SPE #3
Analysis Meeting #3

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Contents

1. GRS containment models

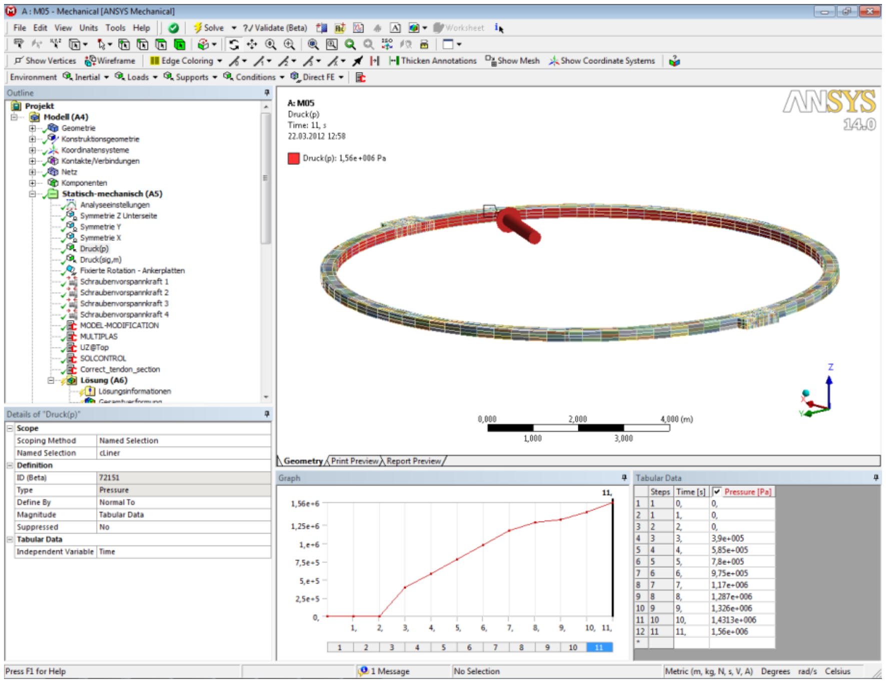
- Started with model 1 in collaboration with Dynardo
- Several modeling approaches for reinforcement
- Modeling and simulation in ANSYS Workbench
- The connection of the ducts to the surrounding concrete in model 3 required use of ANSYS Classic
- Beam-to-beam contact to model tendon within ducts
- Up to now:

  Convergence problems! ☹

1. GRS containment models

Model 1

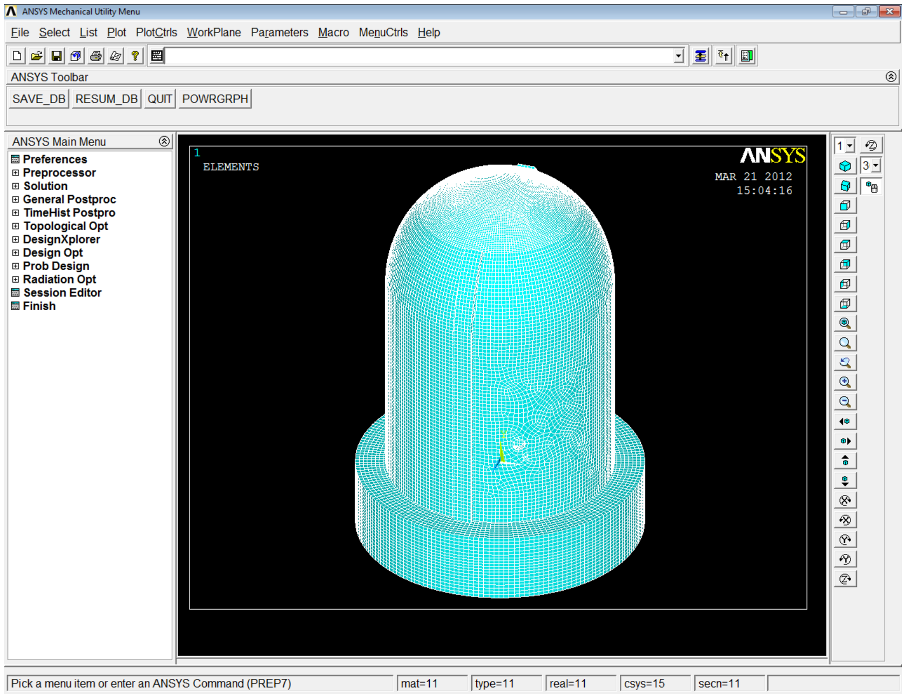
ANSYS Workbench/Mechanical



- Favors graphical input
- Frontend to ANSYS Classic kernel

Model 3

ANSYS Classic



- Favors script input
- more powerful

2. Concrete material model

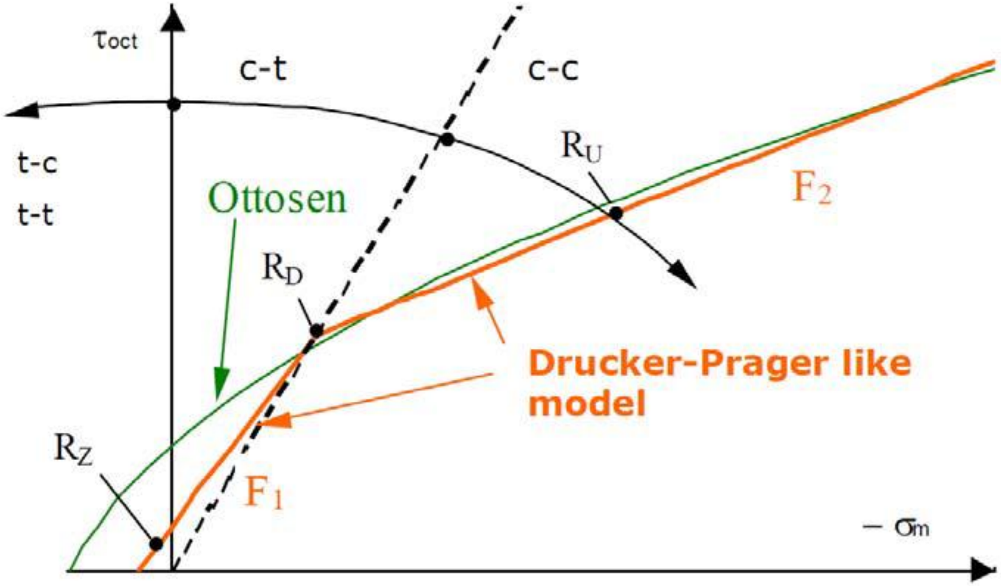
Using multiPlas material library (developed by Dynardo)

- Modified, multi-surface Drucker-Prager yield criterion. Fully defined by

  R_Z: uniaxial tensile strength

  R_D: uniaxial compression strength

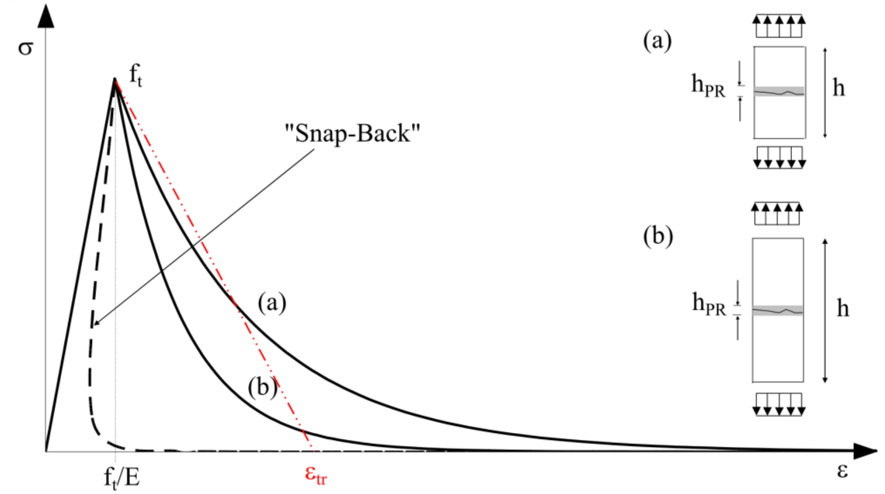
  R_U: biaxial compression strength
- Cracking and crushing described by stress and deformation state
- Follows DIN 1045-1 (now DIN EN 1992-1-1 / Eurocode 2) and DIN EN 1992-1-2



2. Concrete material model

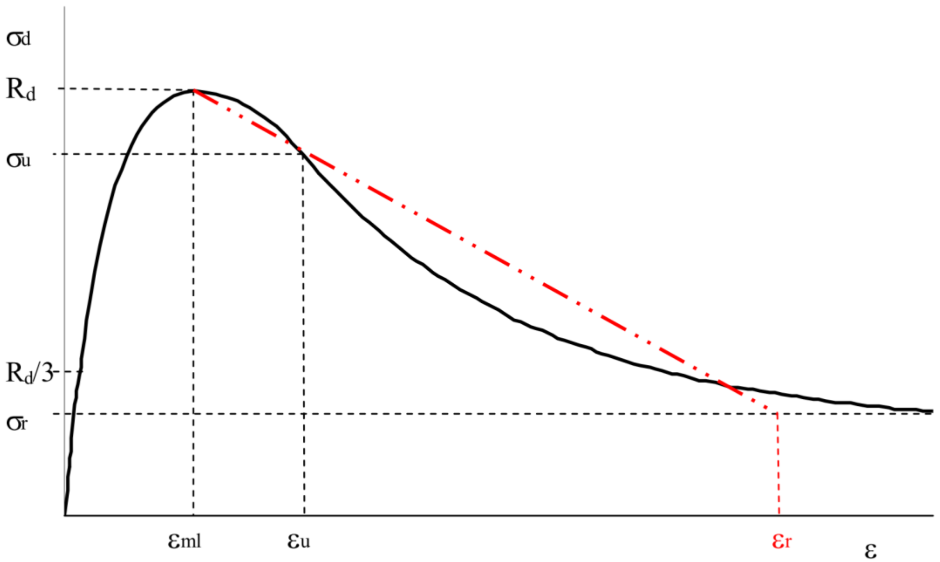
Tension

- Linear up to f_t
- Linear and exponential softening
- According to DIN 1045-1
- “Snap-Back” avoided through automatic calculation of crack band width h_{PR}



Compression

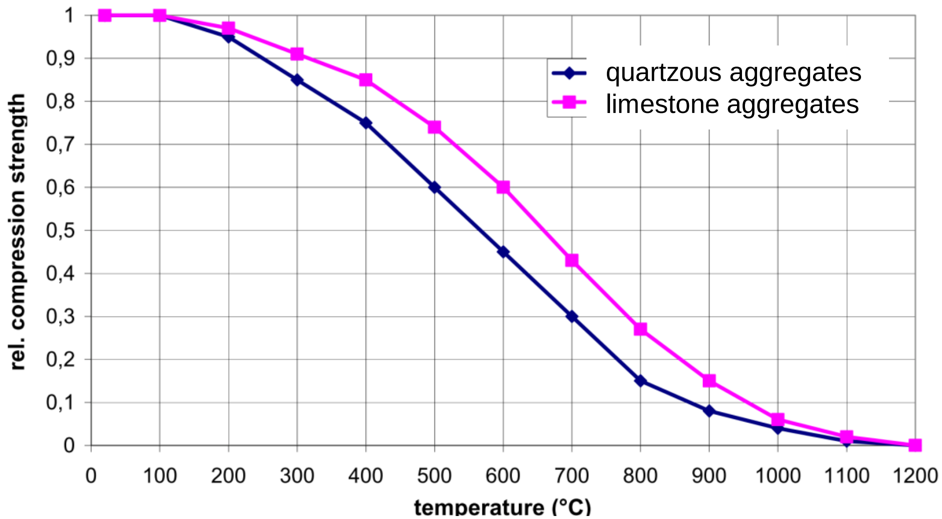
- Linear up to $R_d/3$
- Linear or parabolic-exponential softening
- According to DIN 1045-1

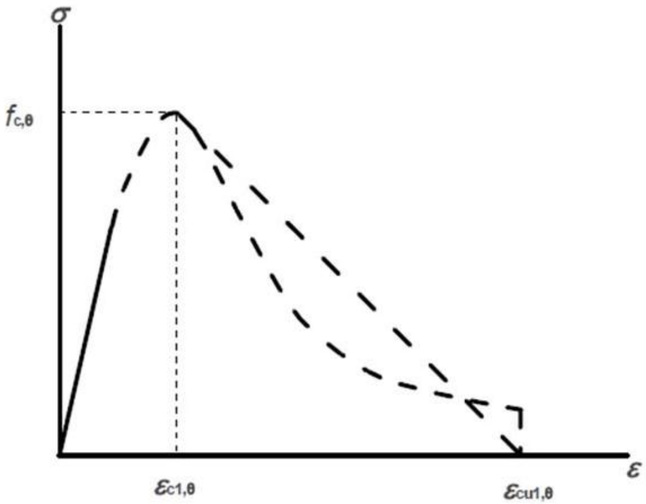


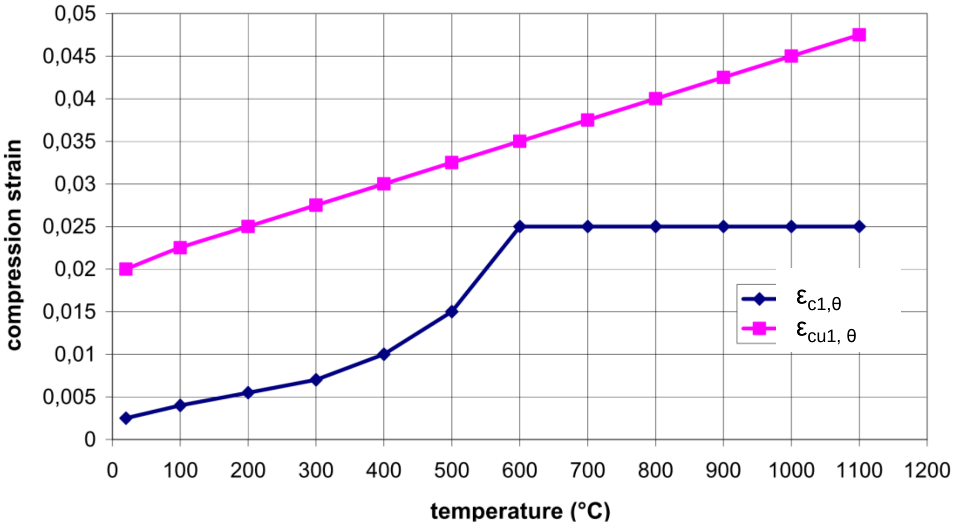
2. Concrete material model

Temperature dependency

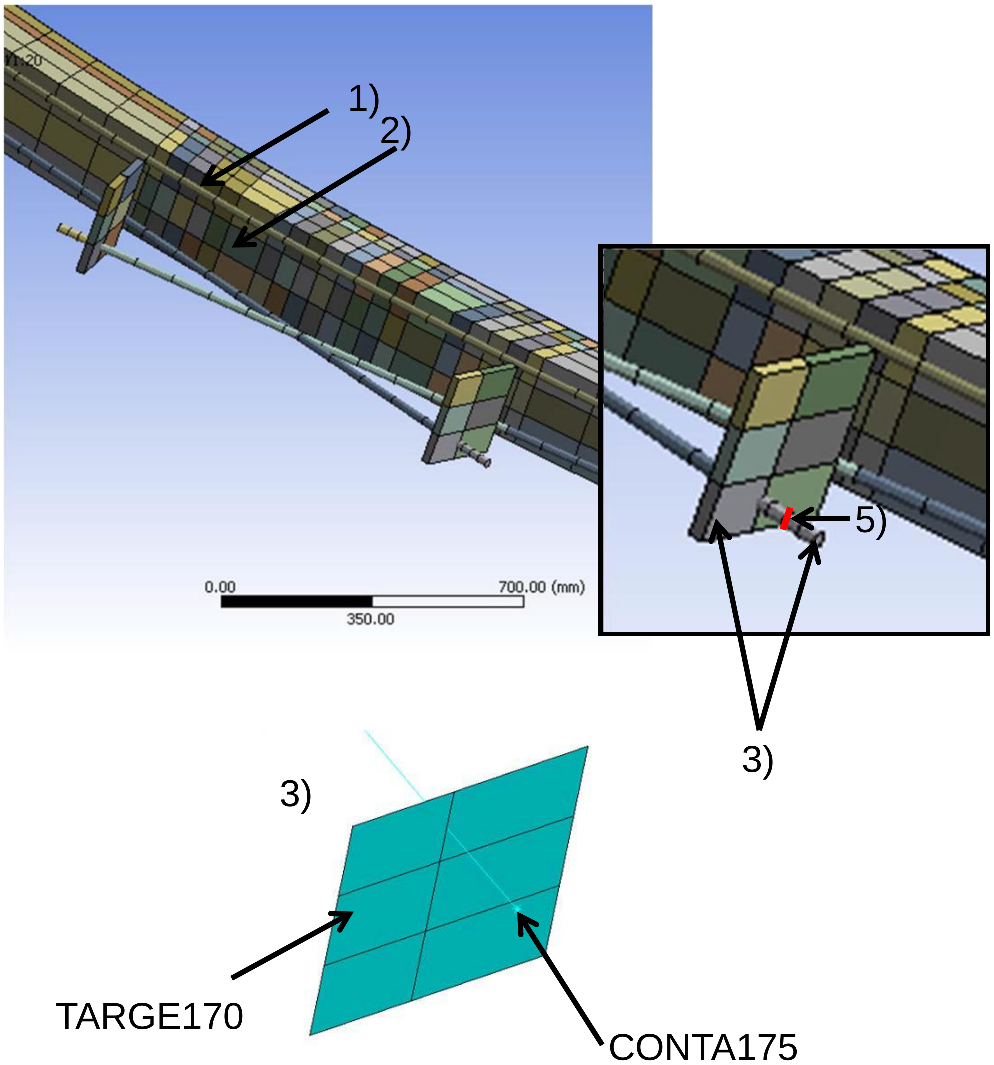
- Following DIN EN 1992-1-2
- Linear interpolation between sampling points







3. Model 1 - Tendons



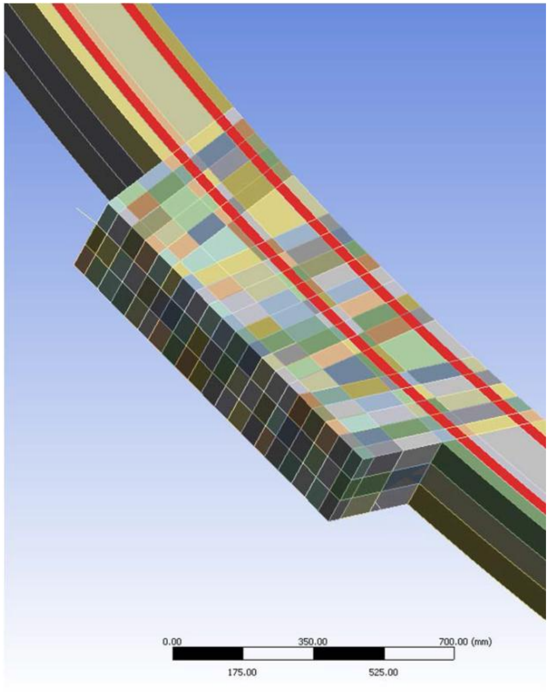
1) Tendon BEAM188
2) Frictional contact between BEAM188 and concrete solid elements (node-to-surface contact, i.e. CONTA175 + TARGE170)
3) Coupling of anchor plate to end node of tendon through MPC184 (multipoint constraint) contact
4) Merge anchor plate with surface of concrete solid elements
5) Insert pretension element PRETS179 for tensioning and anchoring (coupling of two coincident nodes)

3. Model 1 - Reinforcement

Modeling approaches

Joint element reinforcement

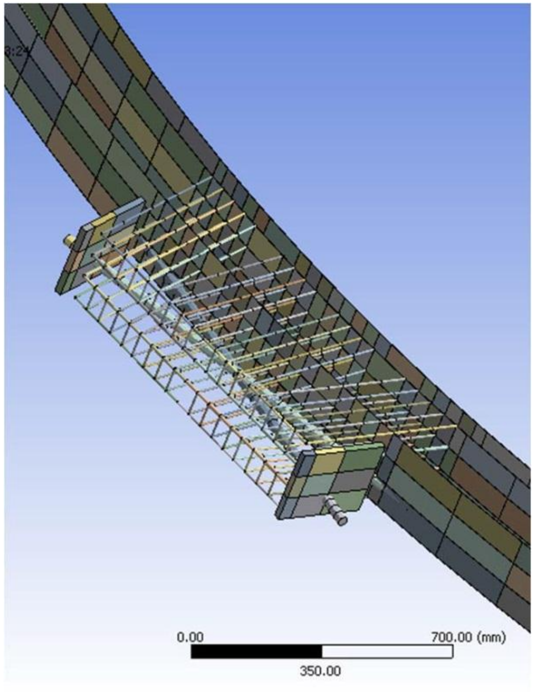
M01



Shell reinforcement

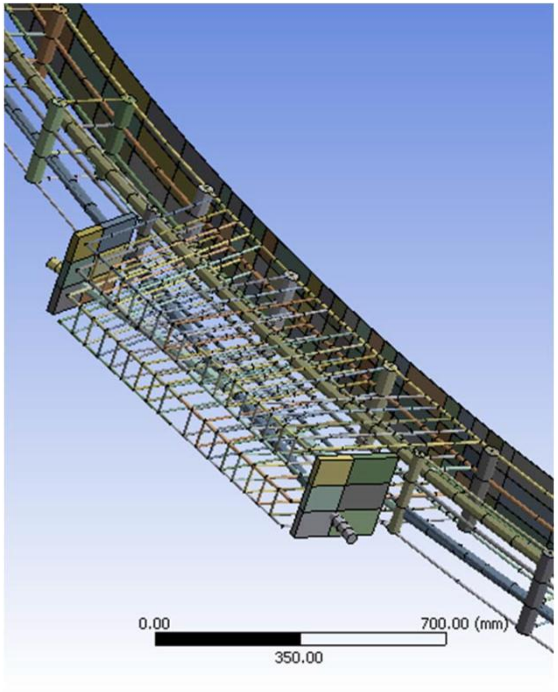
M02: alternating thickness

M04, M05: membrane



Beam reinforcement

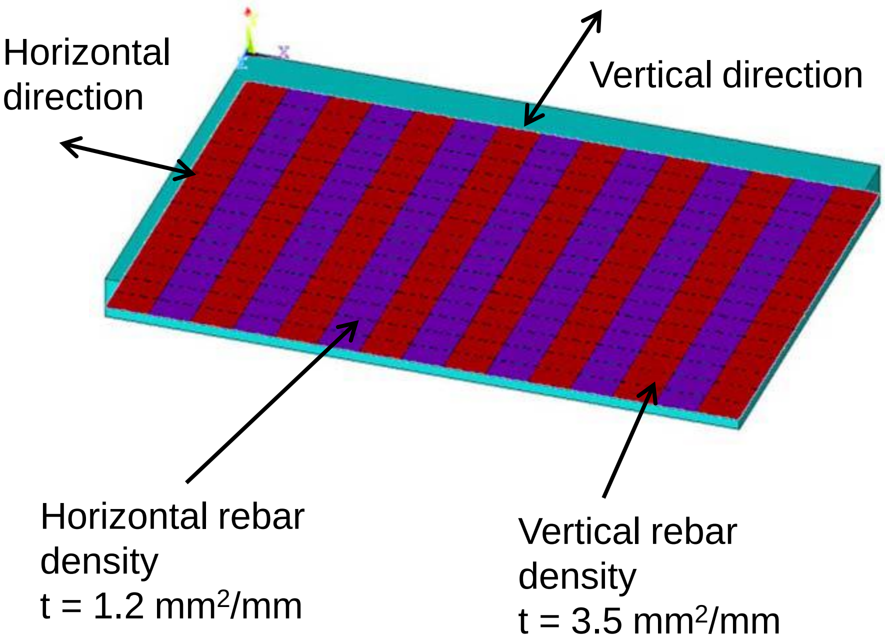
M03



3. Model 1 - Reinforcement

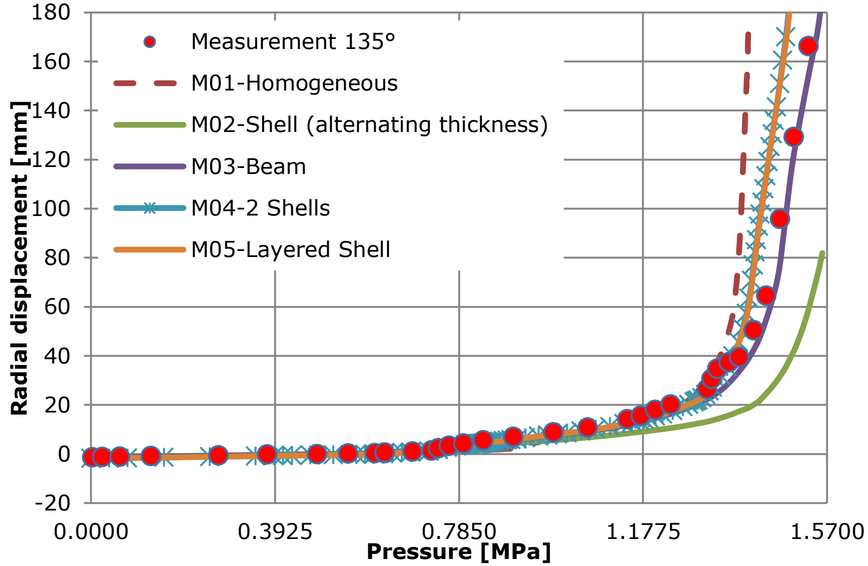
M02:

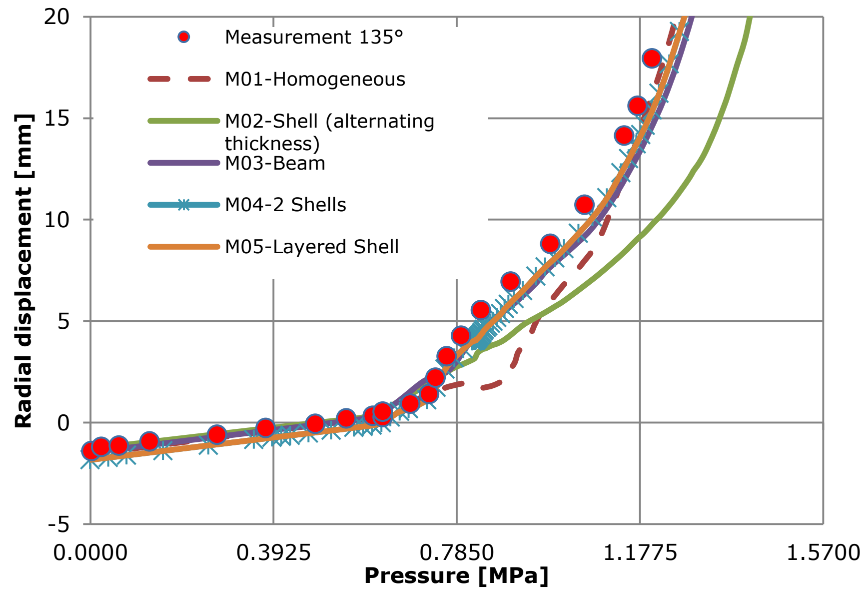
- Grid of reinforcement bars represented by serial and parallel connection of shell elements
- Works best if horizontal and vertical rebar density differs
- In direction of dominant rebar density: shells in parallel
- In direction of lower rebar density: shells in series
- Width of “stripes” determined by rebar spacing



3. Model 1 - Results

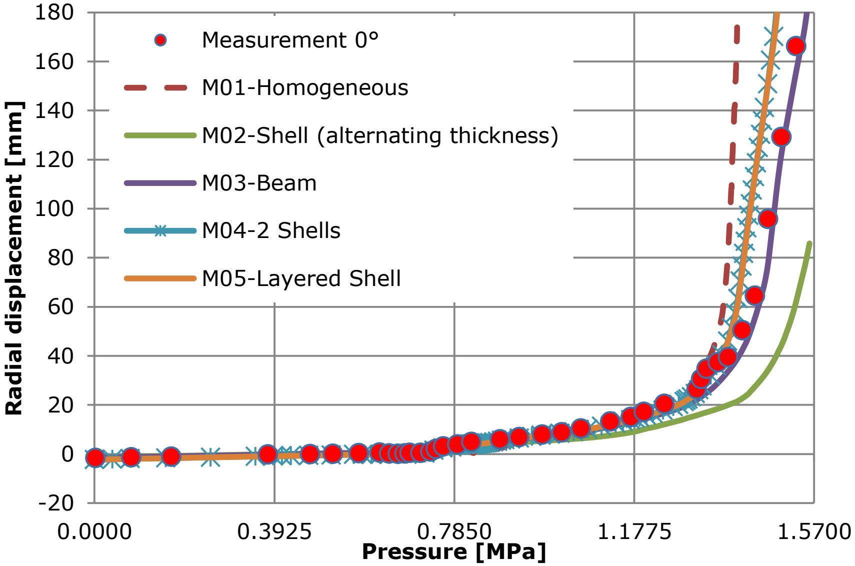
Comparison of radial displacement at elevation 6.2 m, azimuth 135°

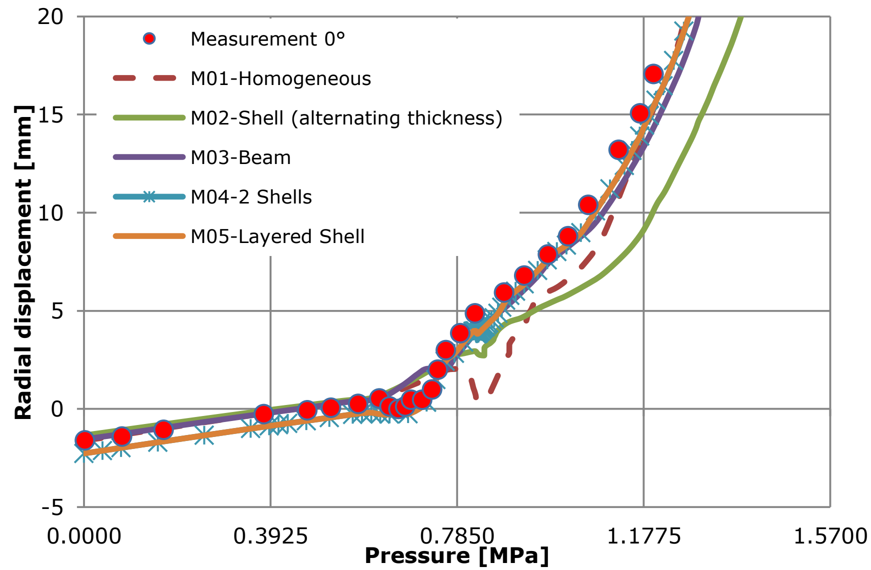




3. Model 1 - Results

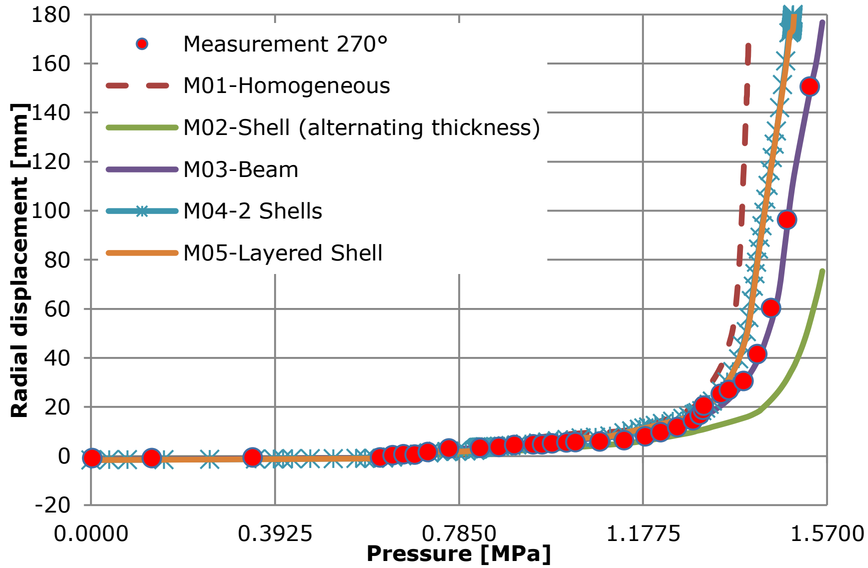
Comparison of radial displacement at elevation 6.2 m, azimuth 0°

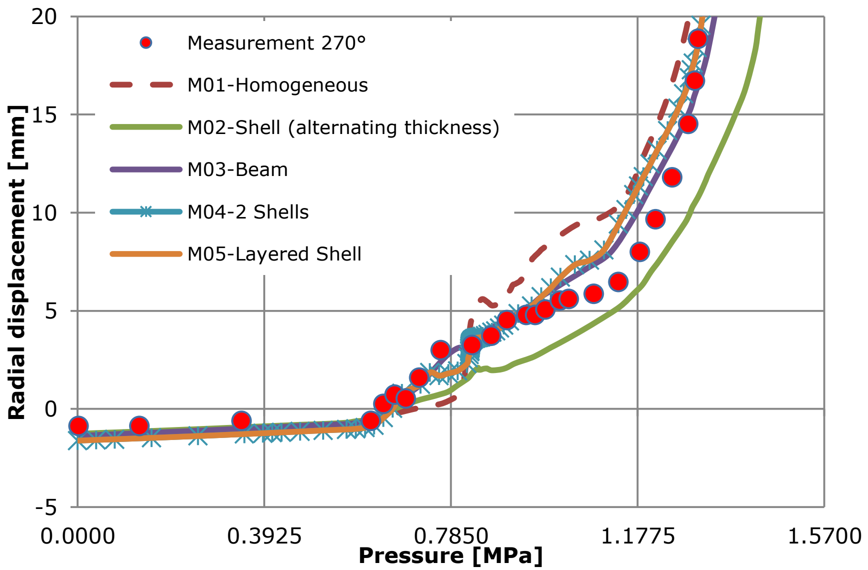




3. Model 1 - Results

Comparison of radial displacement at elevation 6.2 m, azimuth 270°



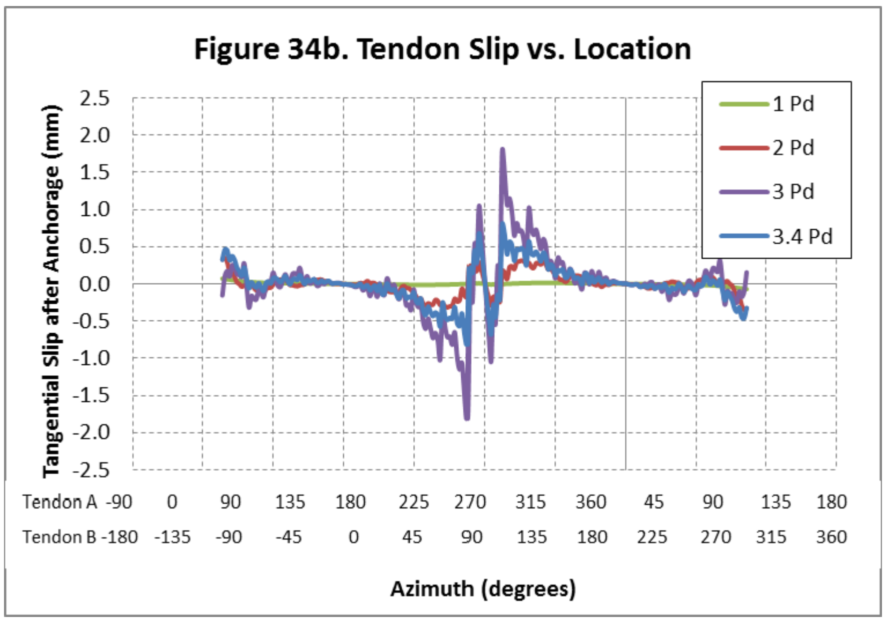


3. Model 1 - Results

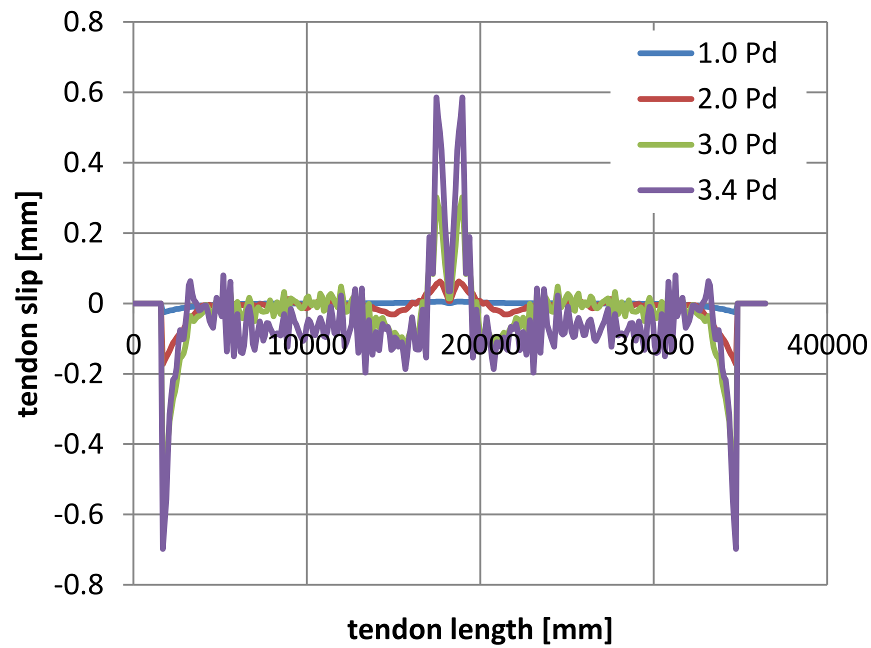
Relative tendon slip

Moffatt & Nichol

PCCV SPE3 Model 1 Results - TECH MEMO

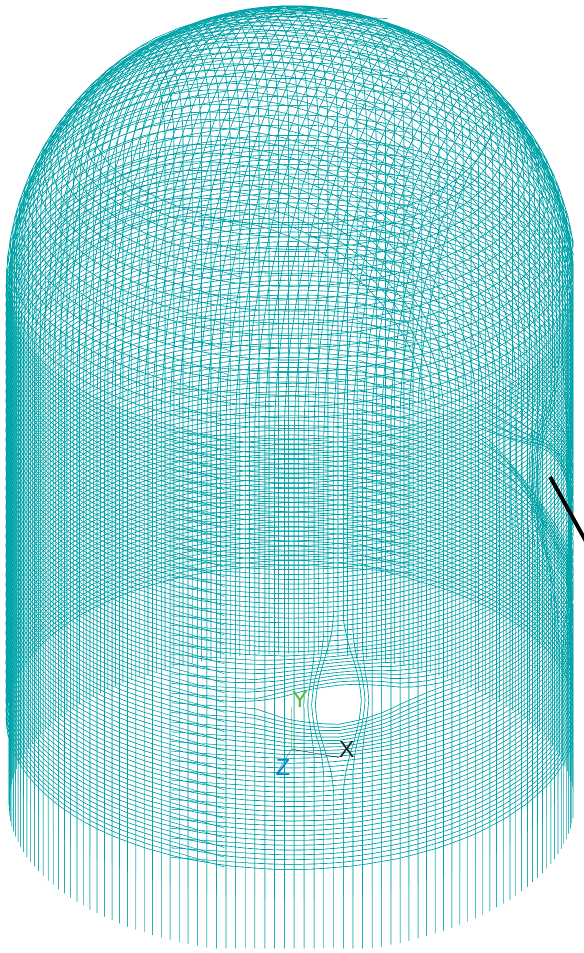


M05-Layered shell



Symmetry of tendon slip?

4. Model 3 - Tendons

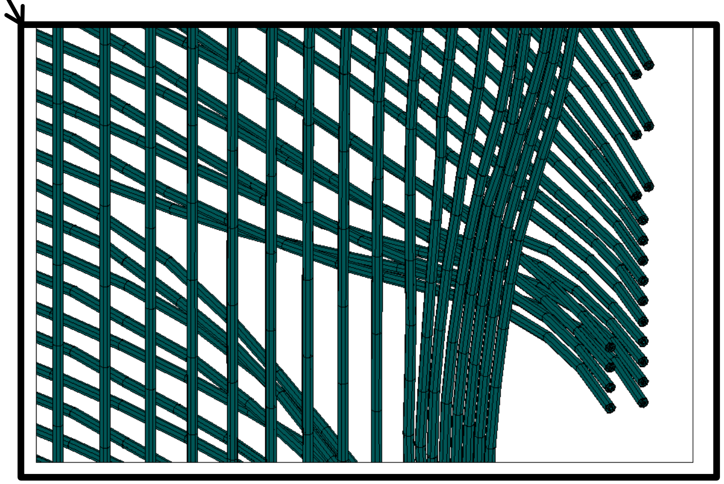


All 198 vertical and hoop tendons modeled individually.

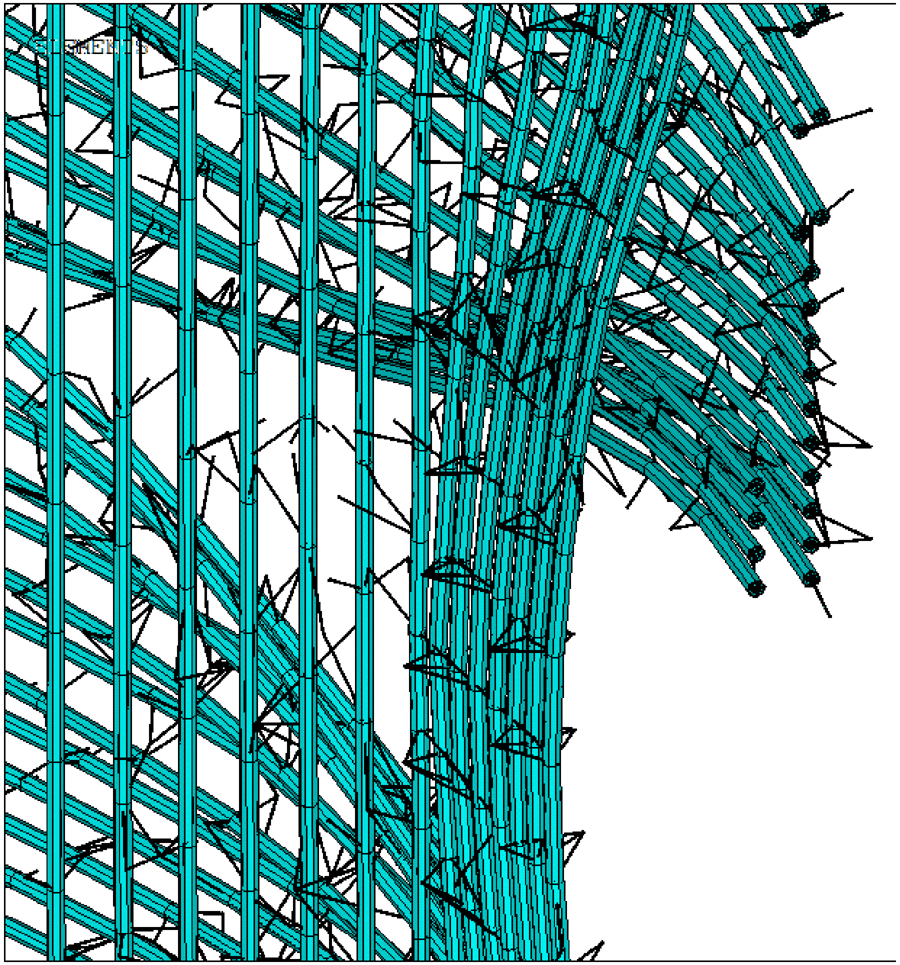
Challenge: Connect tendon ducts to surrounding concrete

Coincident nodes of duct and concrete solid elements do not work due to geometric complexity!

→ Need connection elements or constraints.



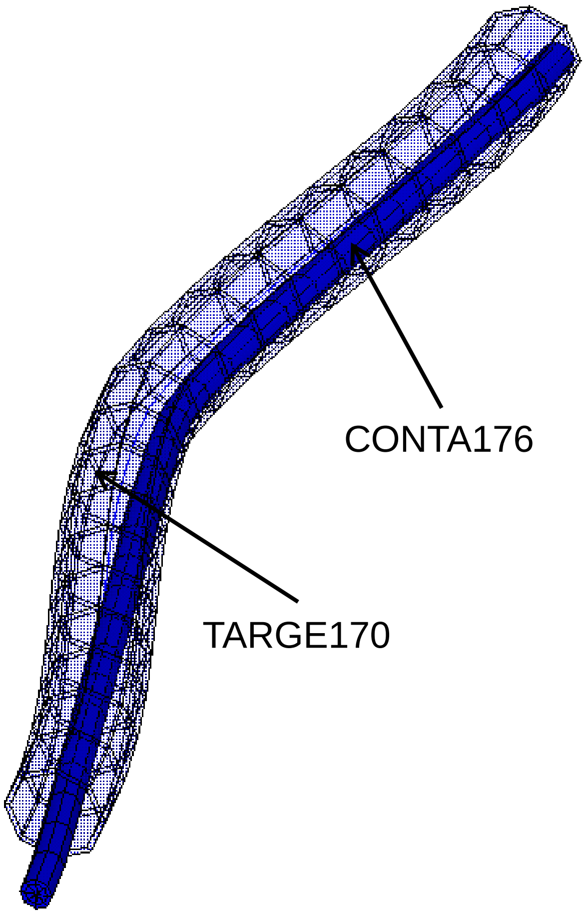
4. Model 3 - Tendons



Duct-Concrete Connection

- Loop over all nodes of duct elements
- Generate 3 beam elements from a duct node to the 3 nearest concrete nodes

4. Model 3 - Convergence problems



Tendon modeled with BEAM188

Contact of tendon and duct modeled by beam-to-beam contact (CONTA176 + TARGE170)

Very slow convergence, or no convergence at all!

Work still ongoing!

5. Leakage in concrete structures

- Validation of correlations
  - Rizkalla, Sami H., et al., Air leakage characteristics in reinforced concrete, Journal of Structural Engineering, Vol. 110(5), pp. 1149-1162, 1984.
  - Greiner, U., Ramm, W., Air leakage characteristics in cracked concrete, Nuclear Engineering and Design, Vol. 156, pp. 167–172, 1995.
- Experiments performed at MPA Karlsruhe (KIT)
- CFD simulation of leakage

  Challenge: Phase change from gaseous to liquid due to heat removal

  → condensation

5. Leakage in concrete structures - CFD simulations

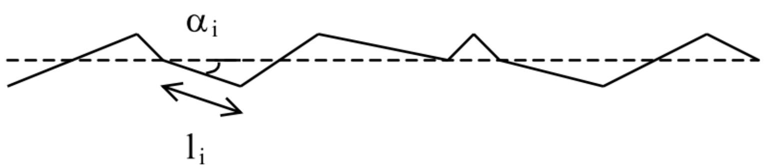
Based on work by:

H. Boussa et al., A model for computation of leakage through damaged concrete structures, Cement and Concrete Composites 2001, 23:279–87.

Experimental evaluation of crack profile

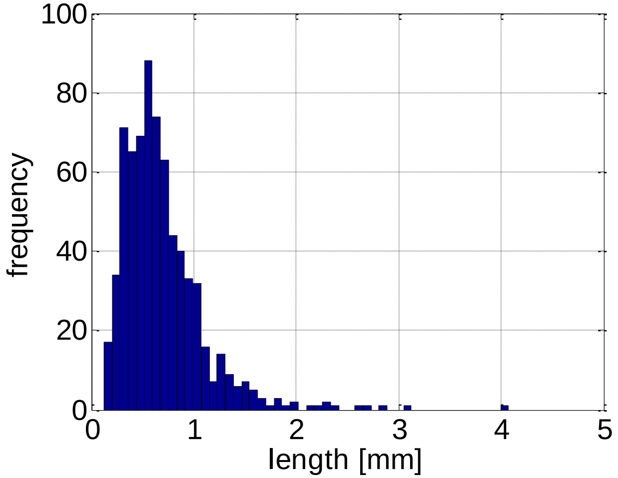
→ model of crack profile

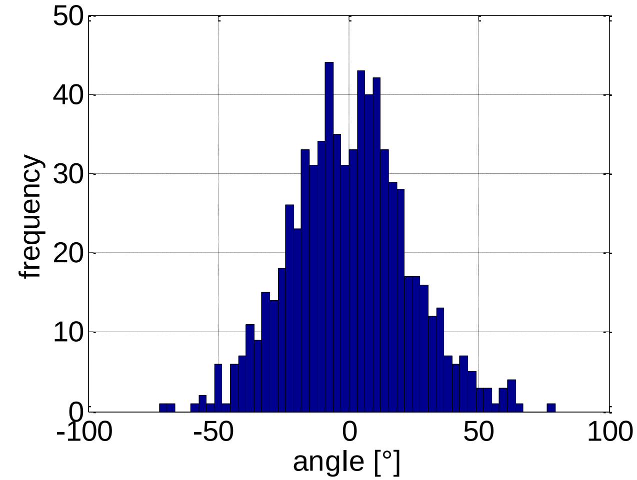
→ discretization



l_i: linear segment

α_i: orientation angle



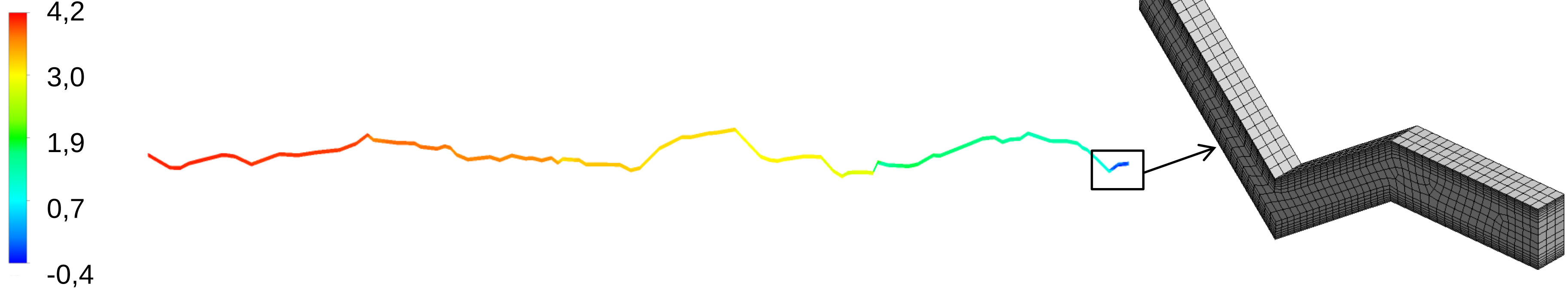


5. Leakage in concrete structures - CFD simulations

Single phase simulation with air
Crack width 0.2 mm, segment of a through wall crack (crack depth 50 mm)

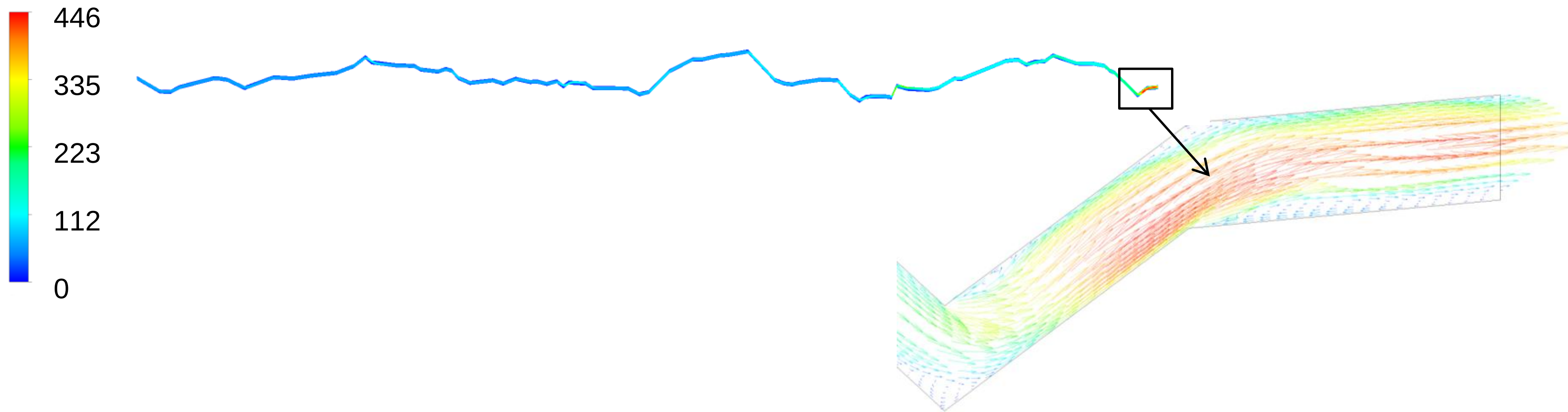
[bar]

- Pressure distribution in crack



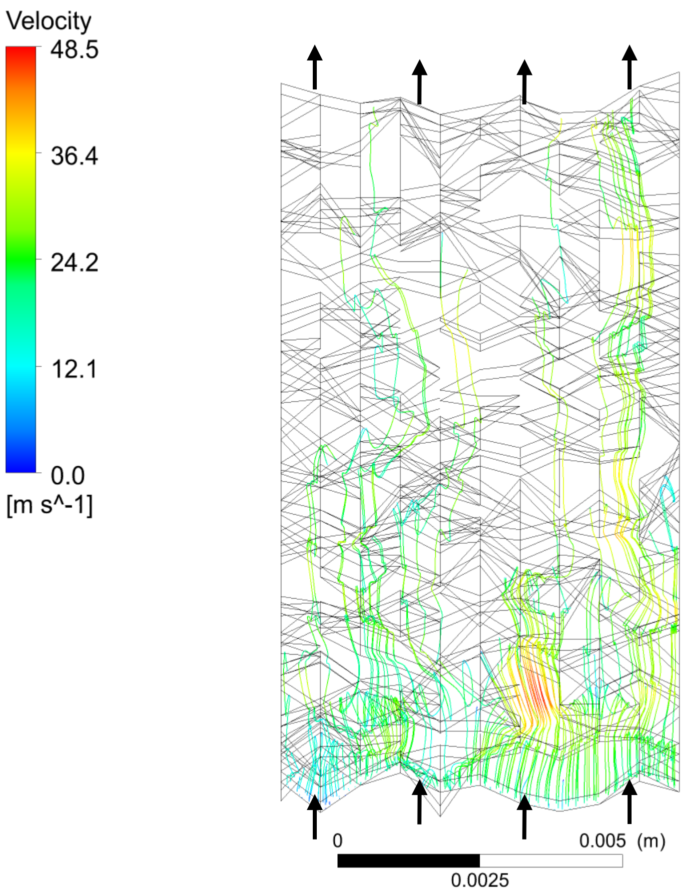
[m/s]

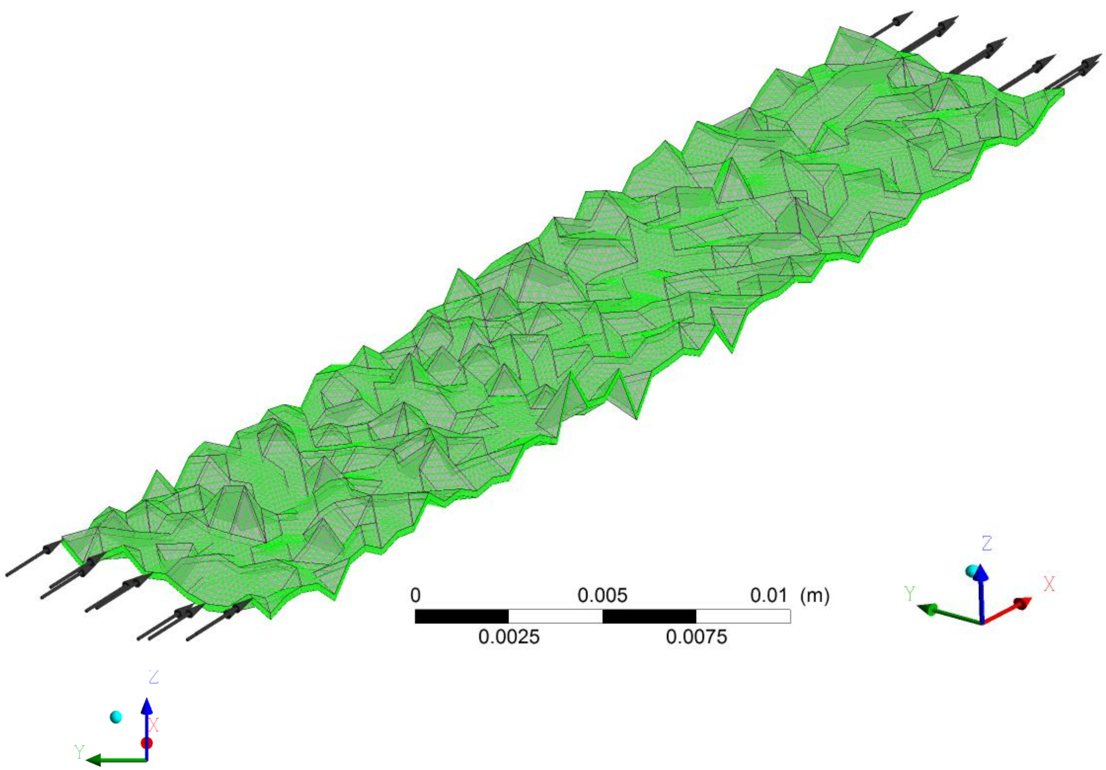
- Velocity distribution in crack



5. Leakage in concrete structures - CFD simulations

3D discretization: Fixed grid, move each grid point by sine of orientation angle





5. Leakage in concrete structures

Conclusions

- Correlations give estimates

  Relevant phenomena like steam condensation, reduction of leak area due to heating not considered
- CFD simulations not yet satisfactory
  - Typical concrete structures have disadvantageous proportions regarding CFD discretization
  - Treatment of wall roughness and resulting turbulence is open question

Backup

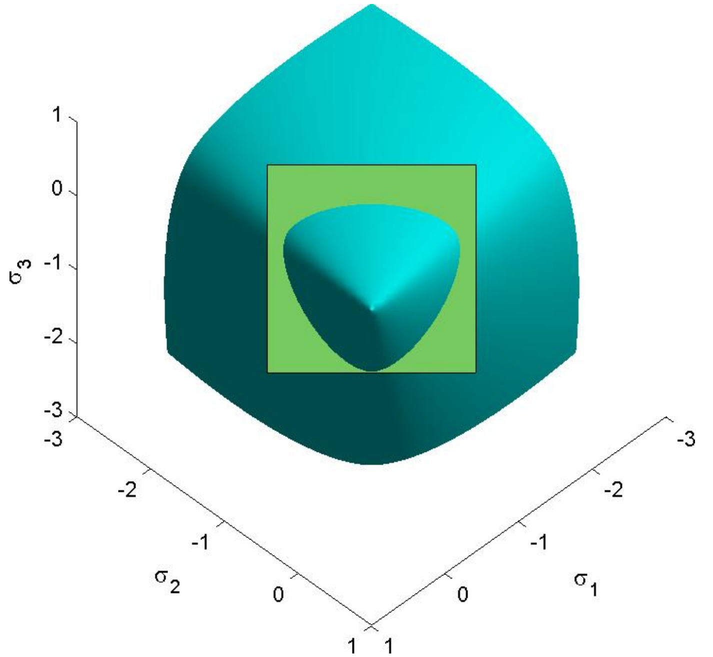
Concrete material model in ANSYS

No model directly accessible (through GUI) in ANSYS Workbench.

Build-in concrete model in ANSYS Classic: SOLID65

- 8-node 3D solid element
- Tensile cracking, crushing,

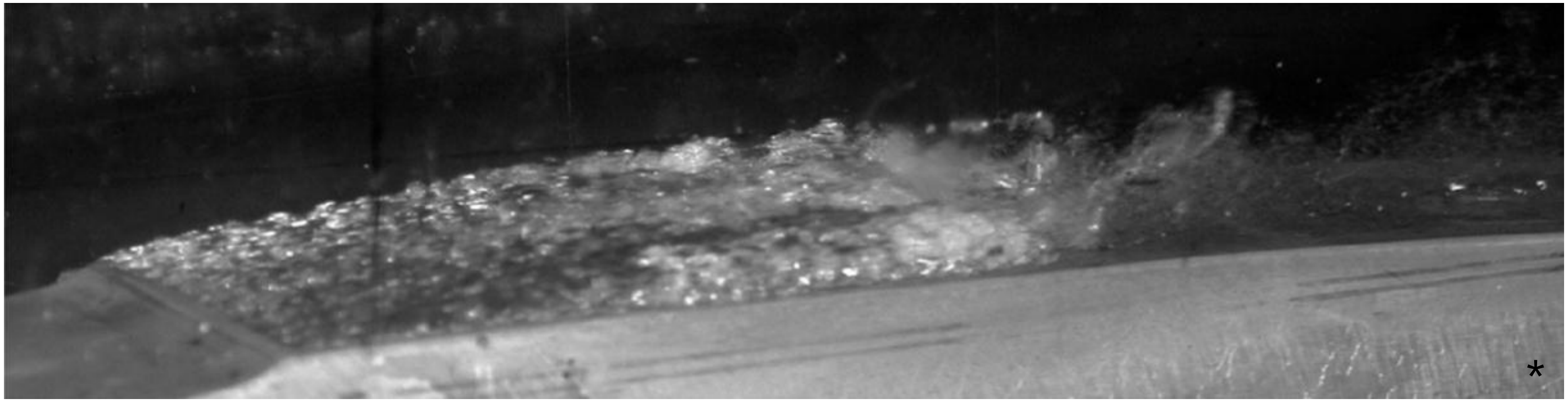
  plastic deformation, and creep
- Smeared reinforcement
- Willam-Warnke yield criterion
  K. J. Willam and E. D. Warnke. "Constitutive Model for the Triaxial Behavior of Concrete". Proceedings, International Association for Bridge and Structural Engineering. Vol. 19. ISMES. Bergamo, Italy. p. 174. 1975.



Leakage in primary circuit

Main challenge: Flashing

Rapid liquid-to-gaseous phase change due to pressure drop (similar to cavitation)



Location of flashing onset within the crack determines greatly the leak rate

* S. Barre, J. Rolland, G. Boitel, E. Goncalves, R. Fortes-Patella, Experiments and modelling of cavitating flows in Venturi: attached sheet cavitation, Eur J Mech B-Fluids 28 (3) (2009), pp. 444–464.

Leakage in primary circuit

Conclusions

- Interpenetrating field approach needed
- Homogeneous model not applicable because water and steam move at different speed
- Euler-Euler model computationally more expensive and may show poor convergence
- Time steps of 10^{-6} s … 10^{-4} s needed to follow the rapid phase change
- Depending on setup flashing process may be unsteady
  → transient simulation

Preliminary study

At first, try to model flashing with simplified setup:

Experiments at BNL

N. Abuaf et al., A study of nonequilibrium flashing of water in a converging-diverging nozzle, 1981.

Single phase flow

Water

27°C

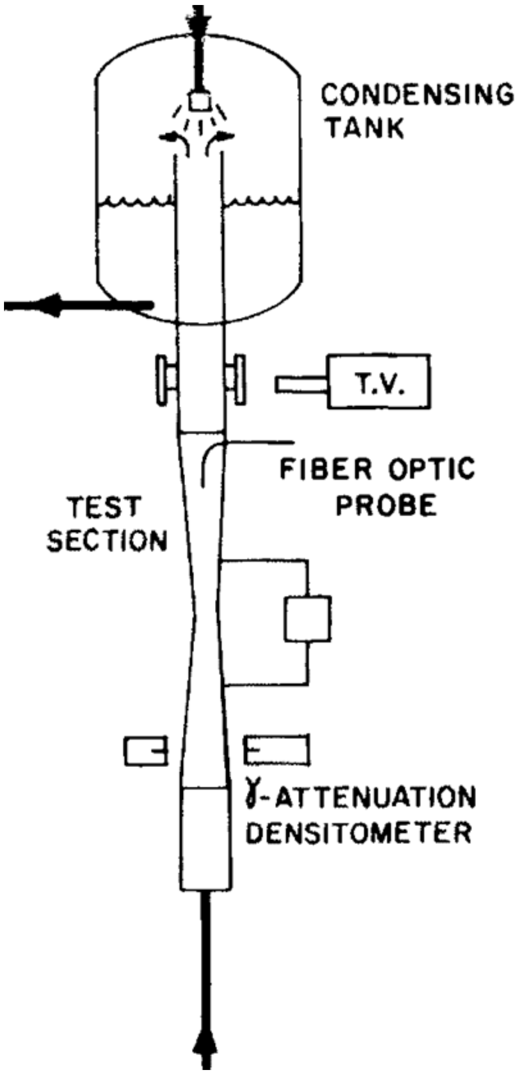
p_{in} = 0.3 … 1 MPa

Two phase flow

Water/Steam

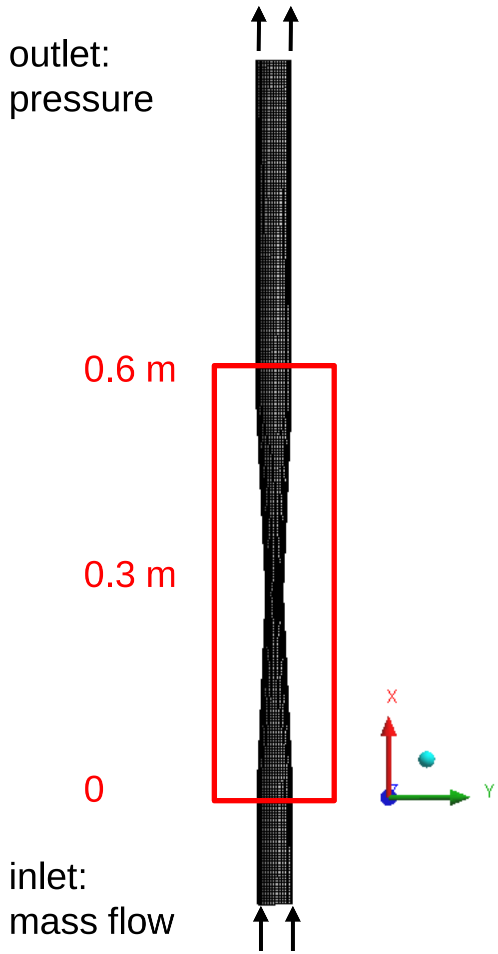
149°C

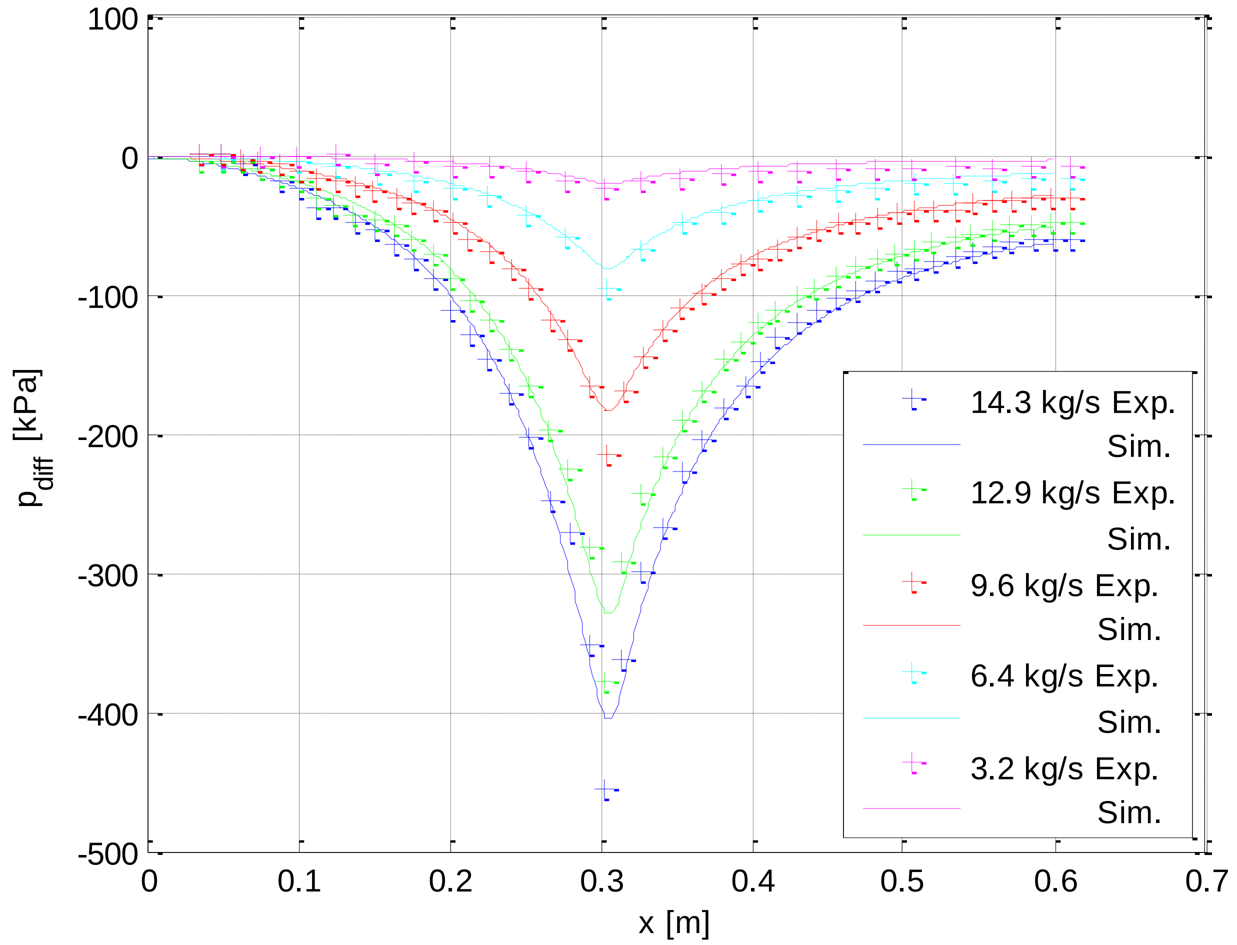
p_{in} = 0.5 … 0.8 MPa



Preliminary study

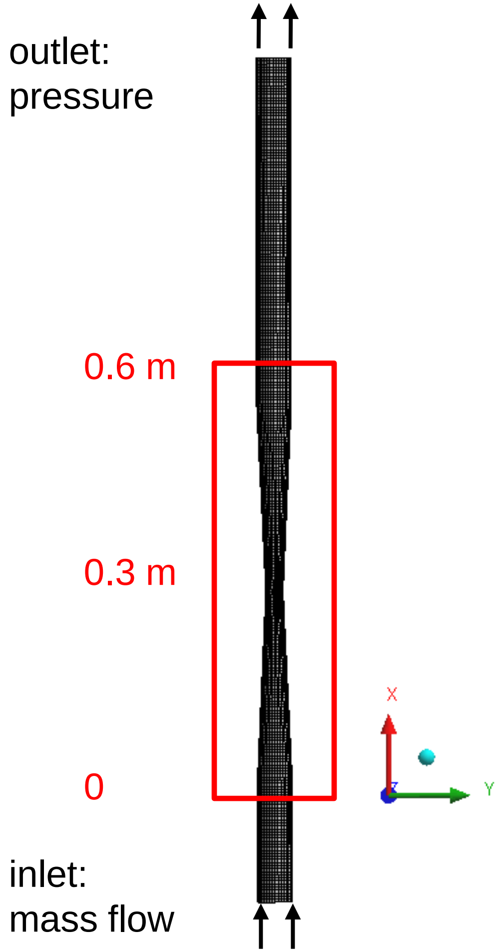
Steady state, single phase flow simulation with water at 27°C

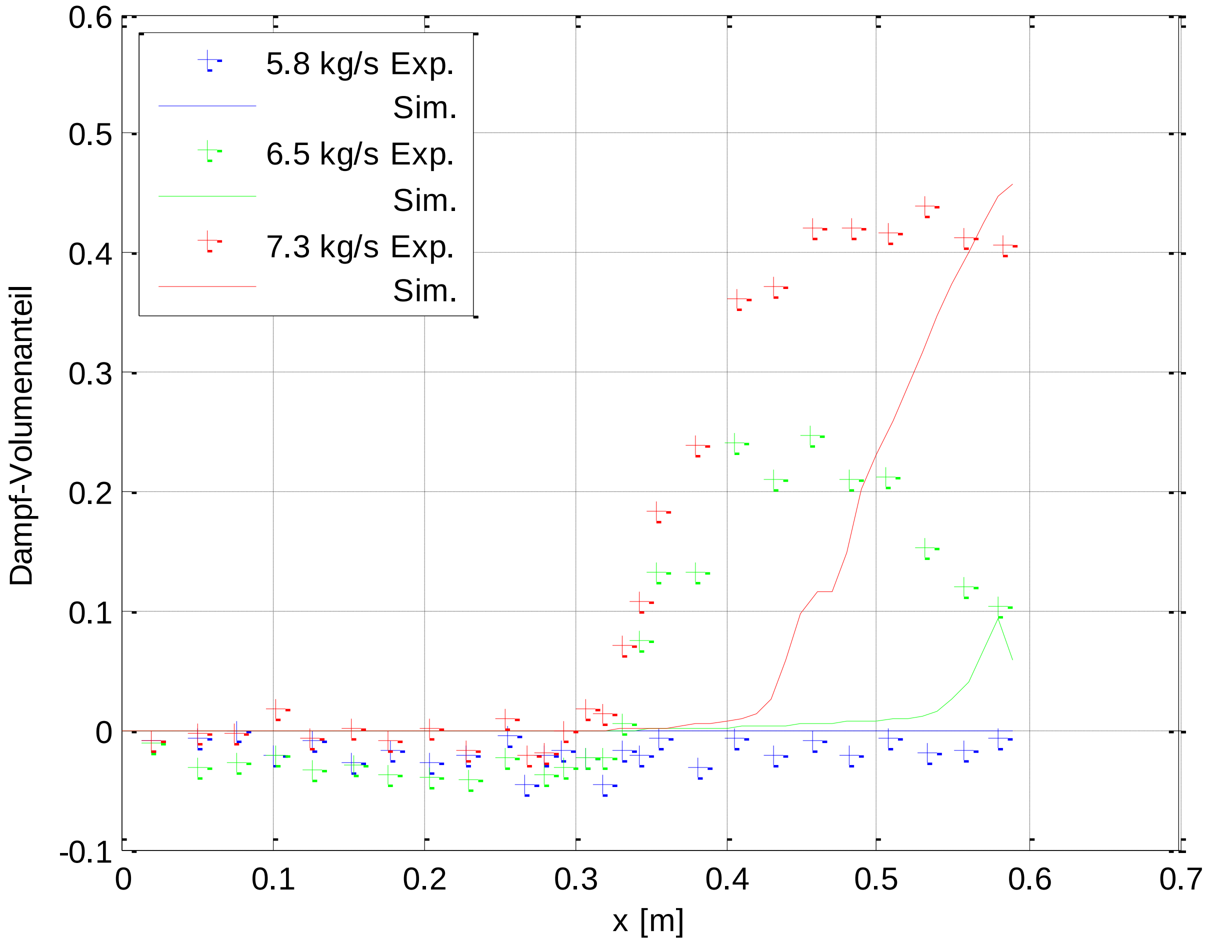




Preliminary study

Steady state, two phase flow simulation with water/steam at 149°C





Preliminary study

Steady state, two phase flow simulation with water/steam at 149°C

- Onset of flashing occurs too far downstream