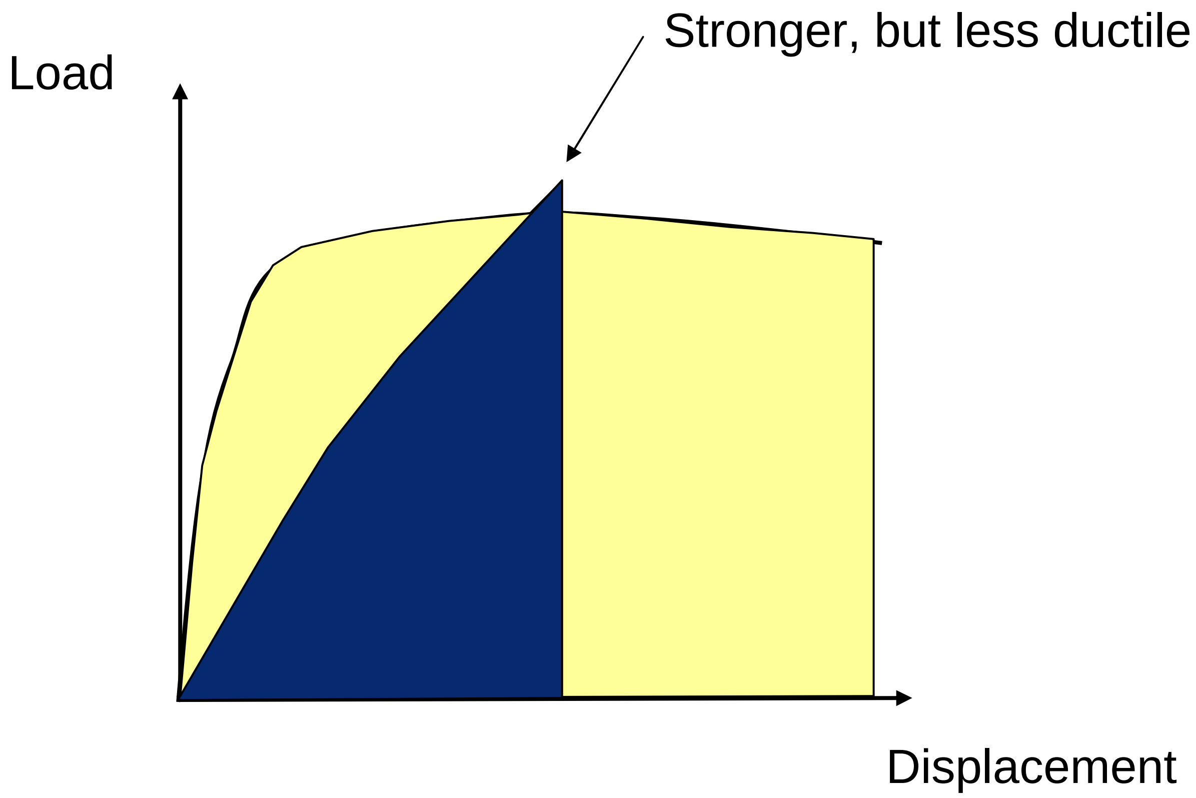
Strain energy at failure



Strain energy at the same displacement

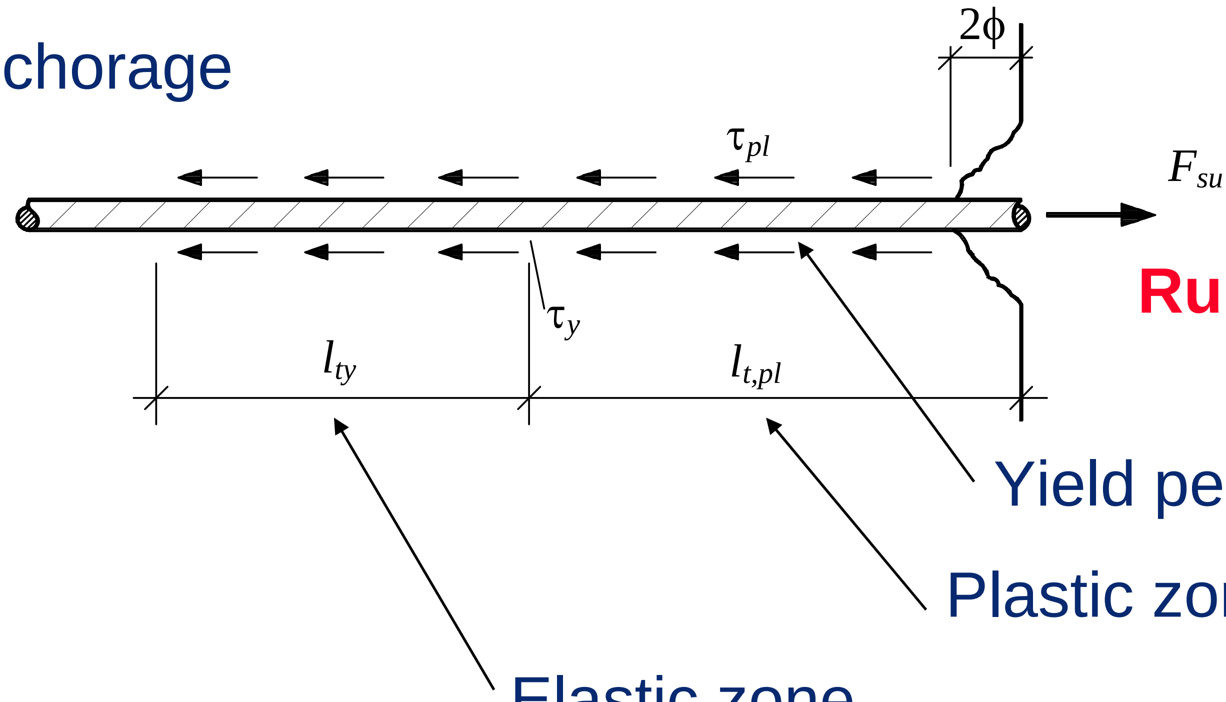


Strain energy at failure

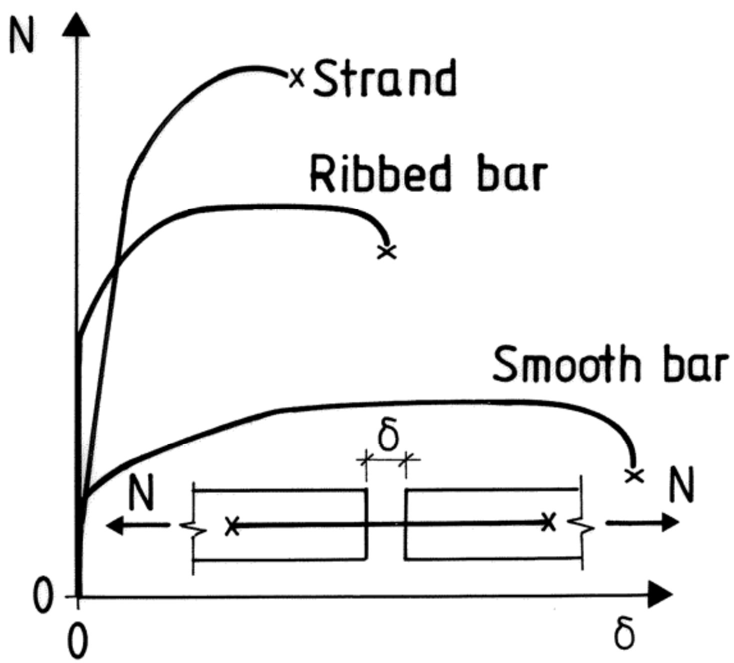


Yield penetration favourable with regard to ductility

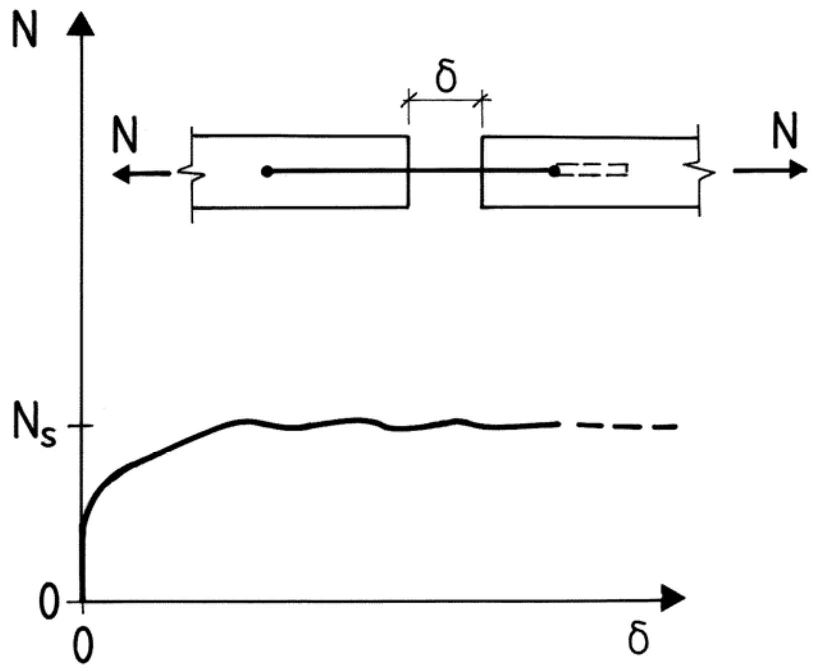
Full anchorage



Different types of tie bars

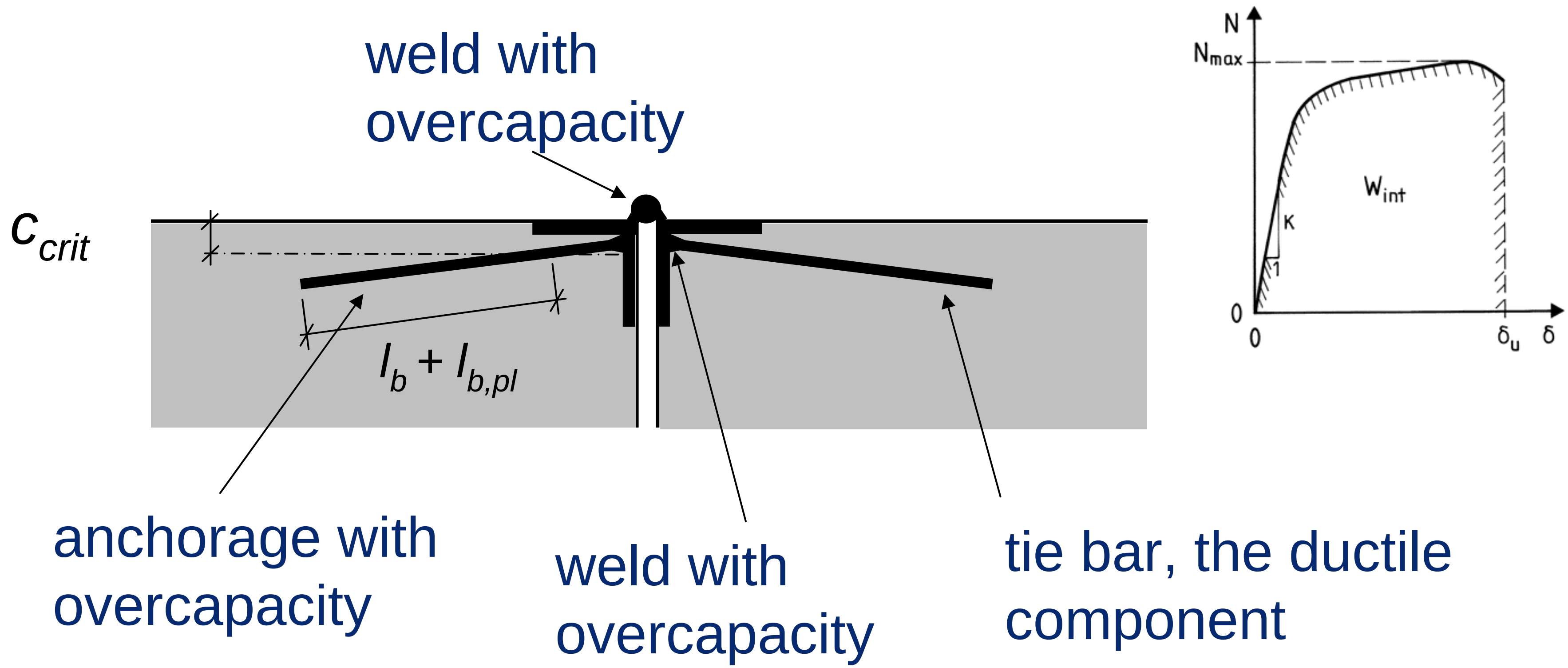


Ductility depends on yielding of steel and yield penetration

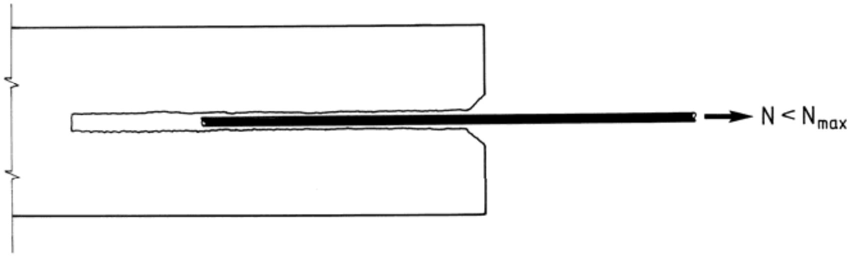


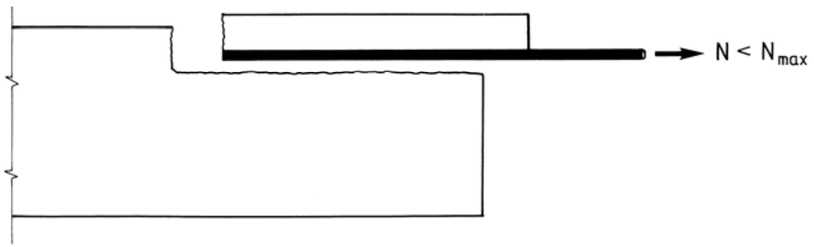
Ductility depends on plastic anchor slip

Balanced design for ductility

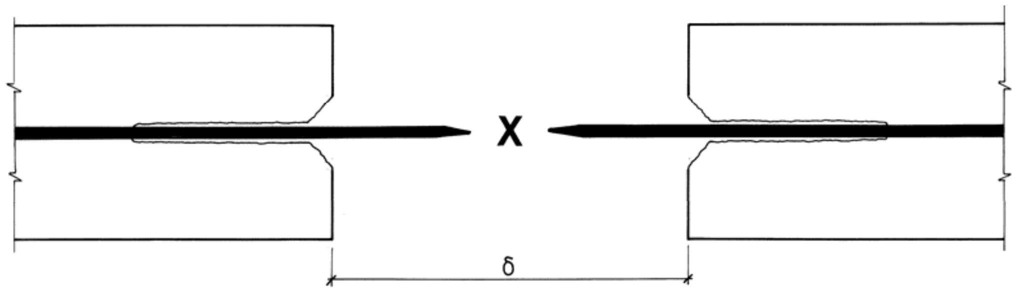


Anchorage for ductility



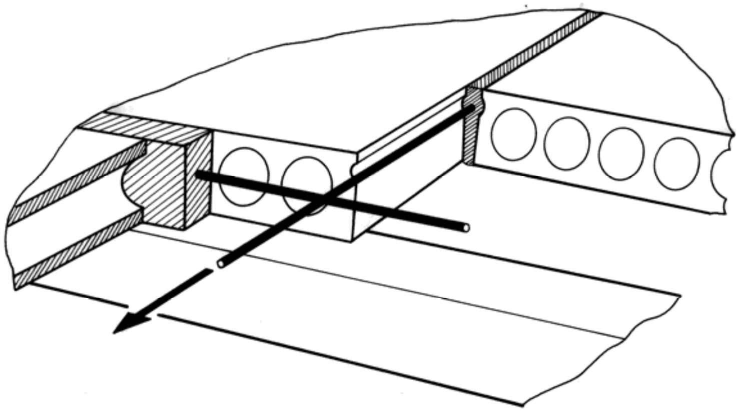


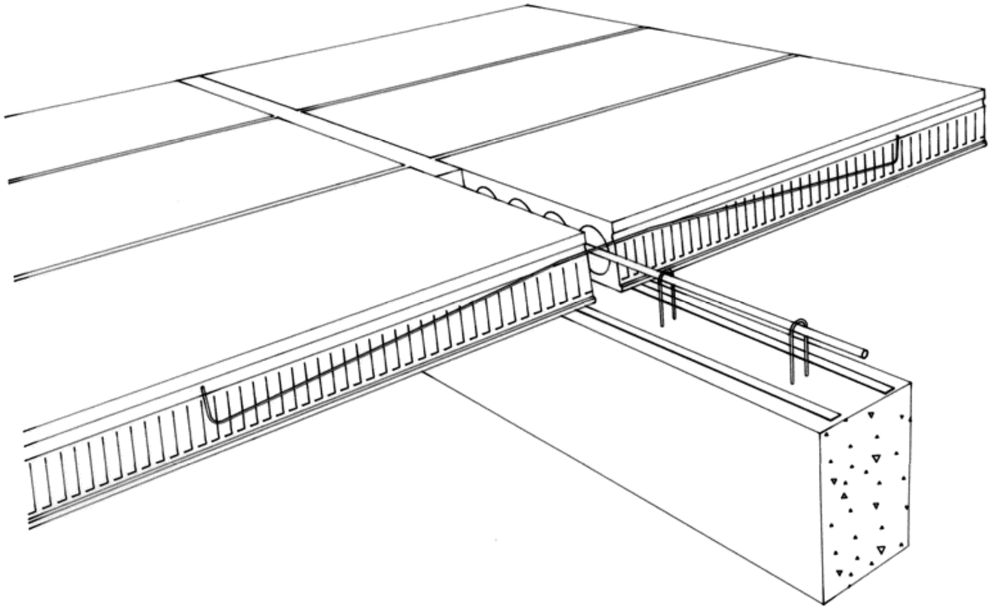
Avoid anchorage failures



Provide anchorage for rupture of the steel

Anchorage in grouted joints

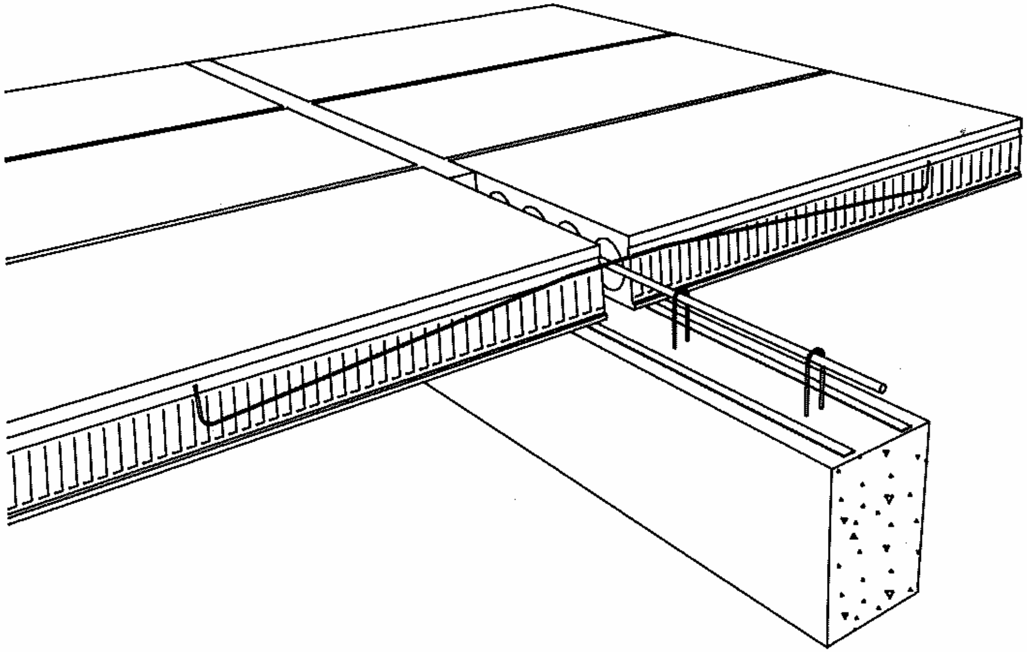




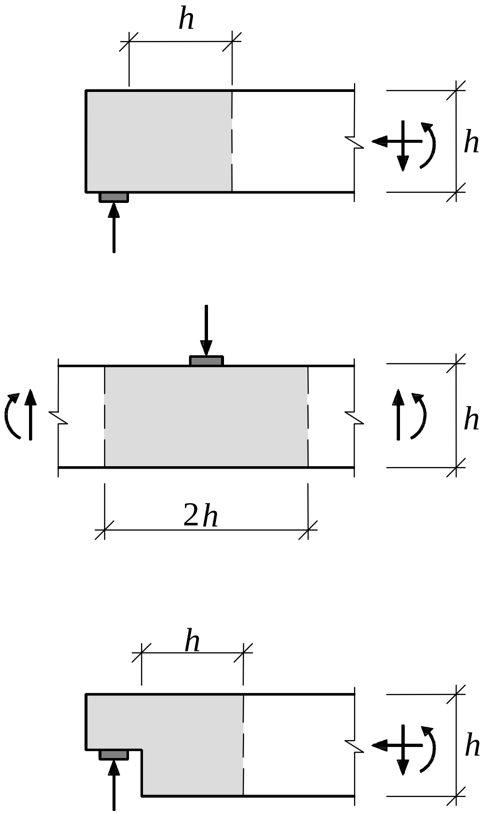
Bar in correct position
Full anchorage in the joint
(anchorage length, fully encased)
Transverse reinforcement

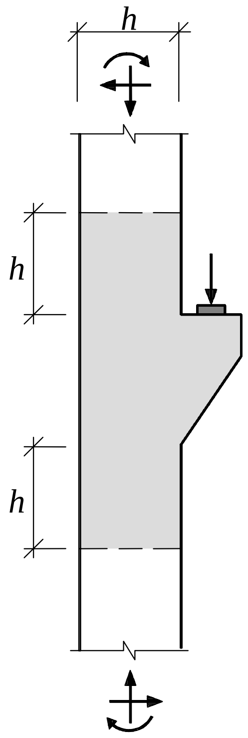
Execution
Workmanship

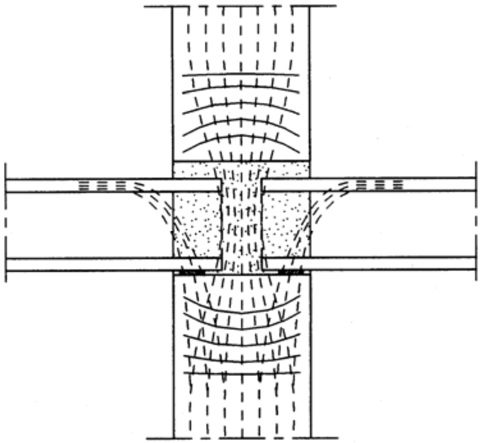
Connection for industrialised construction?



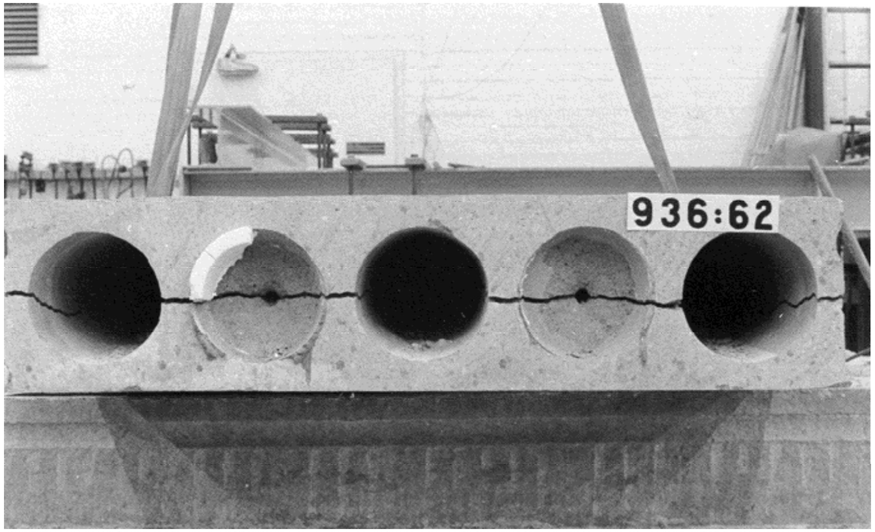
The connection zone – discontinuity region







Analysis of the complex connection zone



Transfer of prestressing
Need for movement
Restraint at the support
Anchorage of strands

Vertical load in wall connections
Anchorage of tie bars
Shear and torsion
Flexible support