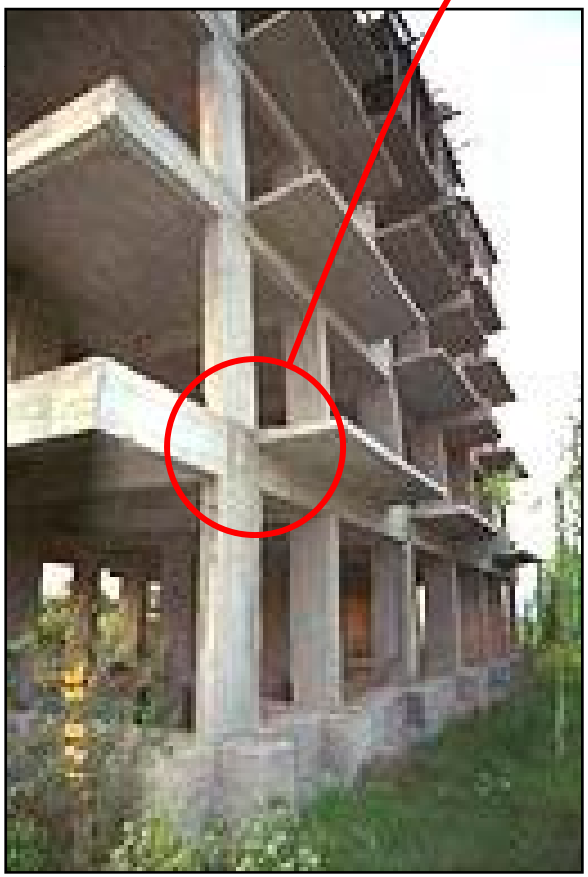
Application field of 3D FE code MASA to Concrete & RC structures

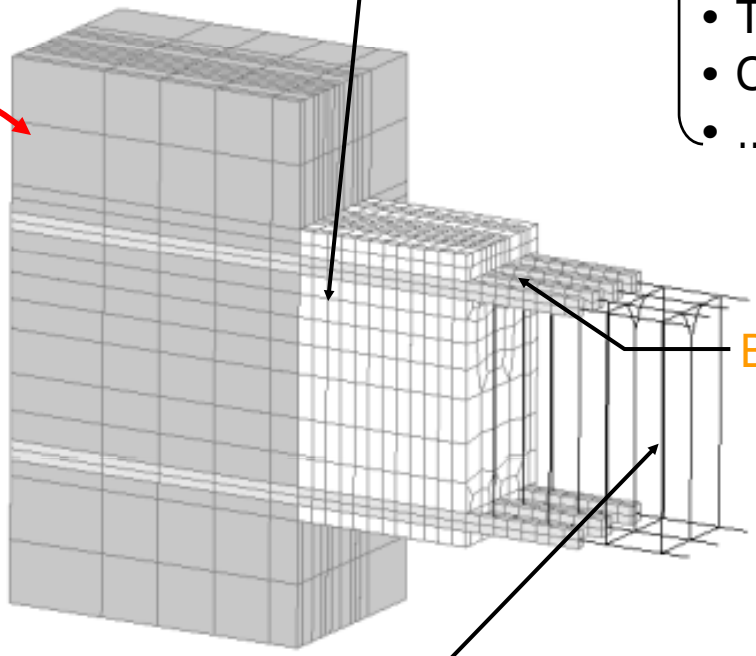
- Theoretical framework
  - Continuum mechanics & irreversible thermodynamics
- Mechanics
  - 3D static and dynamic analysis of RC structures
    - Rate sensitive microplane model
    - Plasticity & damage mechanics based models
    - Discrete bond model
    - Creep & shrinkage of concrete
    - Contact mechanics
    - Remeshing
- Thermo-hygro-mechanical model
  - Modeling of concrete at high temperature
- Chemo-thermo-hygro-mechanical model
  - Modeling of corrosion of reinforcement (processes before and after depassivation)

Modeling of quasi-brittle materials

- Modeling level
  - Macro scale (phenomenological models)
    - global
    - detailed
  - Meso scale
  - Micro scale
- Modeling approach
  - Continuous models: *smeared cracking + regularization*
  - Discrete models
  - Combination
- Spatial discretization
  - Finite elements
  - Finite difference
  - Meshless methods

Detailed macro modeling:





Concrete

- Constitutive law
- Fracture mechanics
- Continuum/Discontinuum
- Cycling
- Time dependent behavior
- Objectivity of analysis
- ....

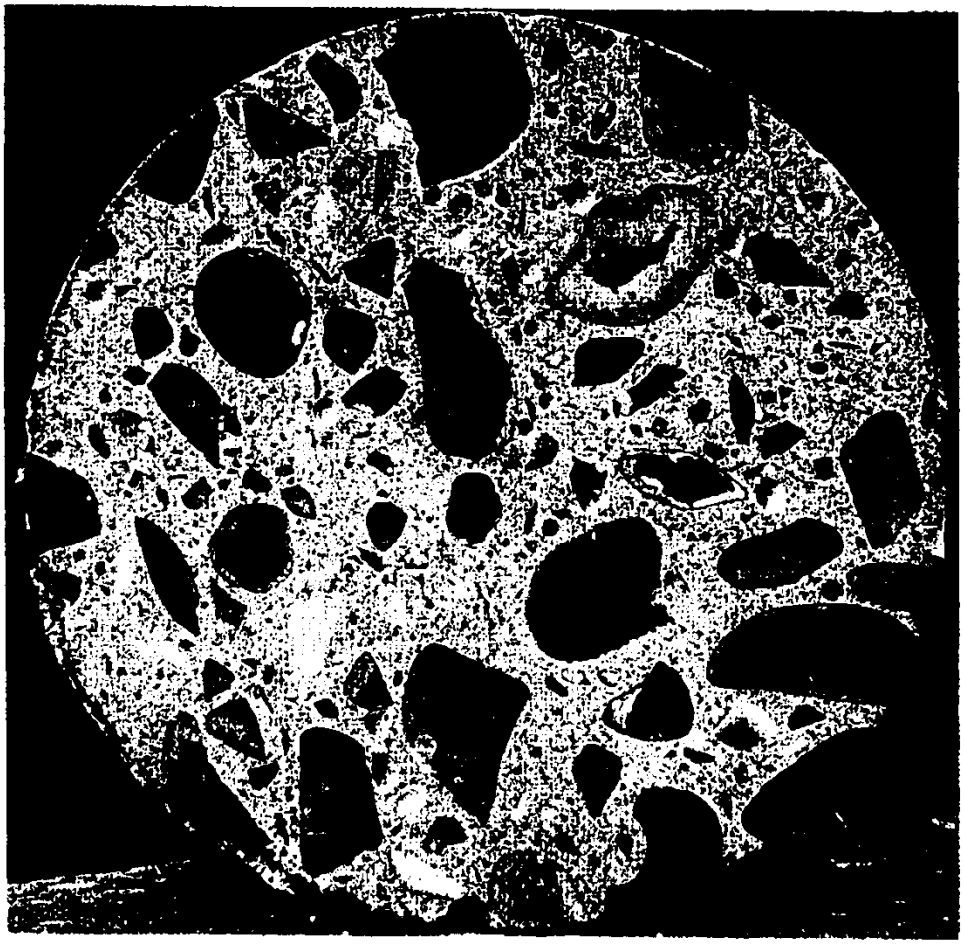
Bond

- Smeared bond
- Discrete bond

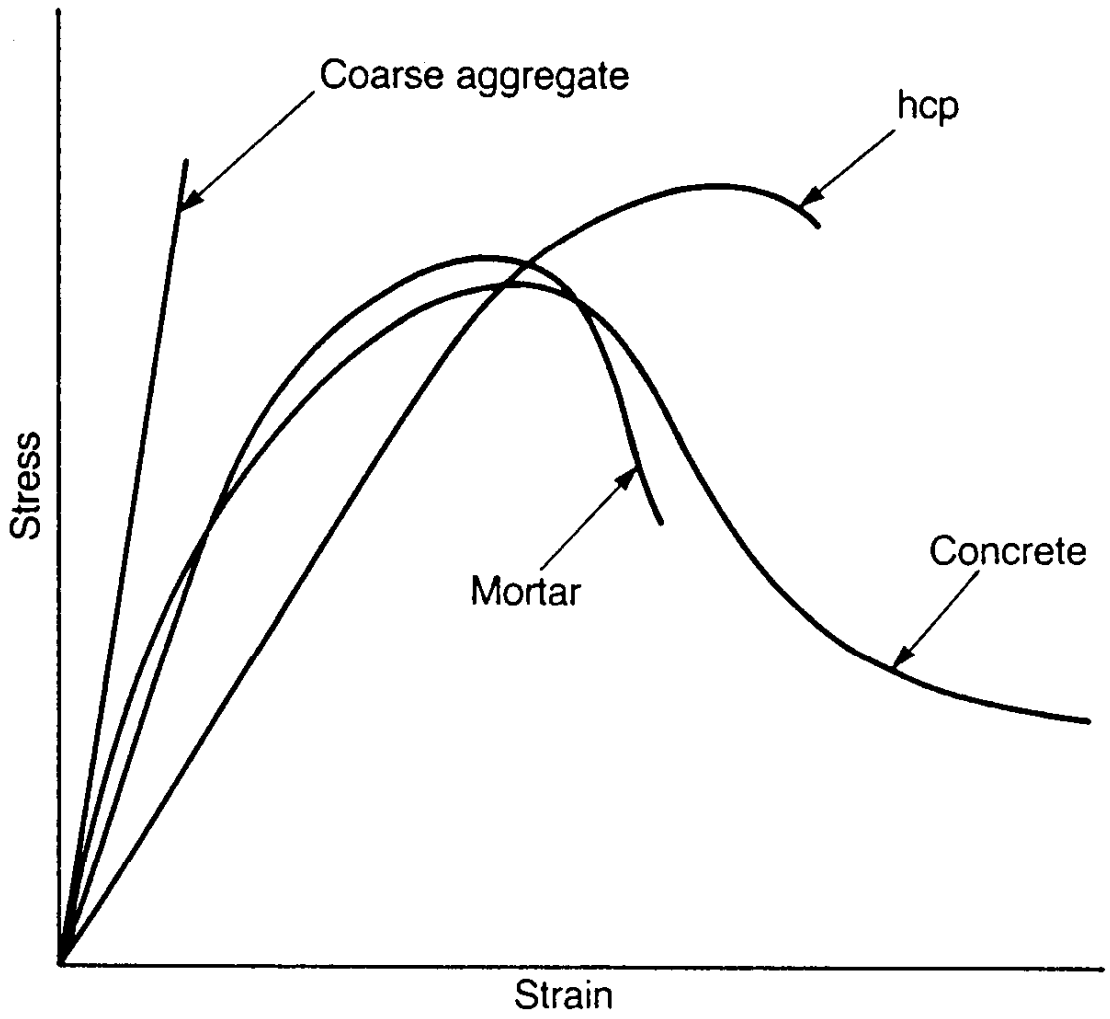
Reinforcement

- 1D vs. 3D modeling
- Constitutive relations
- Cyclic behavior

Concrete as a composite material



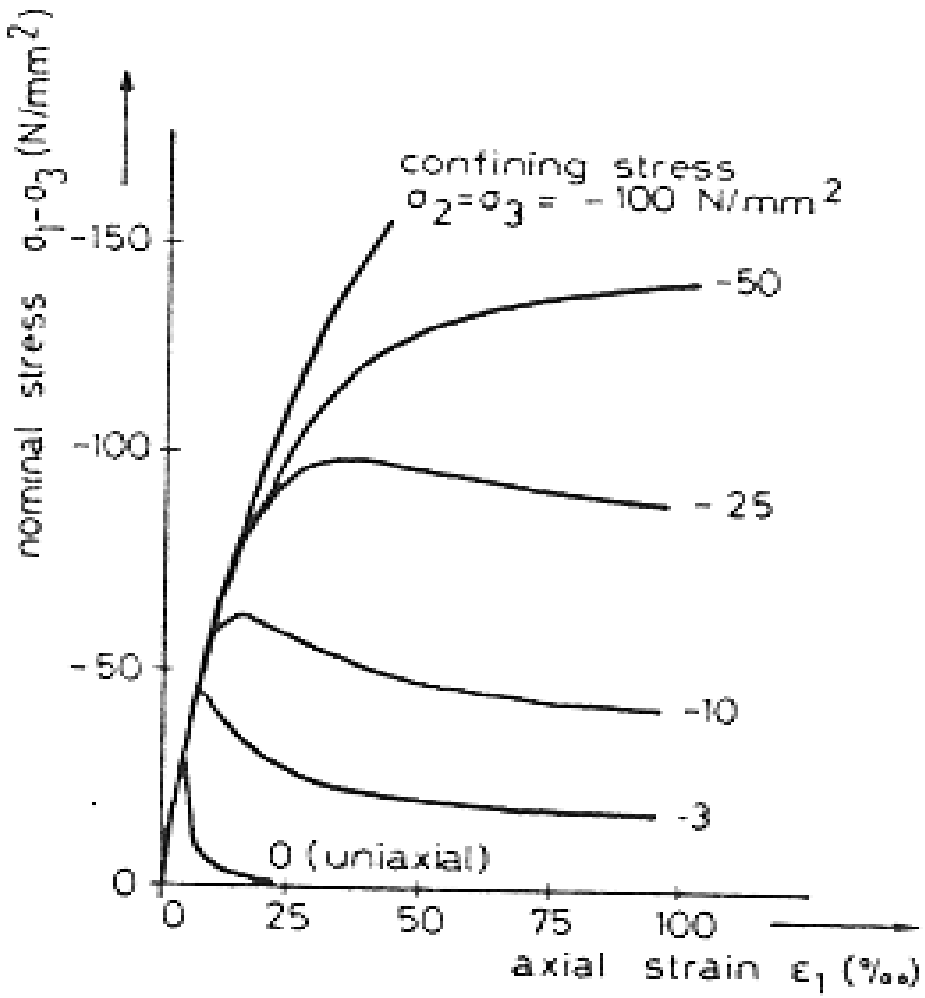
Section through a concrete cylinder showing grading of the aggregate particles



Typical stress-strain characteristics of aggregate, hardened cement paste (hcp), mortar and concrete under compressive loading

Hordijk/van Mier/Reinhardt 1989

Compressive load

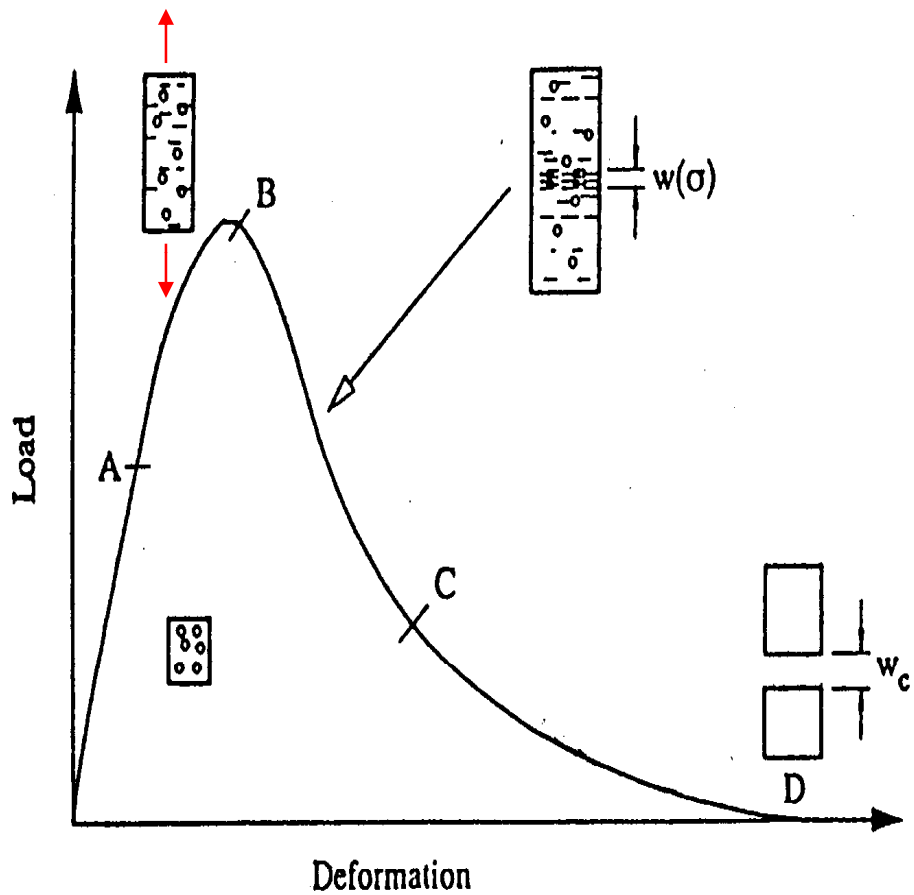


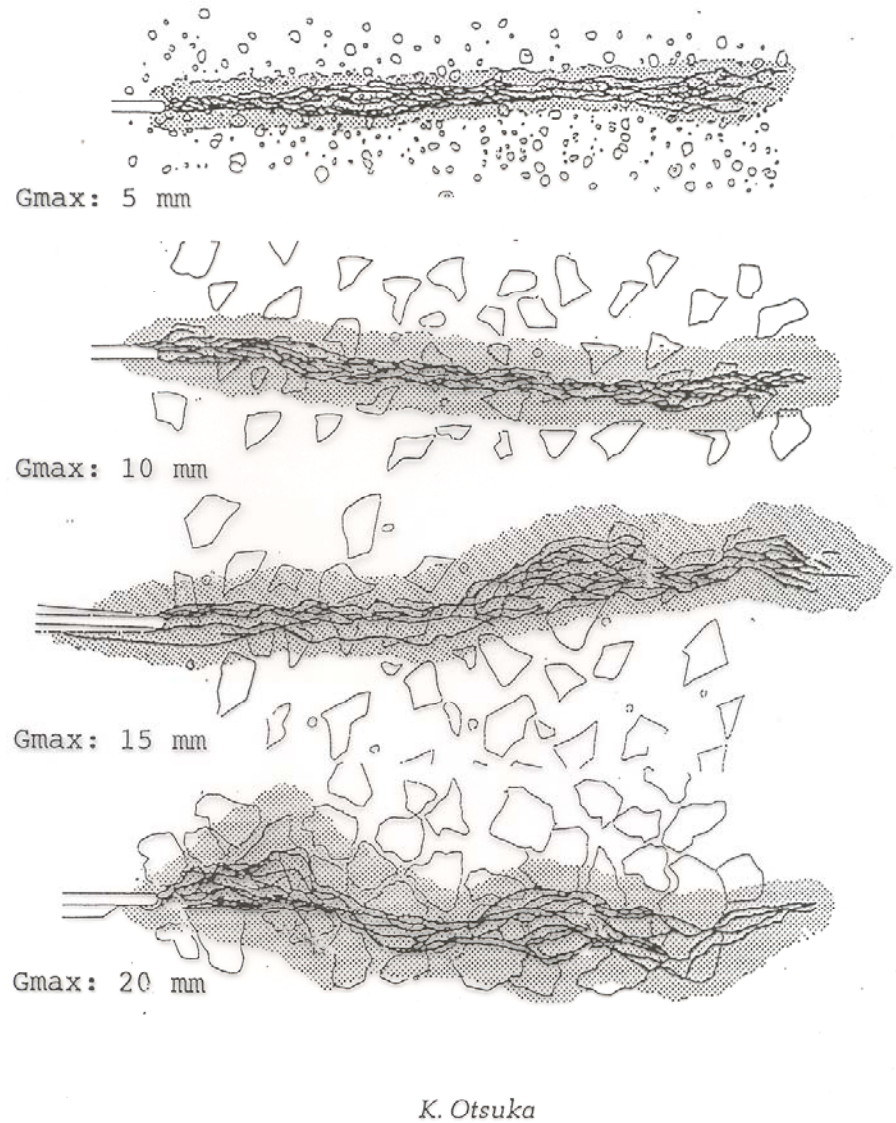
Nominal stress σ_1 - σ_3 versus axial strain ε_1 curves obtained in displacement controlled standard triaxial compression tests

($\sigma_1 < \sigma_2 = \sigma_3 \leq 0$)

Tensile load

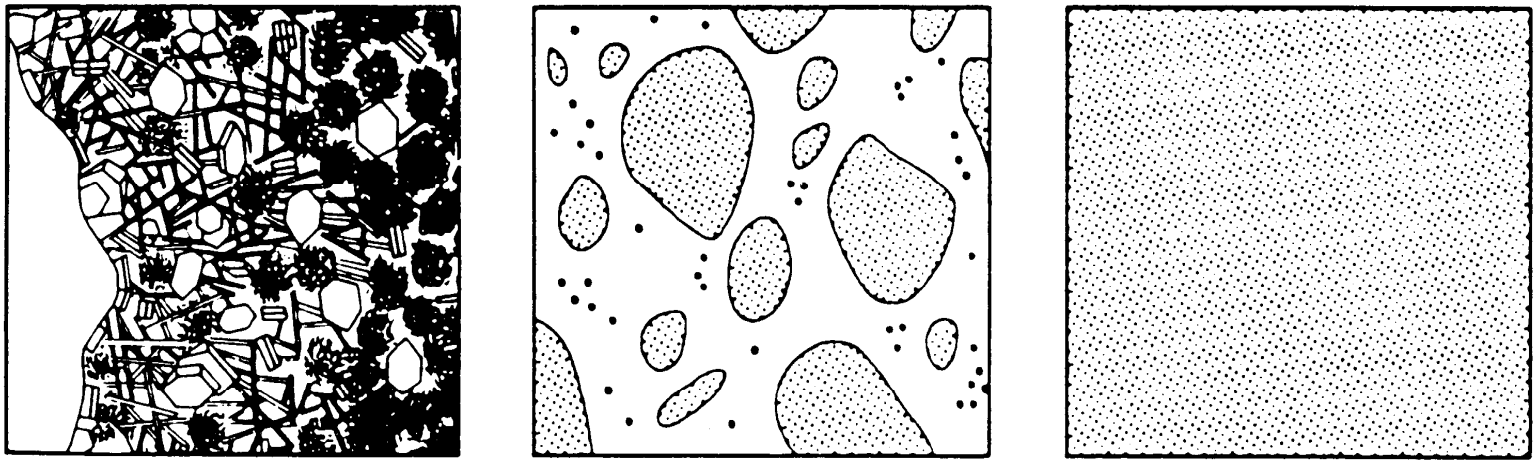
Localization zone - Fracture Process Zone (FPZ)





Size of the FPZ for different aggregate sizes

Modeling of quasi-brittle materials



Order of magnitude:	micro level [μm]	meso level [mm]	macro level [m]

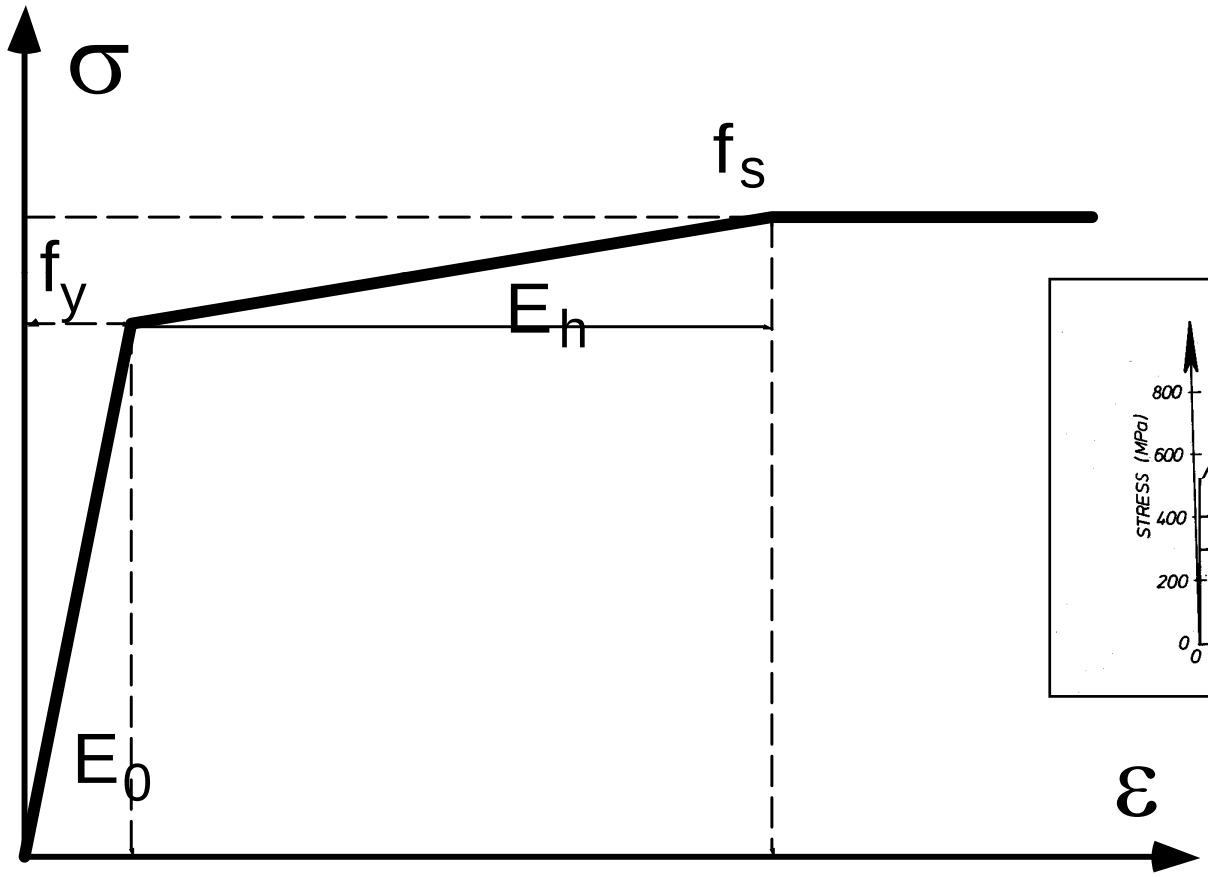
„A Representative Volume Element (RVE) must be small enough to avoid smoothing of high gradients but large enough to represent an average of the microprocesses.“

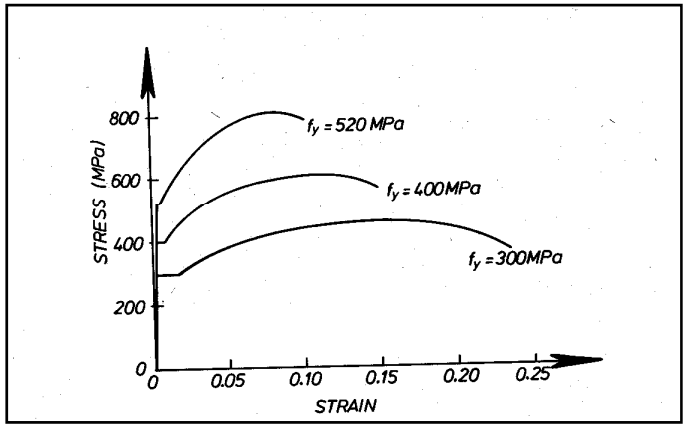
J. Lemaitre

For experimental and numerical purposes the following orders of magnitude on the meso-level are suggested:

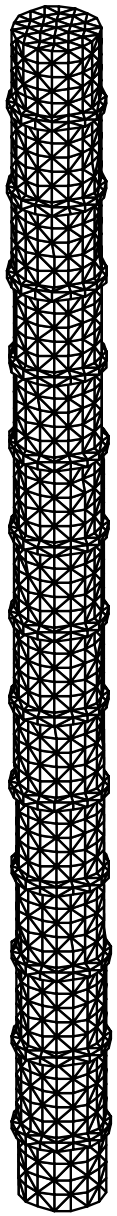
- metals and ceramics: $(0.1\ \text{mm})^3$
- polymers and most composites: $(1\ \text{mm})^3$
- wood: $(10\ \text{mm})^3$
- concrete: $(100\ \text{mm})^3$

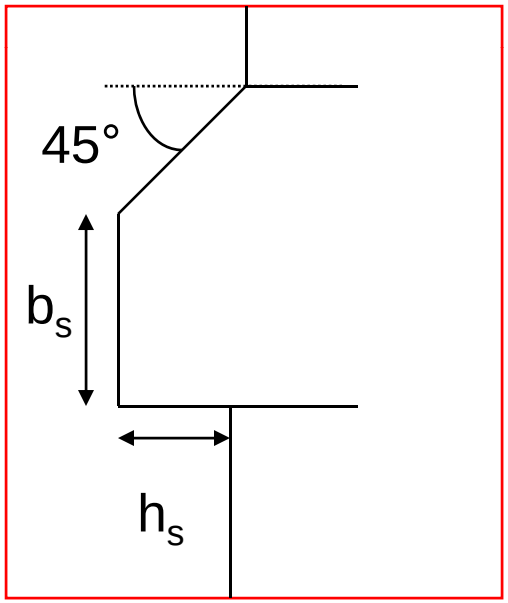
Steel reinforcement: 1D stress-strain relationship

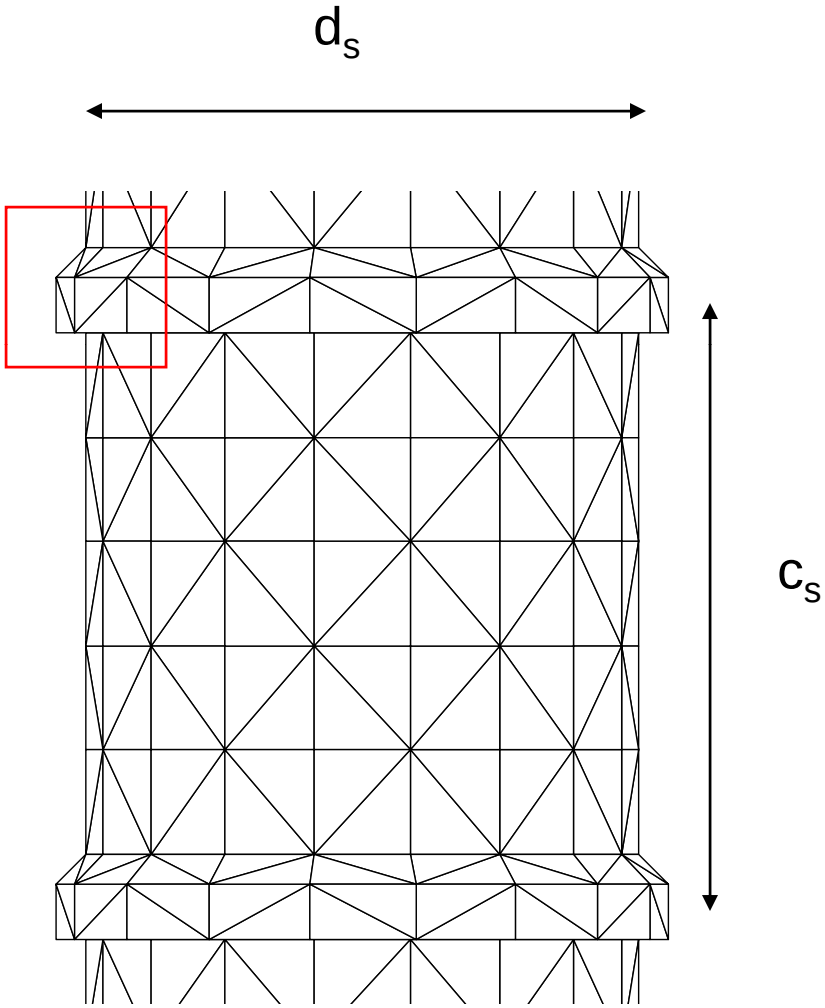




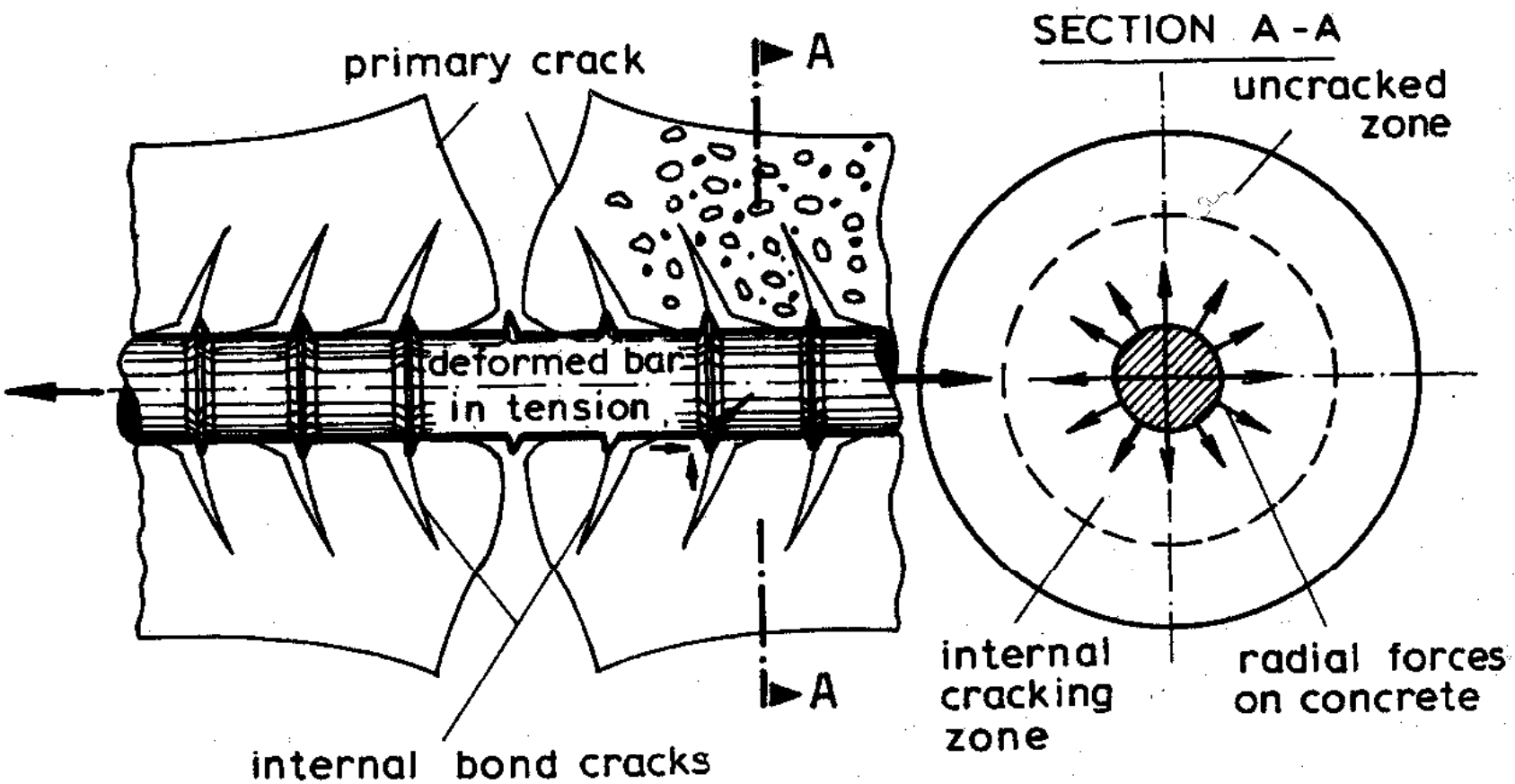
Steel reinforcement: 3D plasticity based constitutive law



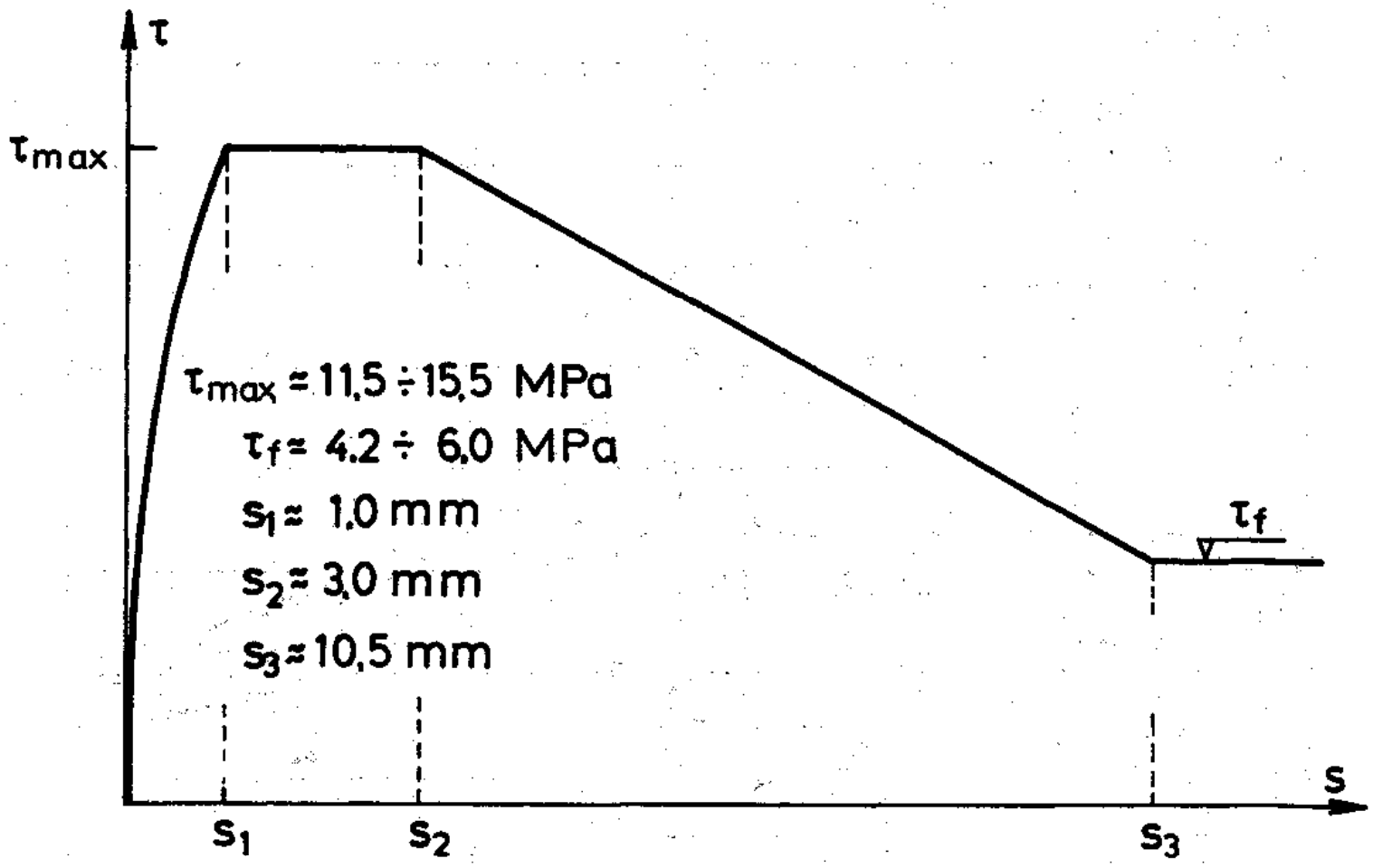




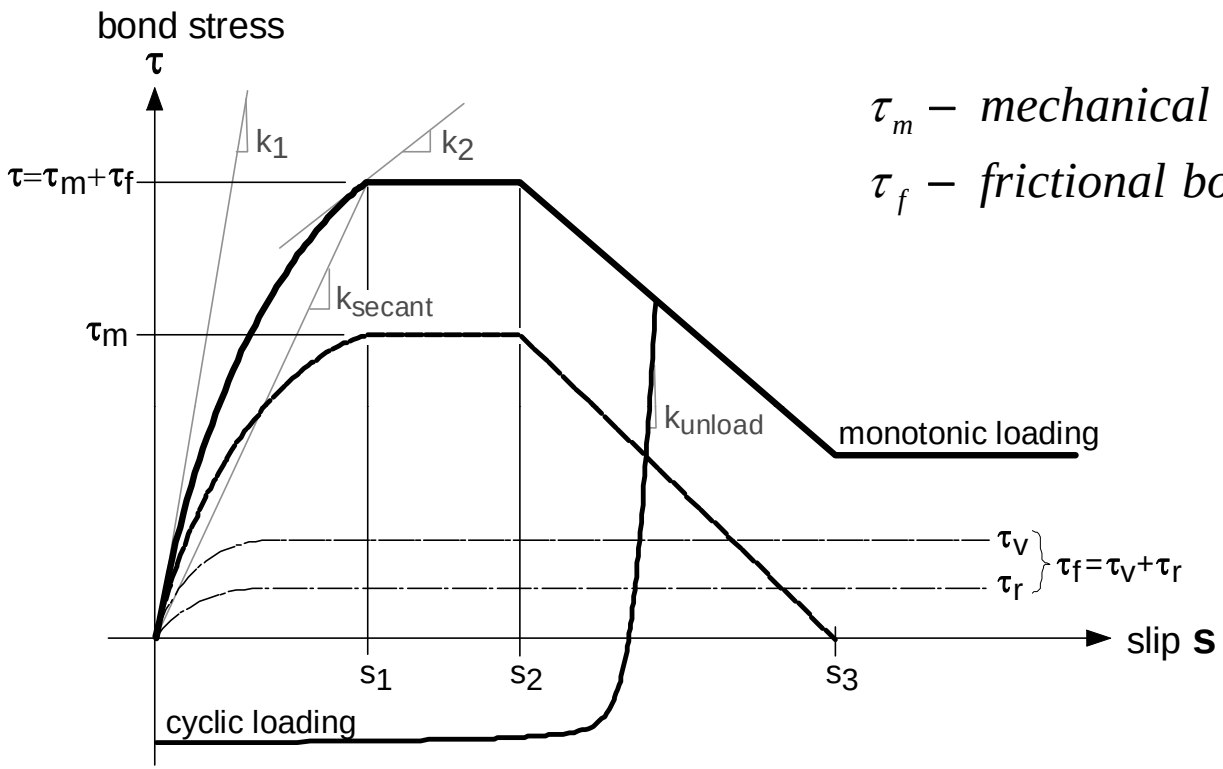
Bond between steel and concrete



Typical bond-slip relationship



Bond-slip relationship



τ_m – *mechanical bond*

τ_f – *frictional bond*

$$\tau = \tau_m + \tau_f \;; \qquad \tau_f = \tau_{f,v} + \tau_{f,r}$$

$$\tilde{\tau} = \tilde{s} \cdot \left(b + (1-b) \left[\frac{1}{1+|\tilde{s}|^R} \right]^{\frac{1}{R}} \right); \quad b = k_2 / k_1$$

<u>Inflenced by:</u>

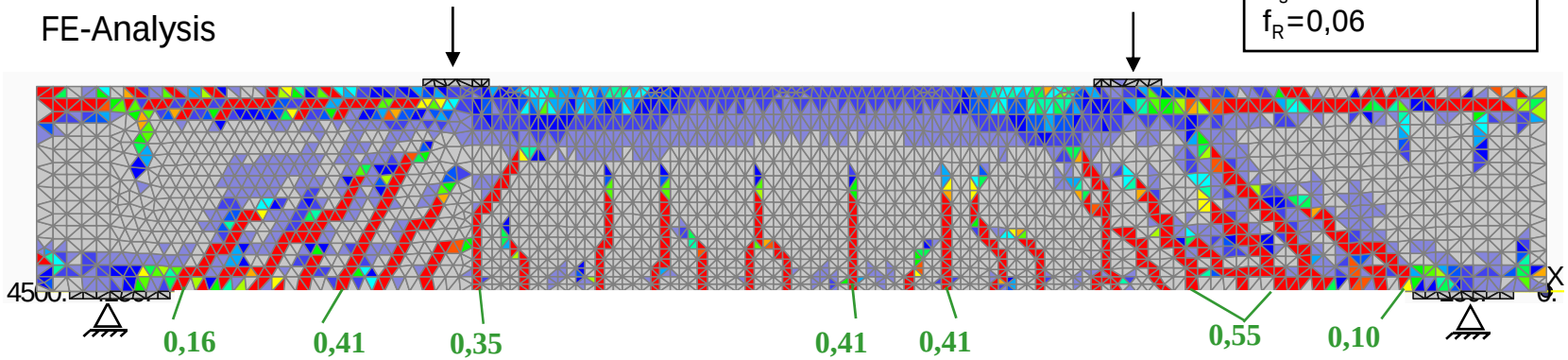
bar geometry (diameter & rib form and height)
stress-strain state of reinforcement bar
stress-strain state of concrete
and taken into account by Ω:

$$\tau = \Omega \, \tau_0$$

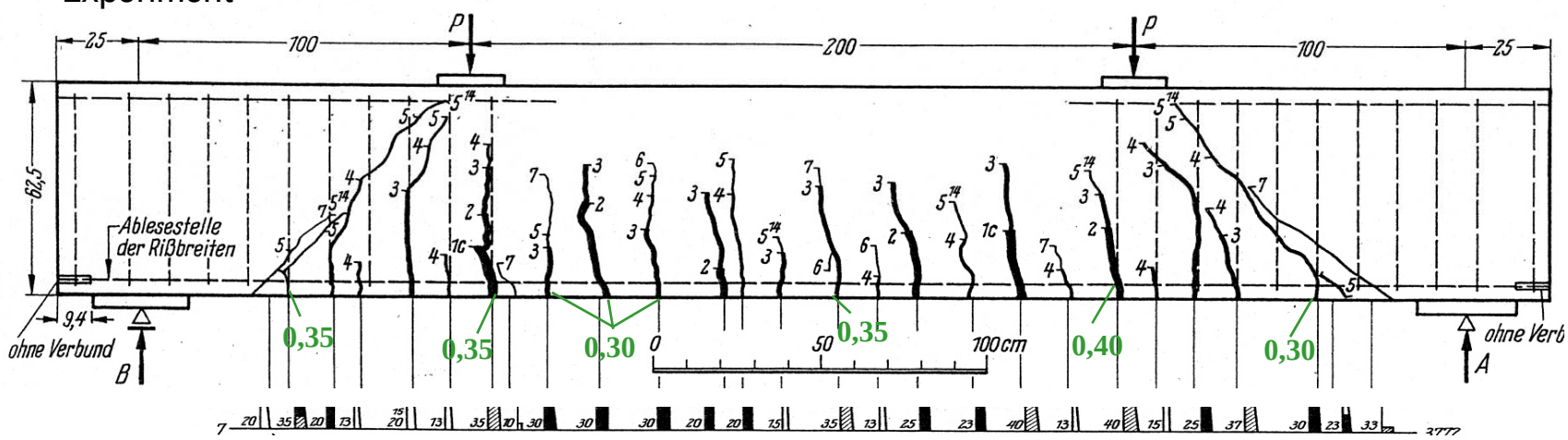
RC beam : Cracks, Analysis vs. Experiment (Rüsch & Rehm, 1963)

f_{cyl}=16,3 N/mm²
d_s=25 mm
f_R=0,06

FE-Analysis

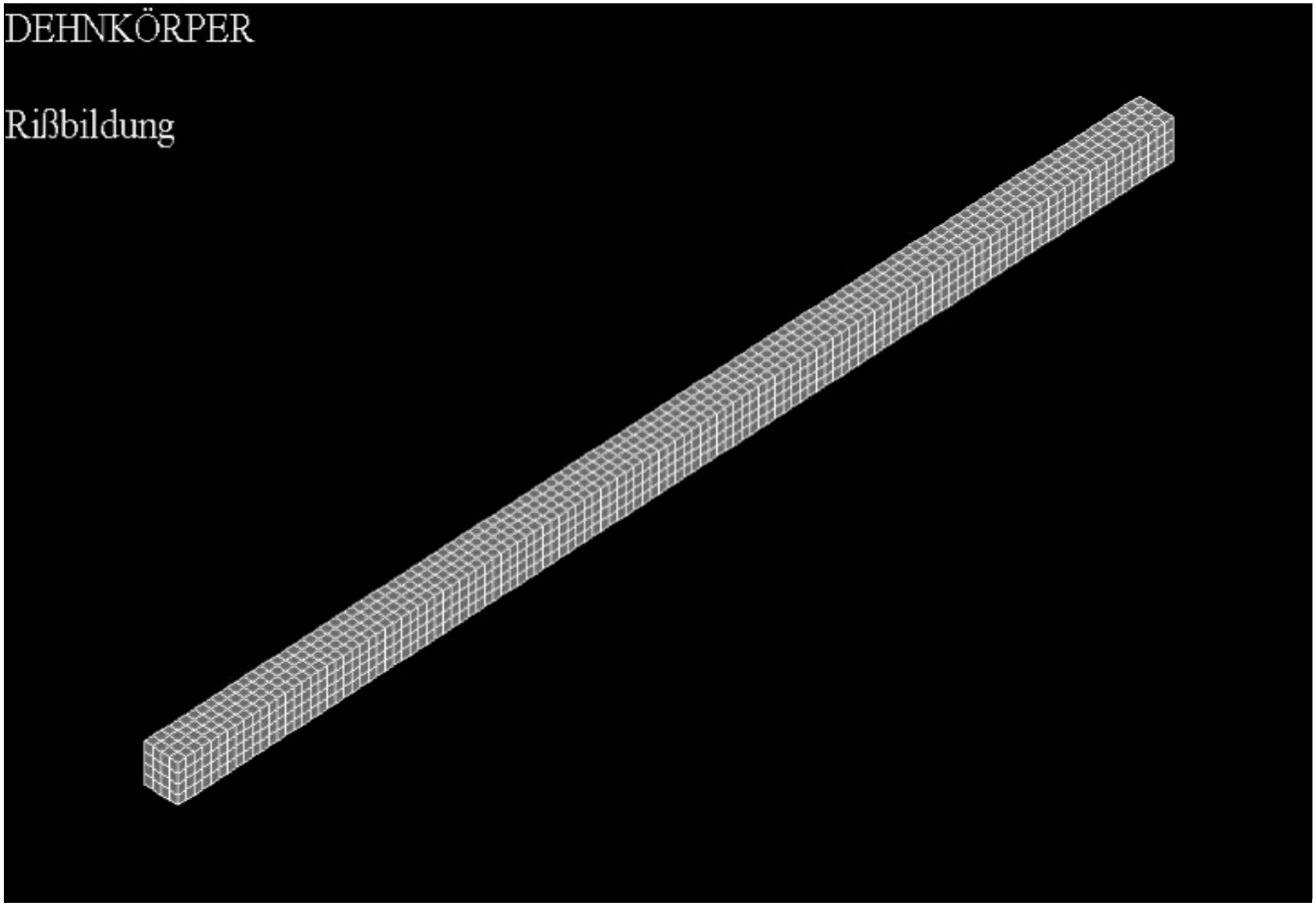


Experiment

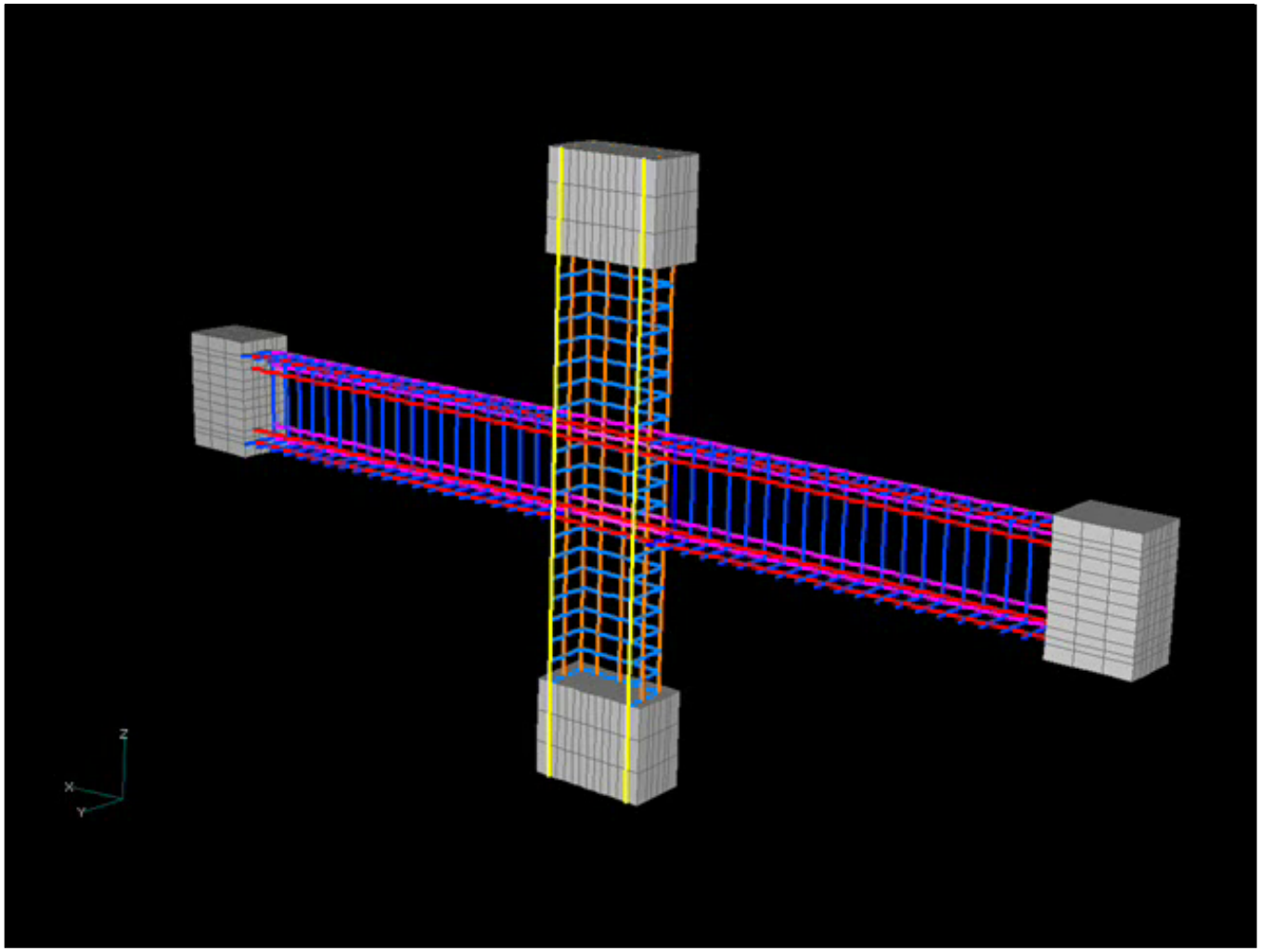


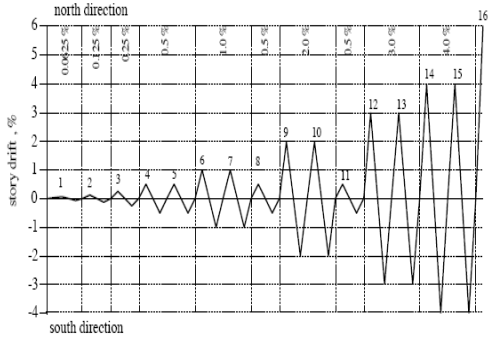
Crack width [mm]

RC beam in tension

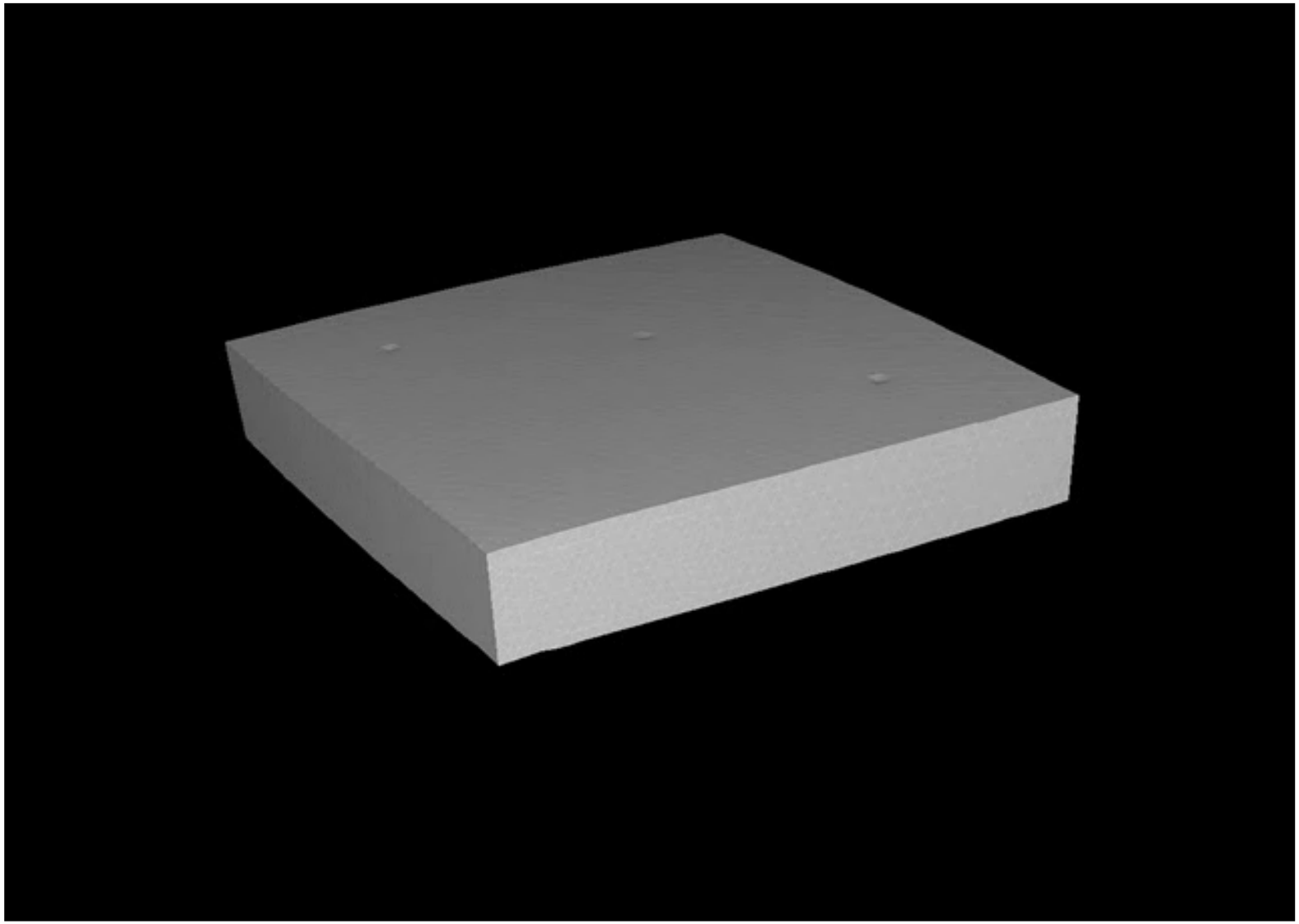


Beam-column connection (cyclic loading)



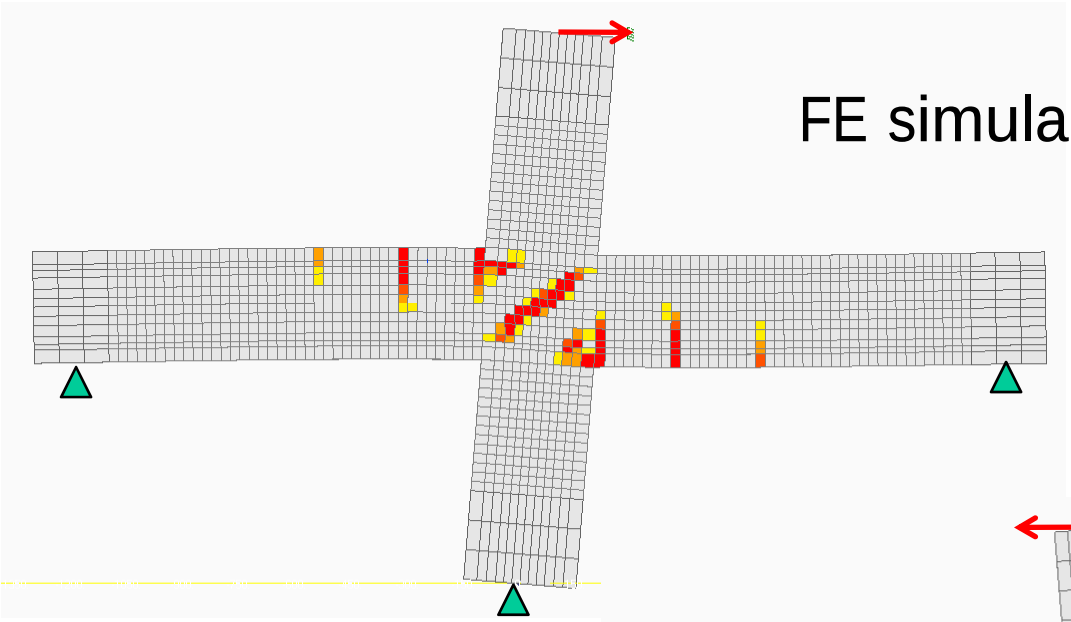


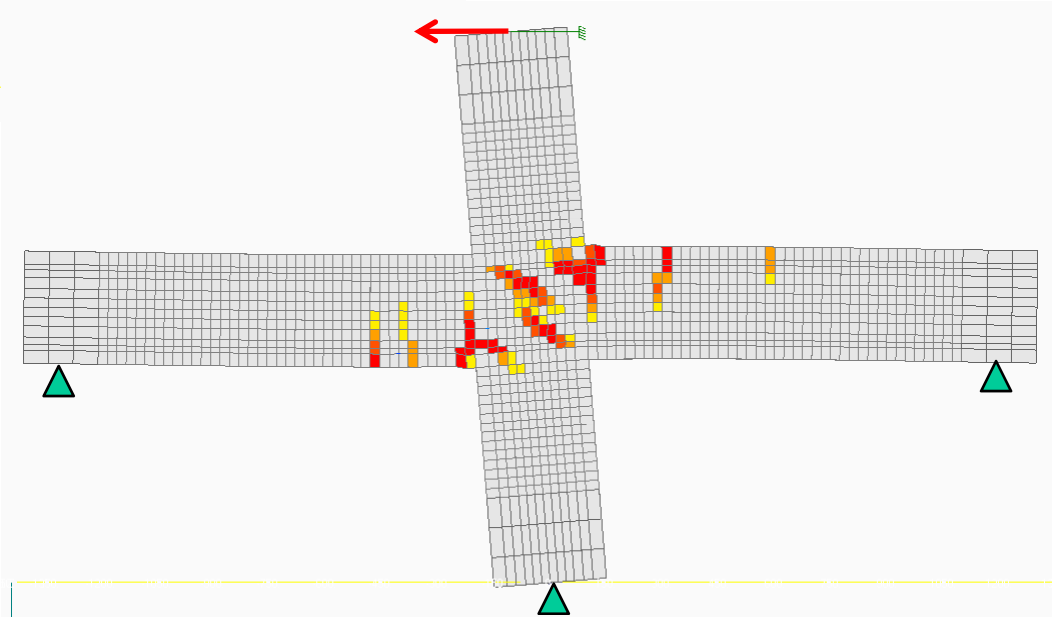
Punching of RC slab



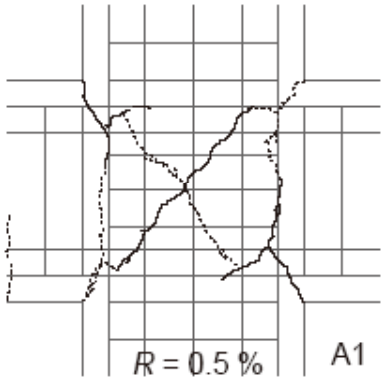
RC Beam-Column Joint before and after Retrofitting

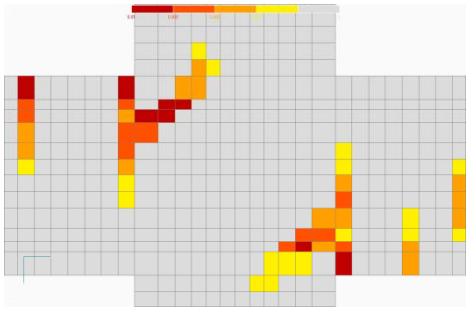
FE simulation – crack patterns



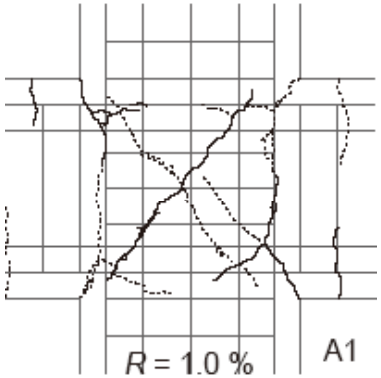


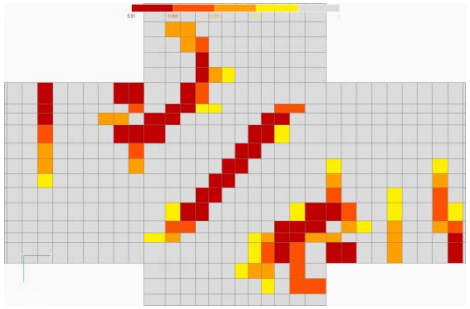
Crack patterns: analysis vs. experiment



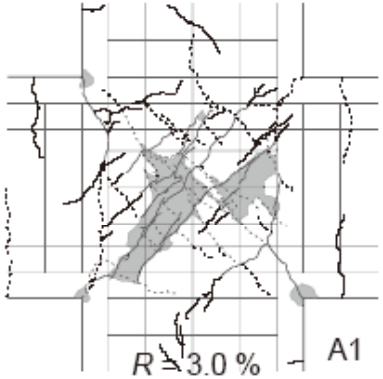


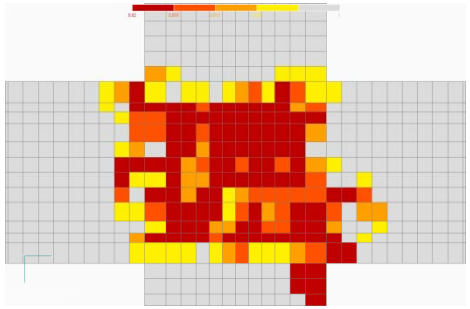
Drift 0.5 %	**Exp.**	Bending and shear cracks
	FE	Bending and minor shear cracks





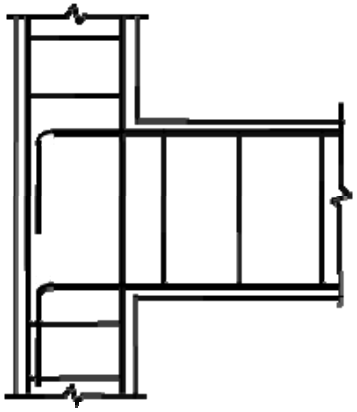
Drift 1.0 %	**Exp.**	Bending cracks in the beam and shear cracks in the joint
	FE	

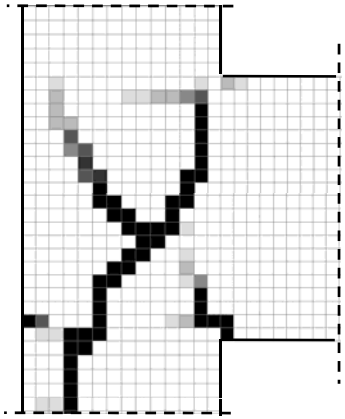


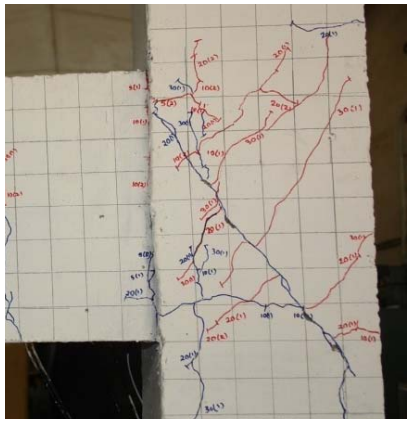


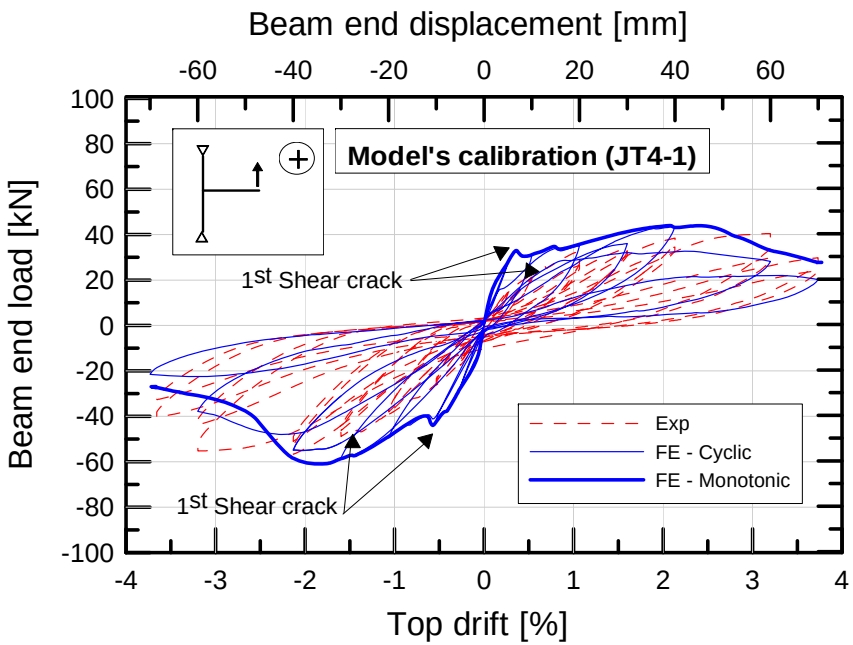
Drift 3.0 %	**Exp.**	Spalling of concrete cover in the joint panel, bending cracks do not grow anymore
	FE	

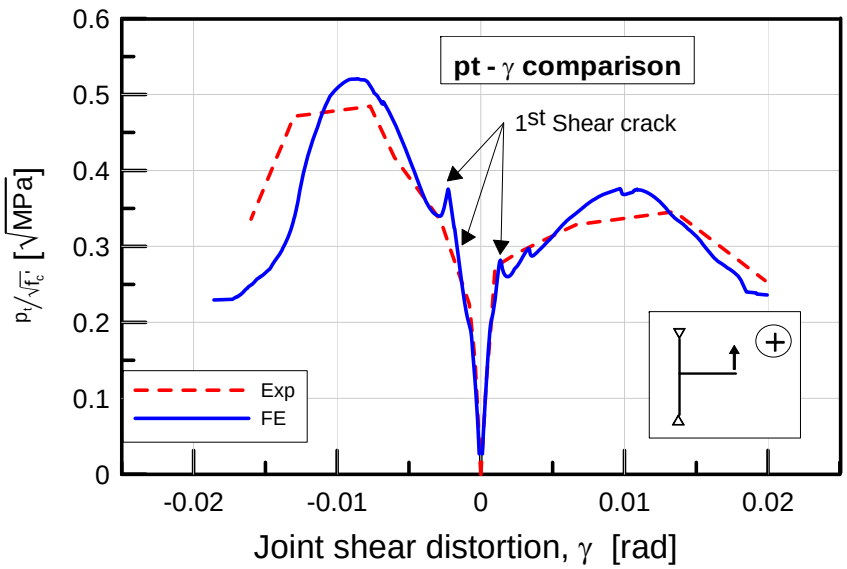
FE simulations of as built joints



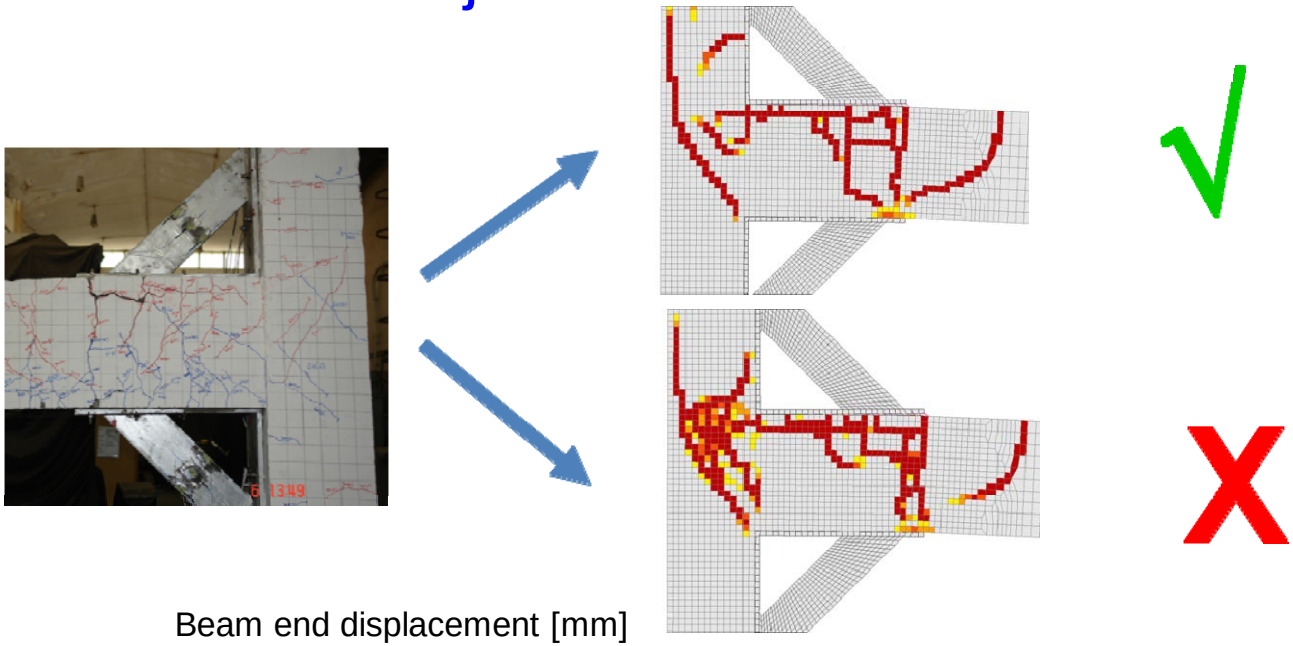


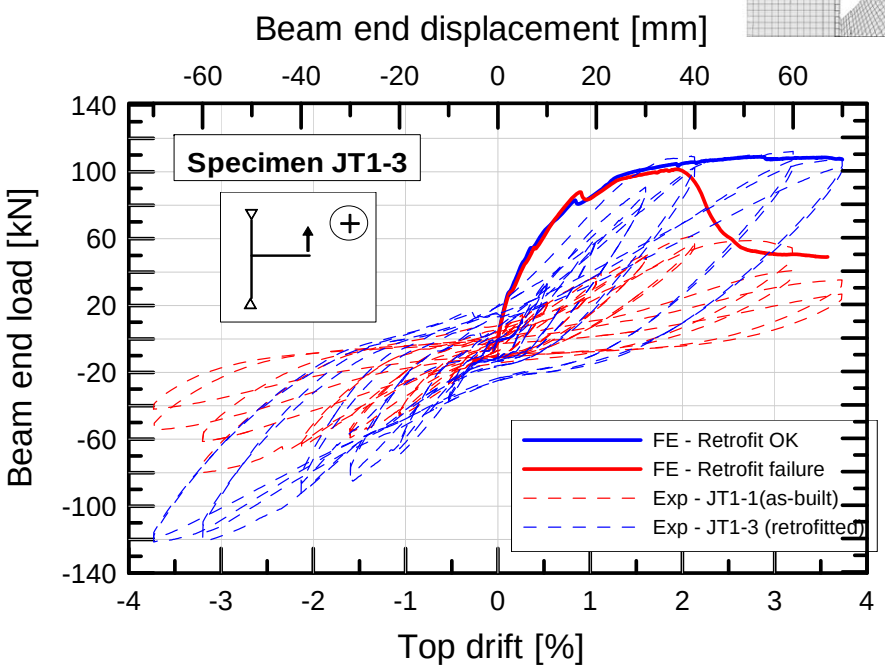




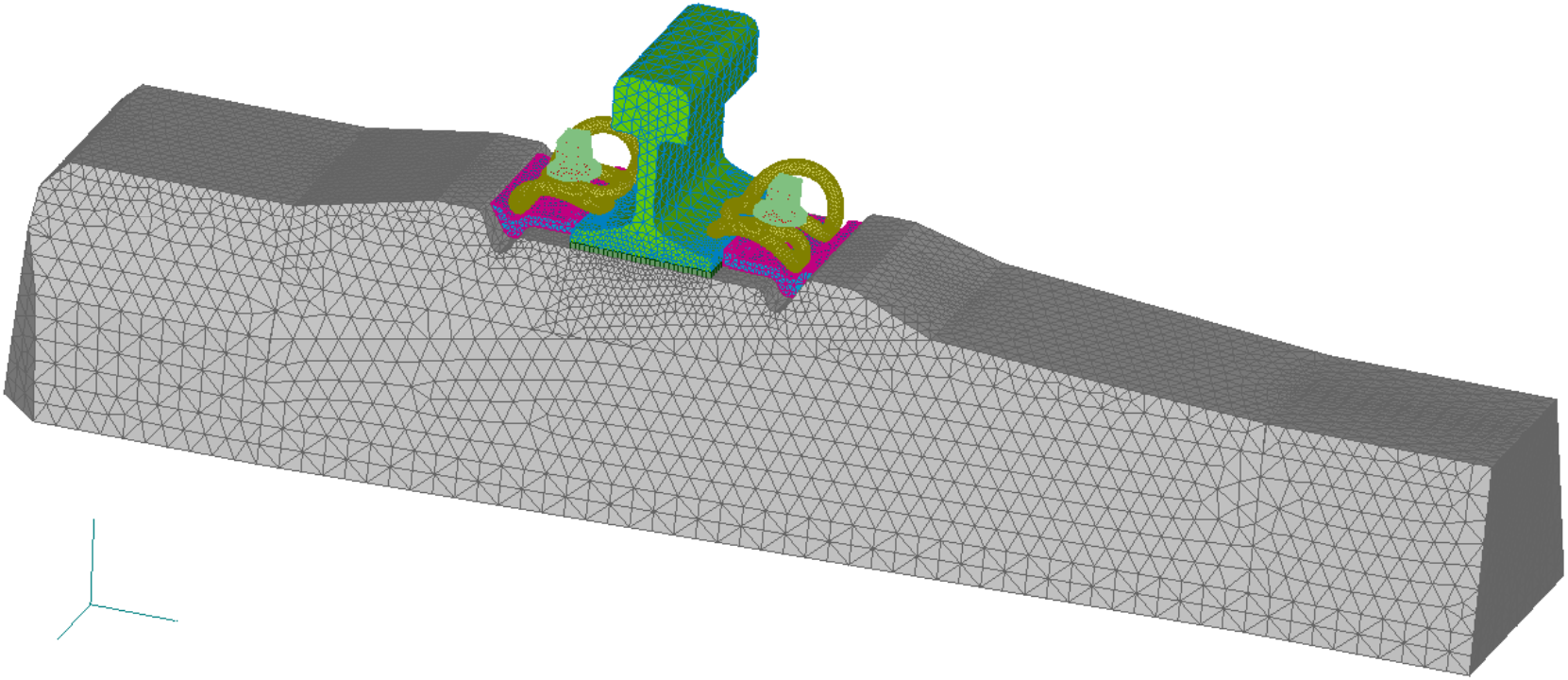


FE simulations of retrofitted joints



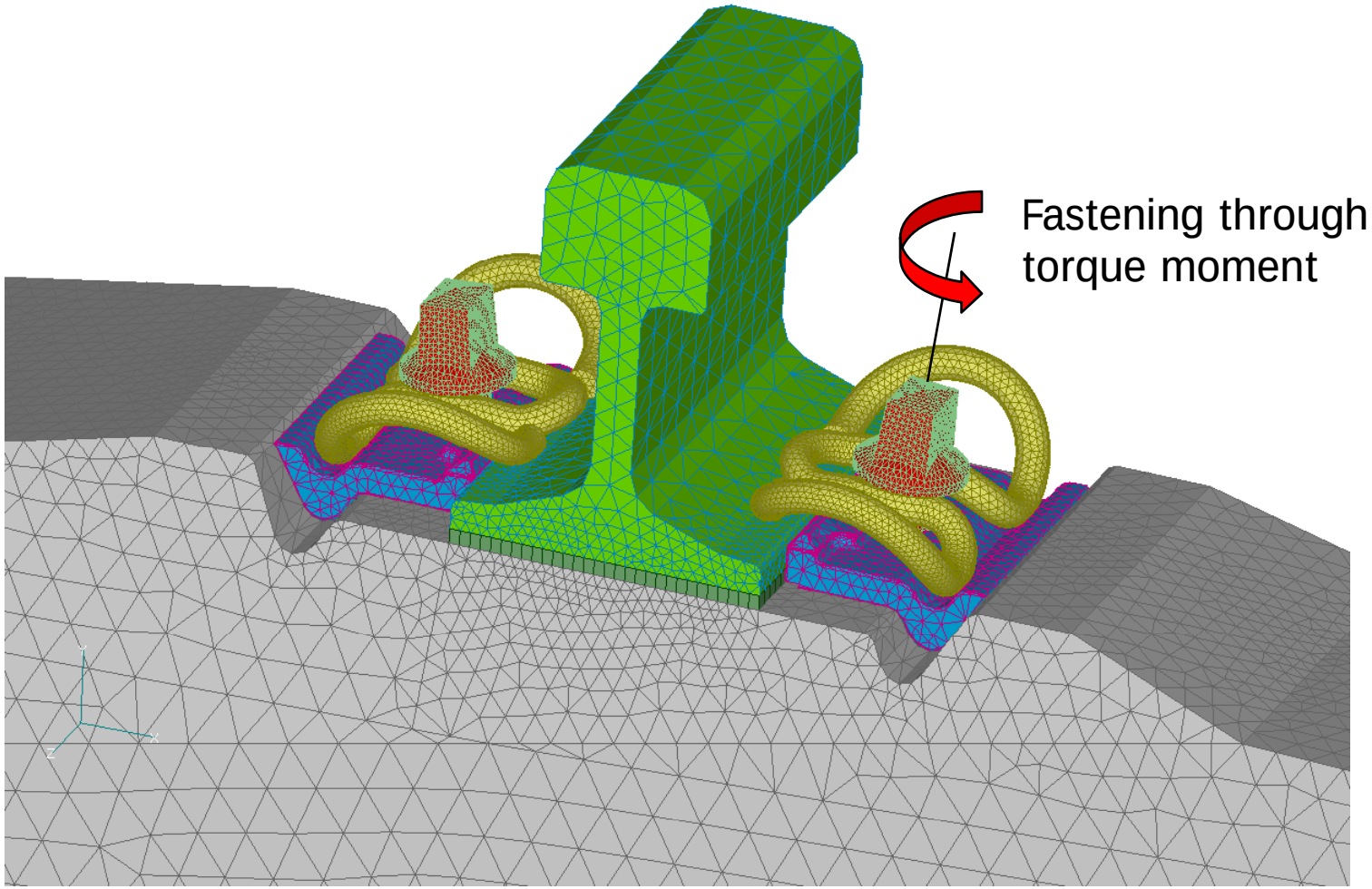


Analysis of prestressed concrete railroad tie

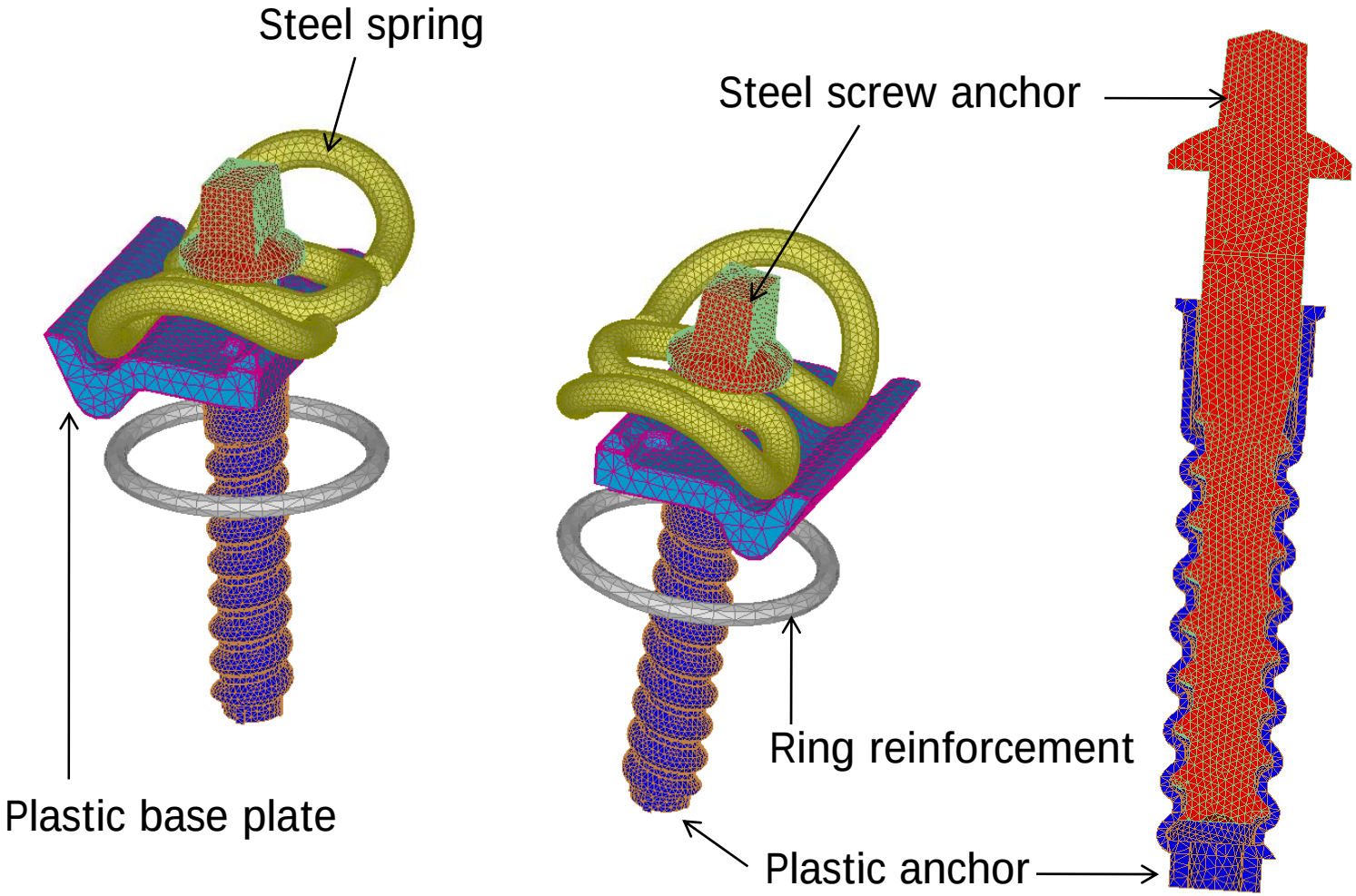


Prestressed concrete railroad tie

Detail: steel-concrete connection

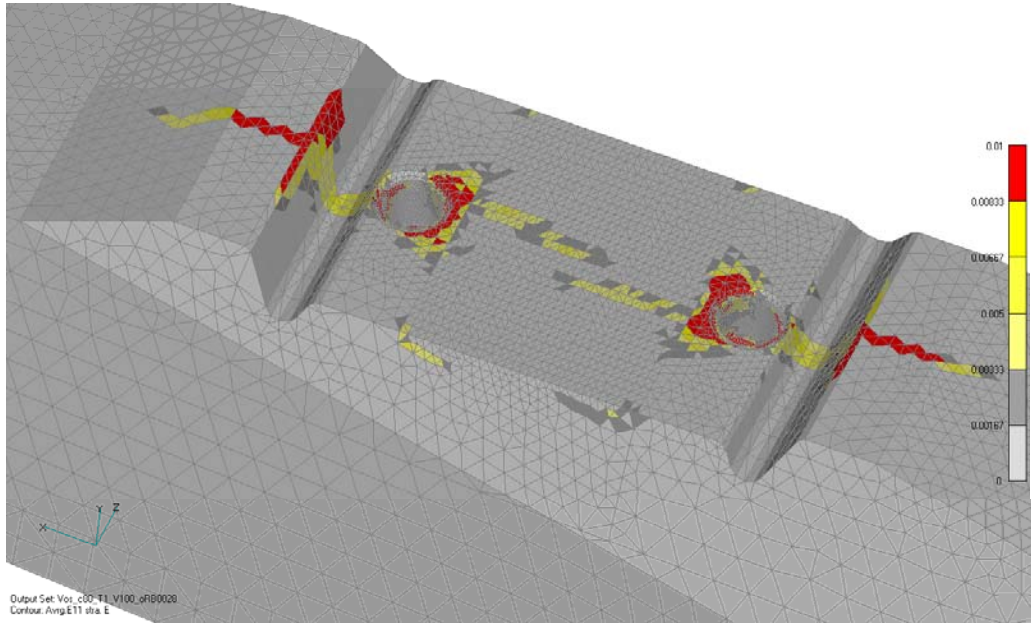


Analysis of prestressed concrete railroad tie



Prestressed concrete railroad tie

Detail: spliting cracks



At peak load

Post-peak