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NORWEGIAN CCS RESEARCH CENTRE

Simulation of a full-scale CO_2 fracture propagation test

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10th Trondheim CCS Conference, 2019-06-19

Outline

- Background
- Experimental
- FE-CFD model
- Results
- Conclusions
- Further work

Background

- CCS is one of the necessary measures to reduce CO_2 emissions
- Important to design and operate CO_2-transport systems in safe and economical way
- Running-ductile fracture (RDF) may be triggered e.g. by corrosion or third-party damage to pipeline

- Governed by 'race' between decompression wave in fluid inside the pipe, and fracture-propagation velocity
  - If depressurization wave faster, pressure at fracture tip will decrease and RDF will arrest
  - Otherwise RDF may continue for long distances, with economical and human loss

Background

5-10 times more energy stored in dense phase CO_2 than natural gas

→ Challenging for existing design methods

Methane

G. Demofonti et al. (2002) IPDC / S. D.Papka et al. (2003) IOPC

CO_2

A Cosham et al. (2012) IPC2012-90463 / E. Aursand et al. (2016) Eng. Struct.

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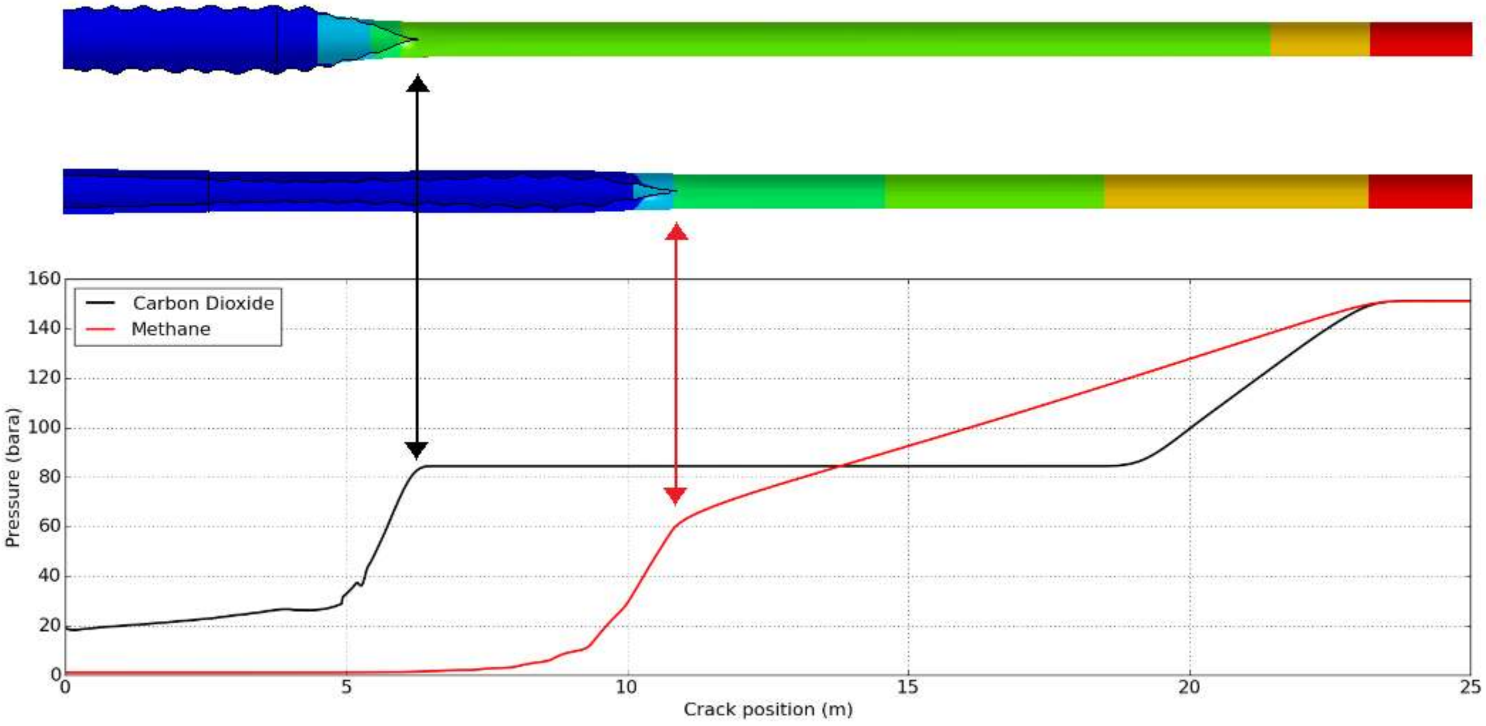
Background

- Typically higher pressure at the crack-tip
- Higher pressure downstream the crack-tip



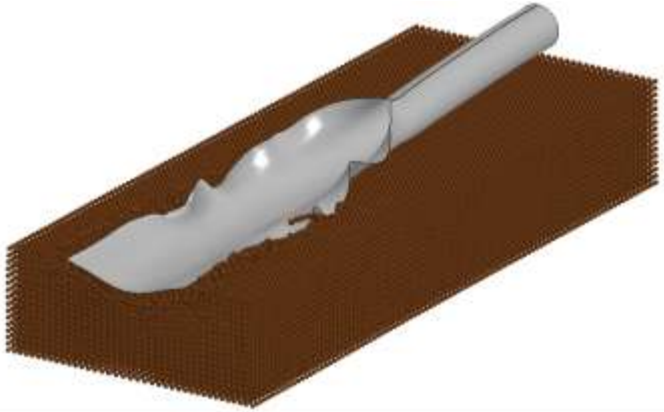
Background

- Two-Curve Method + CO_2 = Uncertainties
- Need full-scale testing
- Valid only in restricted domain!
- Better understanding of the phenomenon is needed!

Background

<u>SINTEF coupled FE-CFD code</u>

- Developed over several years by an interdisciplinary team
- Includes more physics than analytical solutions
- A validated code can:
  - Be applied as a design tool
  - Give insight into RDF problem
  - Reduce uncertainties in traditional design methods

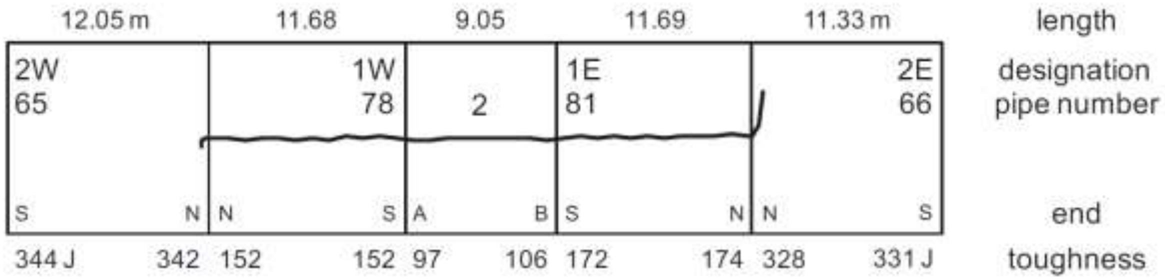


H. Nordhagen et al. (2012) Comp. & Struct.
E. Aursand et al. (2016) Eng. Struct.
H. Nordhagen et al. (2017) Eng. Struct.

Experimental

<u>Full scale tests presented at IPC 2016*</u>

- 24"/19.1 mm telescopic set-up, 7 sections + reservoirs
- CO_2 mixture (N_2, CH_4, H_2):
  - 150 barg / 15 °C
  - Saturation pressure 89 barg

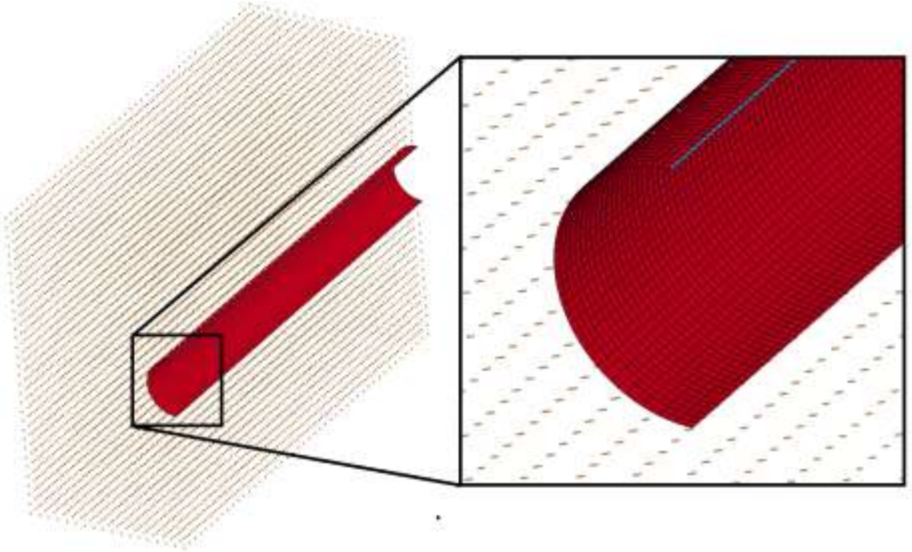


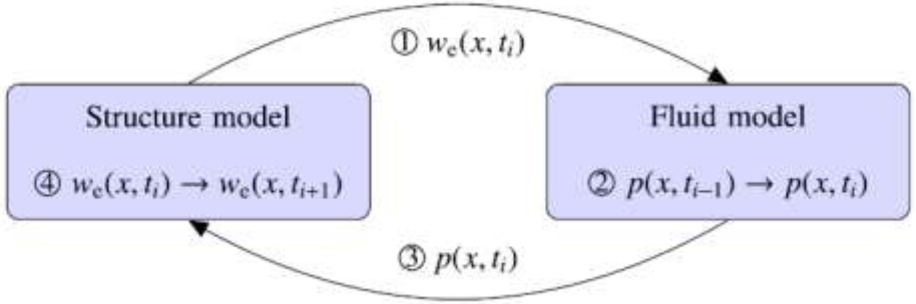
* A. Cosham, D. G. Jones, K. Armstrong, D. Allason, J. Barnett
IPC2016-64456 Analysis of a dense phase carbon dioxide full-scale fracture propagation test in 24 inch diameter pipe

FE-CFD code

- LS-DYNA FEA framework
- In-house CFD solver (user load sub.)

- Structure: Pipe, shell elements
- BC: Backfill, SPH particles
- Loading: Escaping CO_2, 1D Eulerian grid



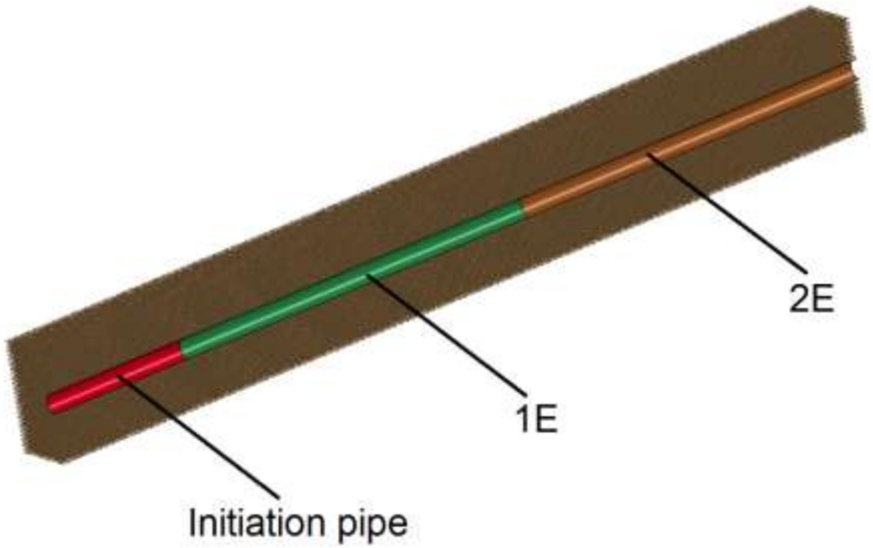


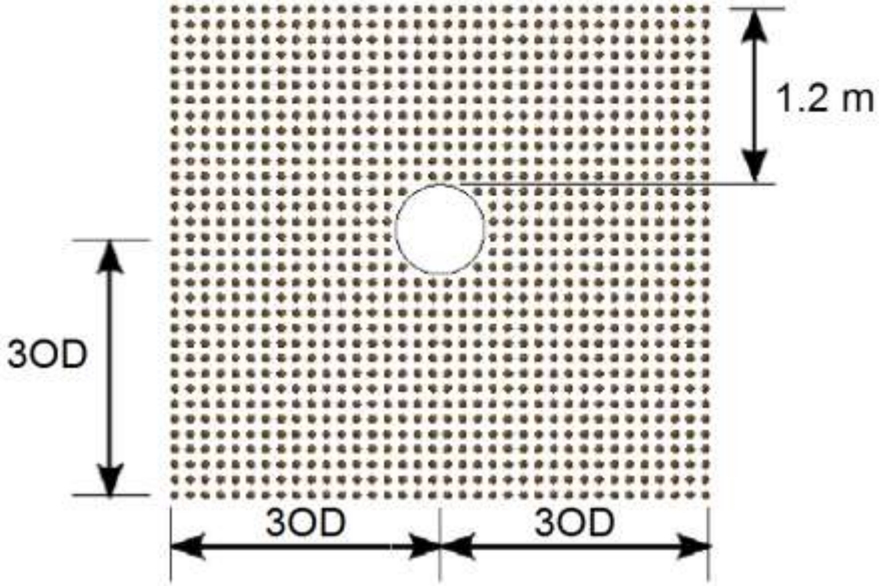
FE-CFD model

<u>Geometry, IC and BC</u>

Symmetry in set-up and results

→ Model East direction only

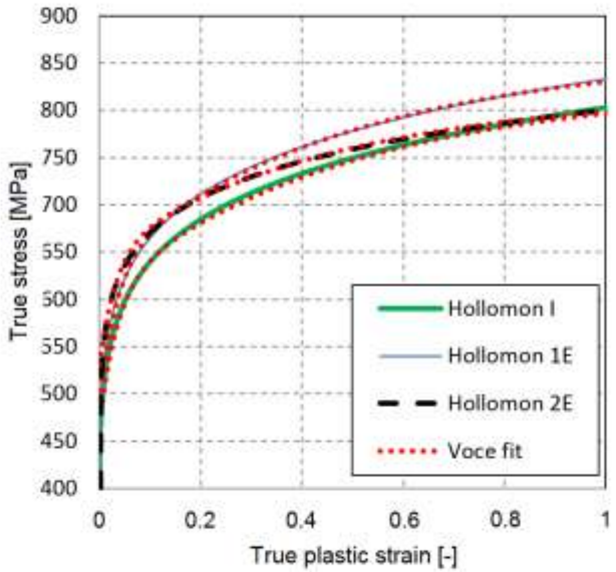


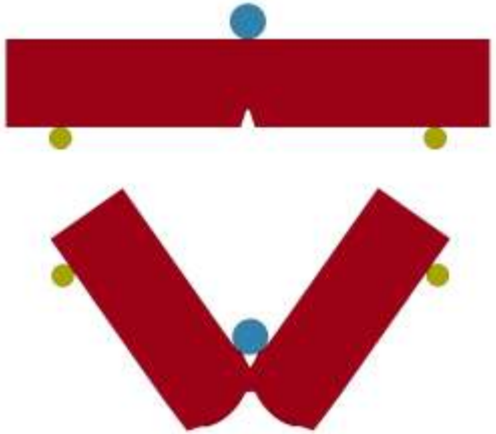


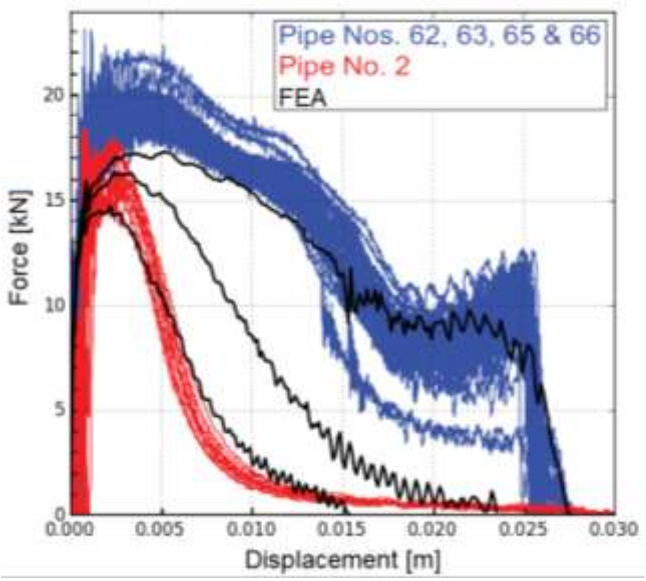
FE-CFD model

Steel material

- Work hardening curves estimated from R_{p02} and R_m
- Fracture parameter determined from FEA of Charpy tests





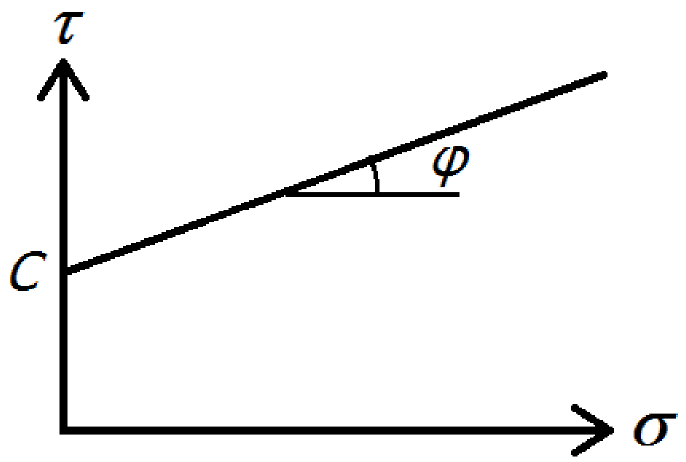


A. Liessem et al. (2007) ISOPE

FE-CFD model

Backfill material

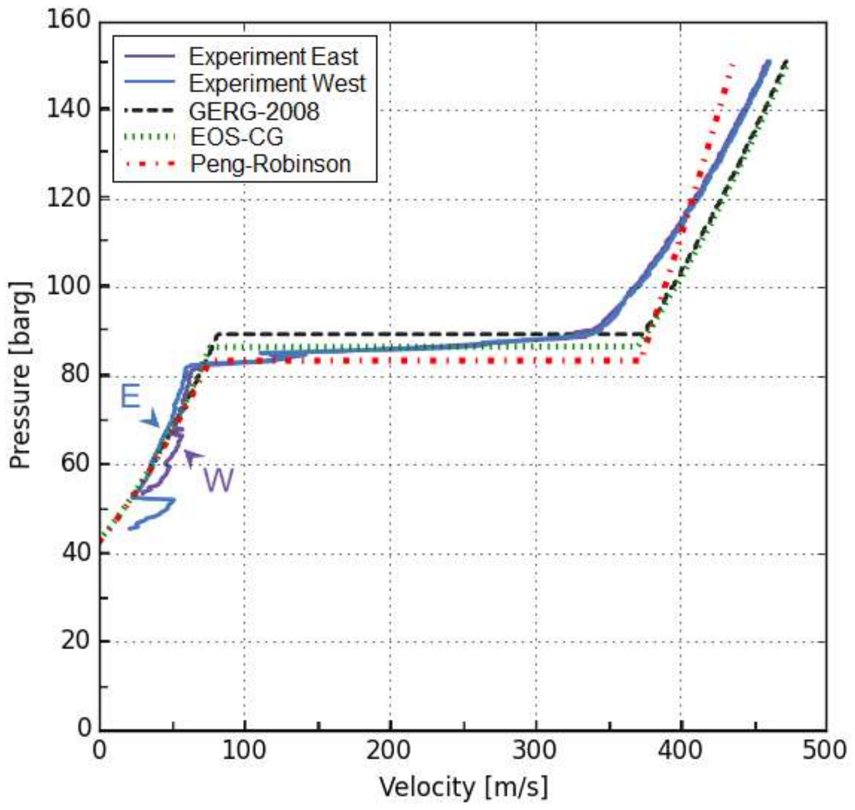
- Backfill: on-site boulder clay, no data
  - Apply data for clay found in literature
  - Mohr-Coulomb model



FE-CFD model

Loading with CO_2

- Peng-Robinson EOS, saturation pressure 83.4 barg



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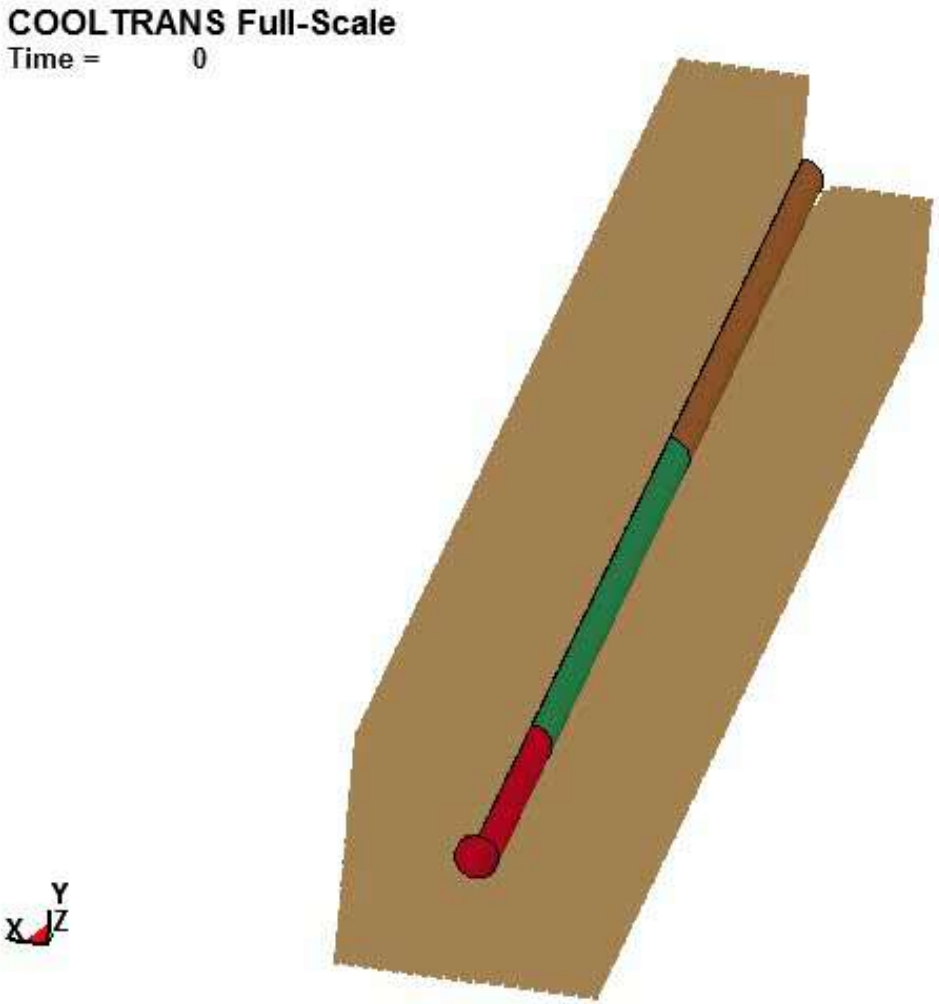
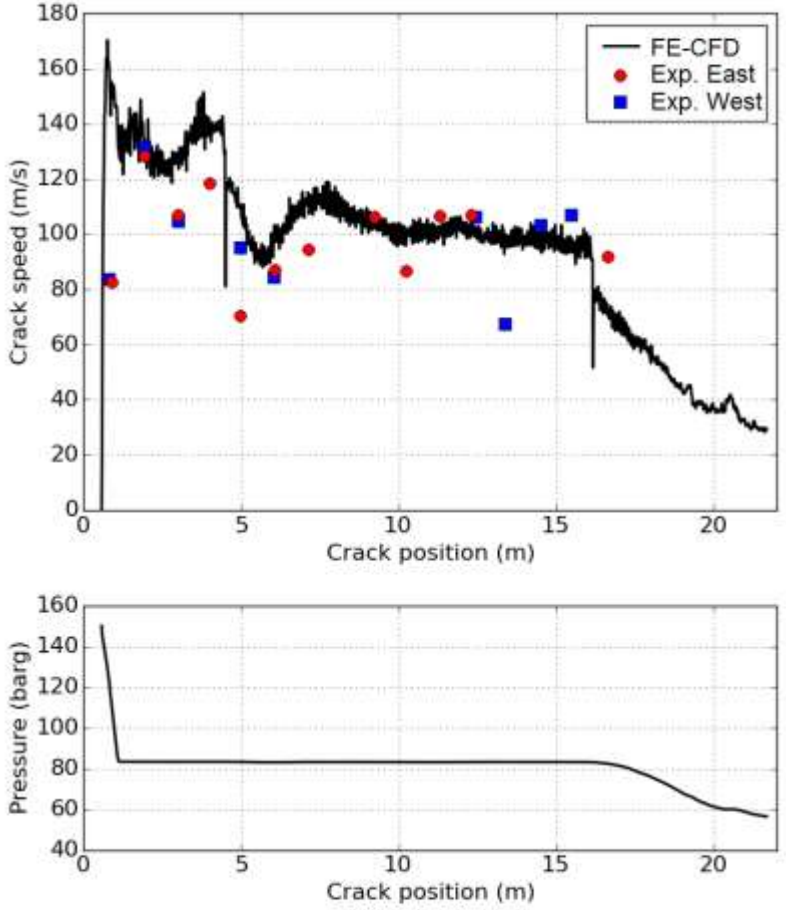
Results

Simulation of full-scale test



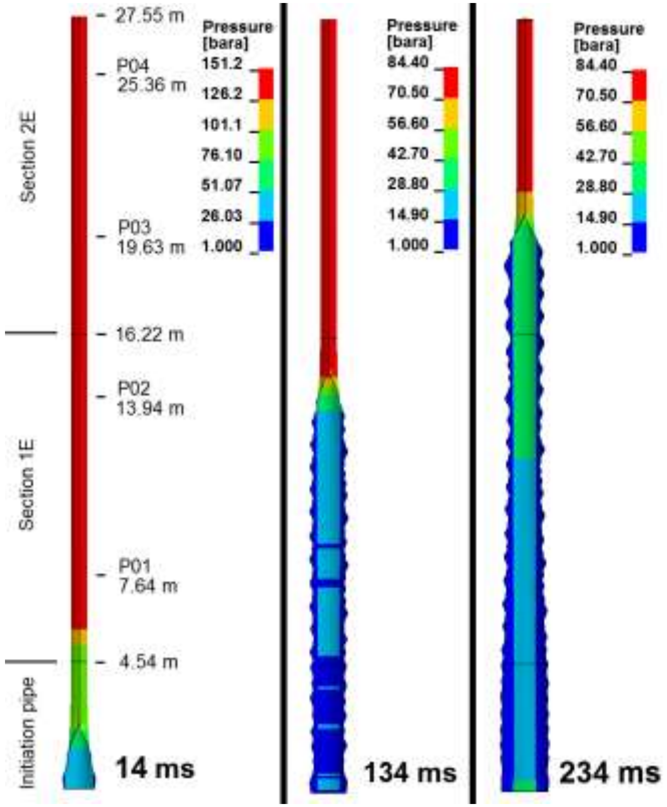
Results

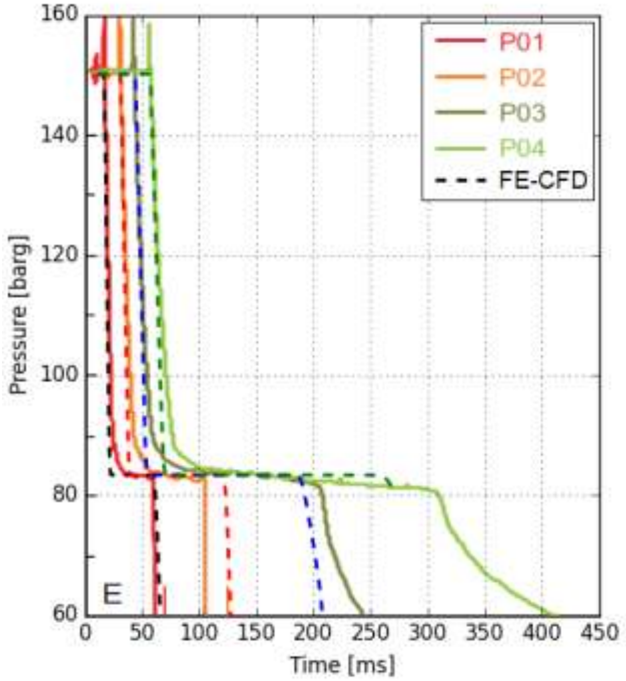
Simulation of full-scale test



Results

Simulation of full-scale test



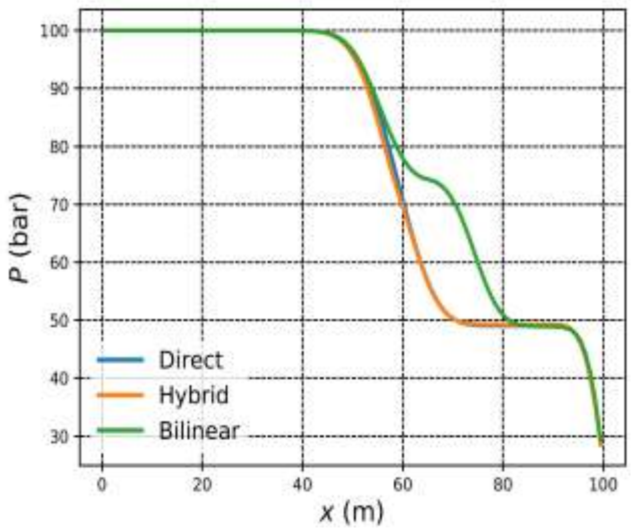


Conclusions

- Good agreement between simulation and experiment, but more validation work needed
- The simulation agrees well with the experiment in the low and medium toughness sections
- A slower deceleration in crack velocity in the high-toughness section
- Using the DWTT test in fracture calibration might increase the accuracy in the high-toughness section
- >50% energy dissipated in the backfill, <3% along the crack path

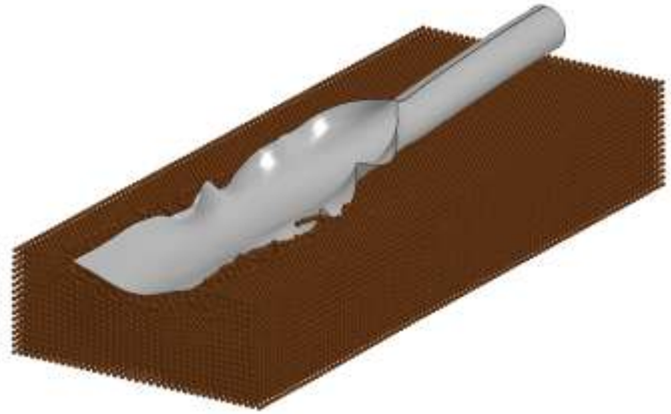
Further work

- Objective: Improve accuracy and computational efficiency for calculation of thermophysical properties of mixtures
- Hybrid interpolation scheme developed



- Needs to be implemented in coupled model and tested
- Assess sensitivity of coupled model/RDF to EOS

Thank you for your attention



Questions?

Acknowledgement: This publication has been produced with support from the NCCS Centre, performed under the Norwegian research programme Centres for Environment-friendly Energy Research (FME). The authors acknowledge the following partners for their contributions: Aker Solutions, Ansaldo Energia, CoorsTek Membrane Sciences, EMGS, Equinor, Gassco, Krohne, Larvik Shipping, Norcem, Norwegian Oil and Gas, Quad Geometrics, Shell, Total, Vår Energi and the Research Council of Norway (257579)

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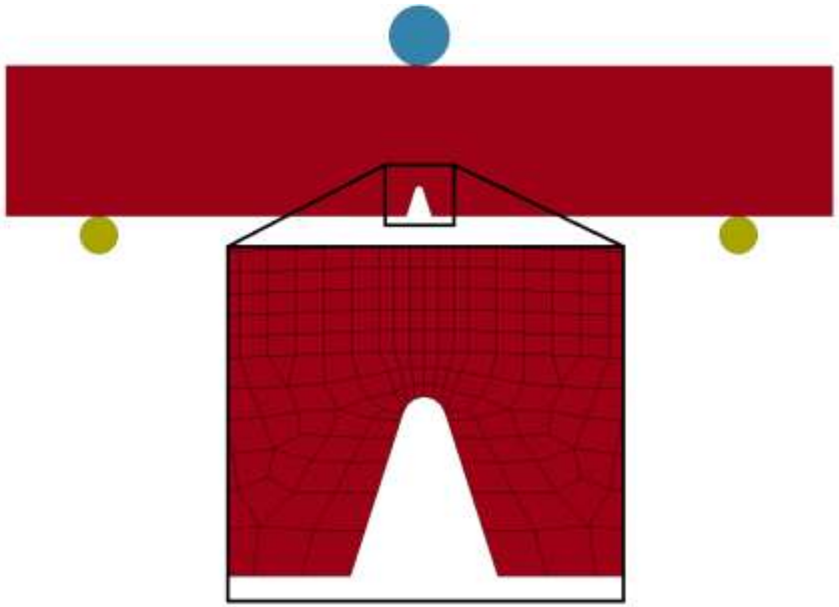
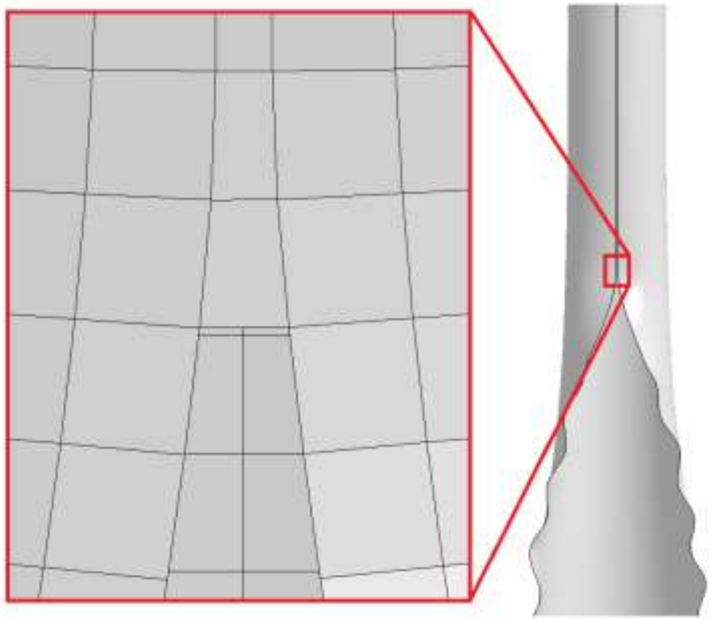
FE-CFD model

Steel material

- Scaling of fracture parameter for larger shell elements

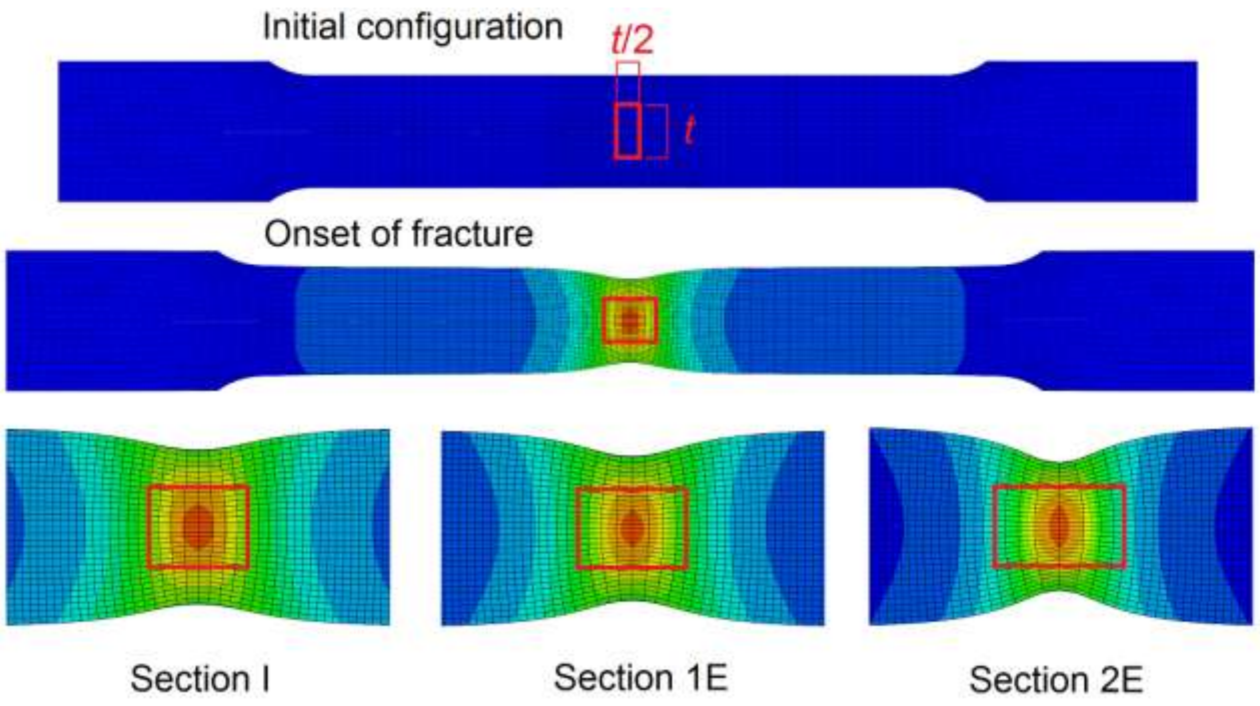




FE-CFD model

<u>Steel material</u>

- Scaling of fracture parameter for larger shell elements



Results

Energy dissipation