Phase I: Model1, Model3 and Some Fracture Mechanics of the Liner

NRC Headquarters, Standard Problem Exercise, April 13 - 14, Washington DC

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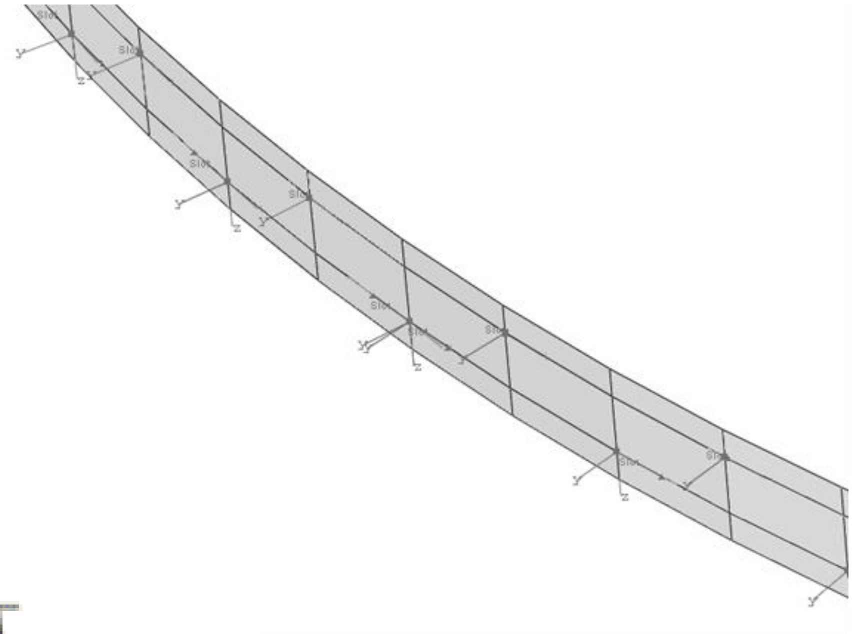
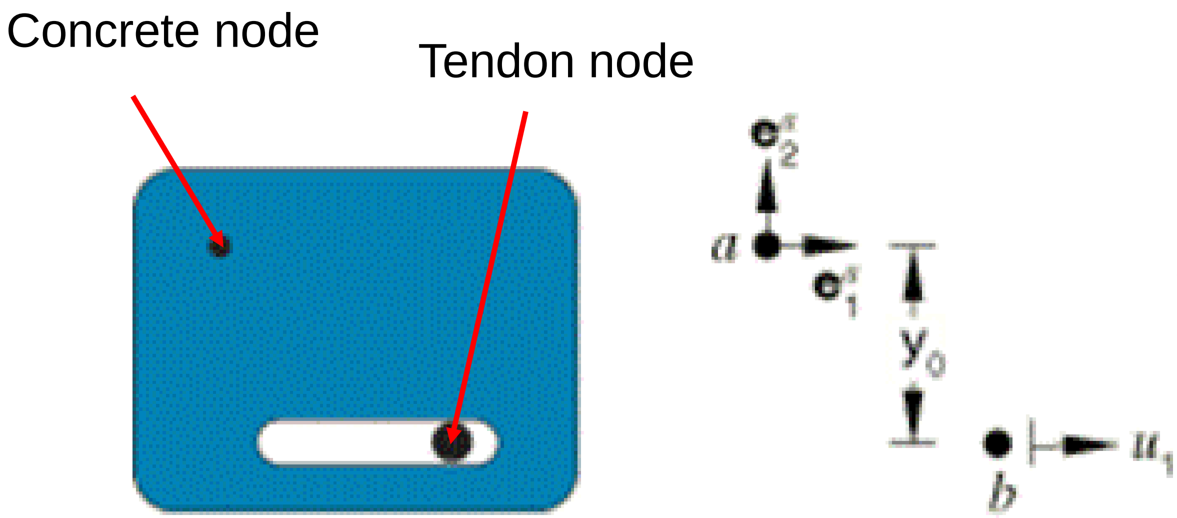
Model1: General

- Modeling with Abaqus-6.10
- Shell model
  - 420 elements
- Reinforcement with rebar layers (shell property)
- Tendons with truss elements
- Liner with "skin" reinforcement.

Model1: Tendon-Concrete Interaction

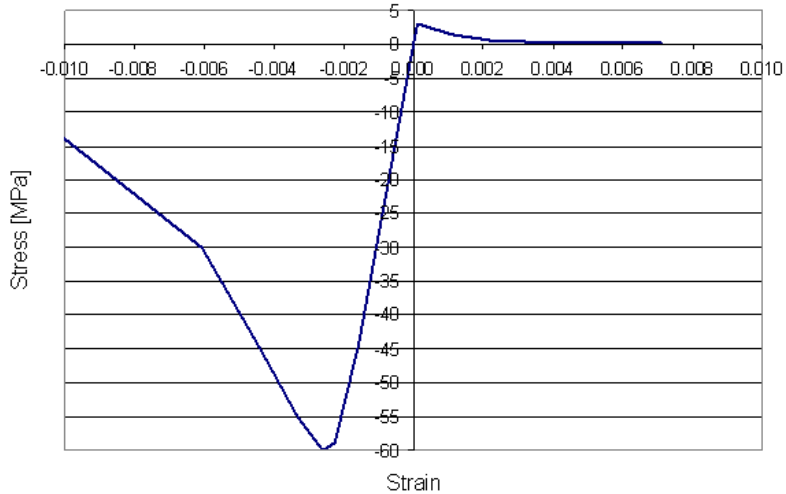
- 140 "slot" connector elements
- Friction factor 0.21
- Prestressing displacement guided.



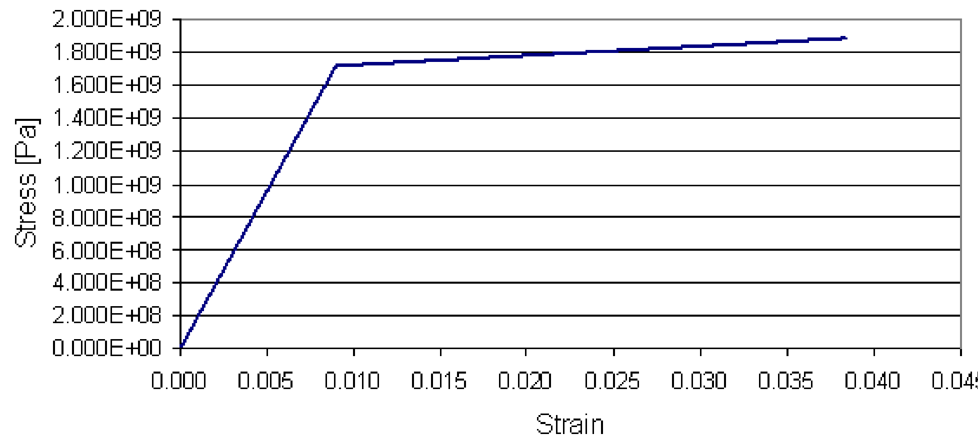


Model1: Material models

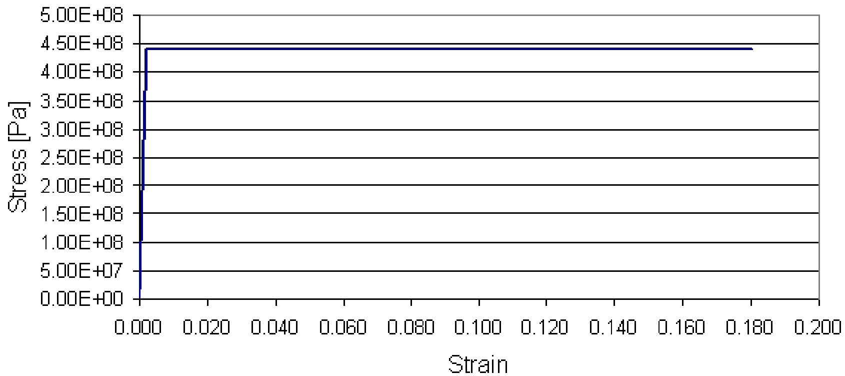
Concrete with Damage Plasticity model



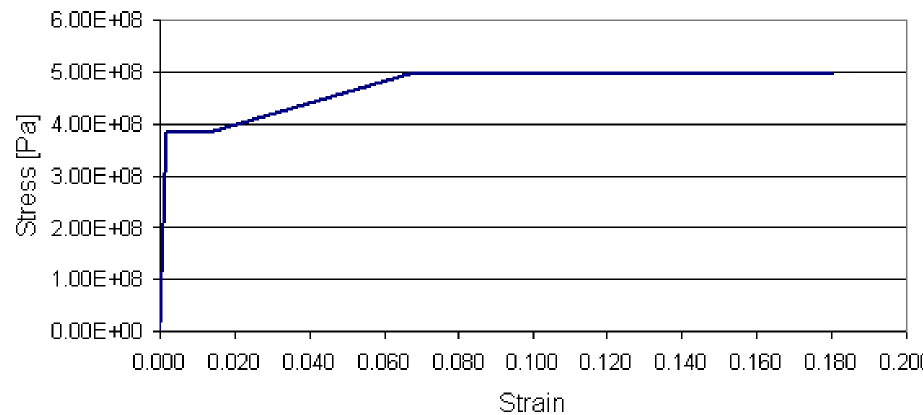
Tendon Steel



Reinforcement Steel

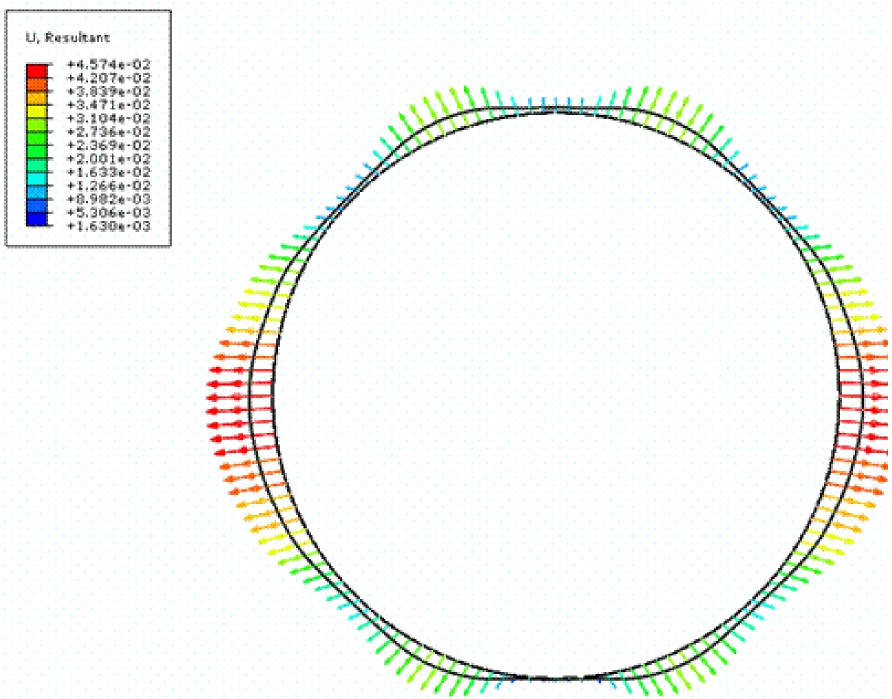


Liner Steel

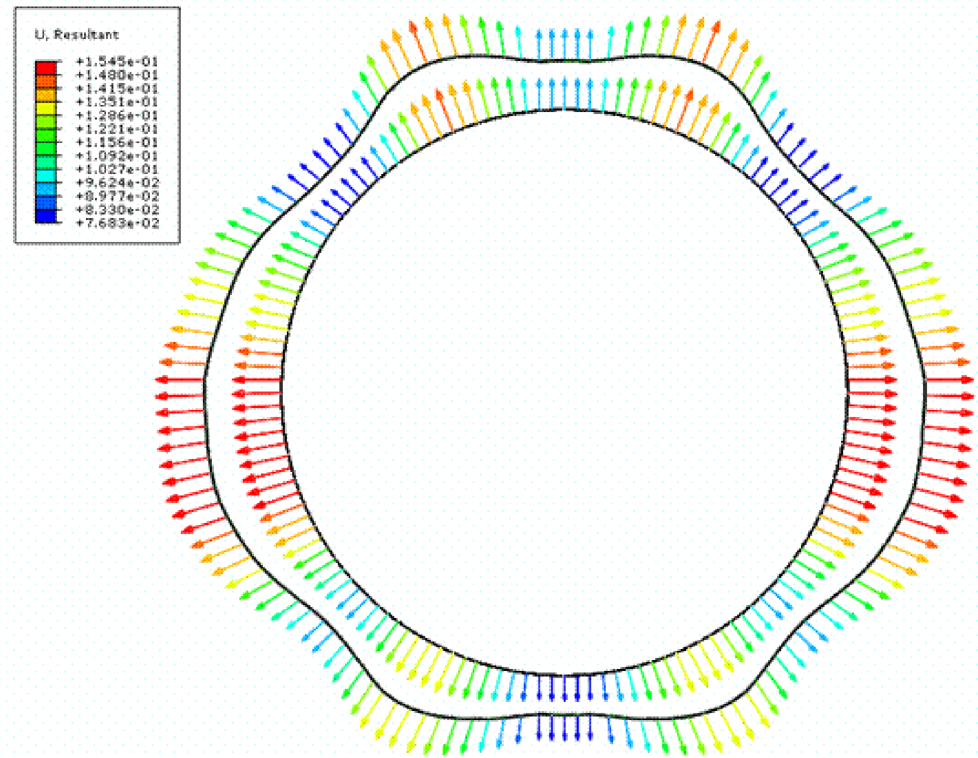


Model1: Results (1/2)

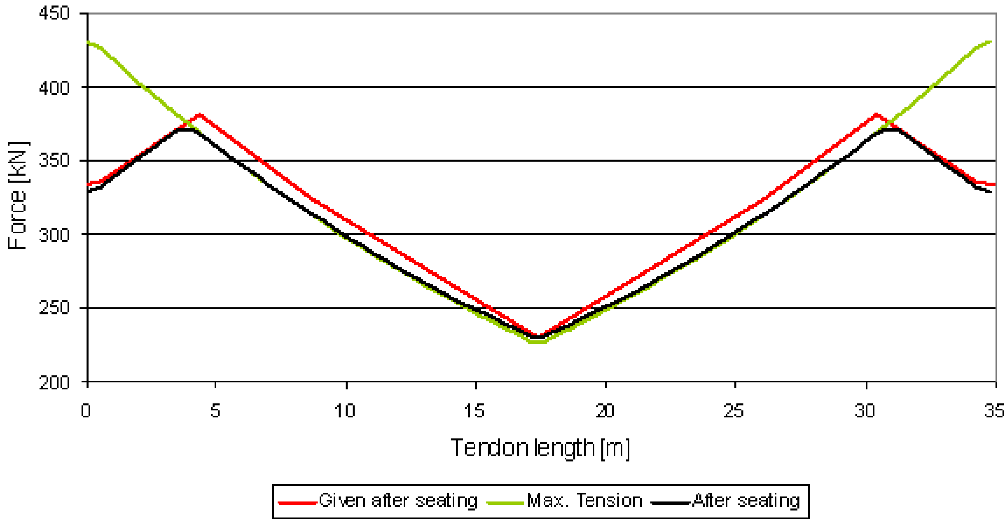
Deformation 3.3xPd
(scale x 10)



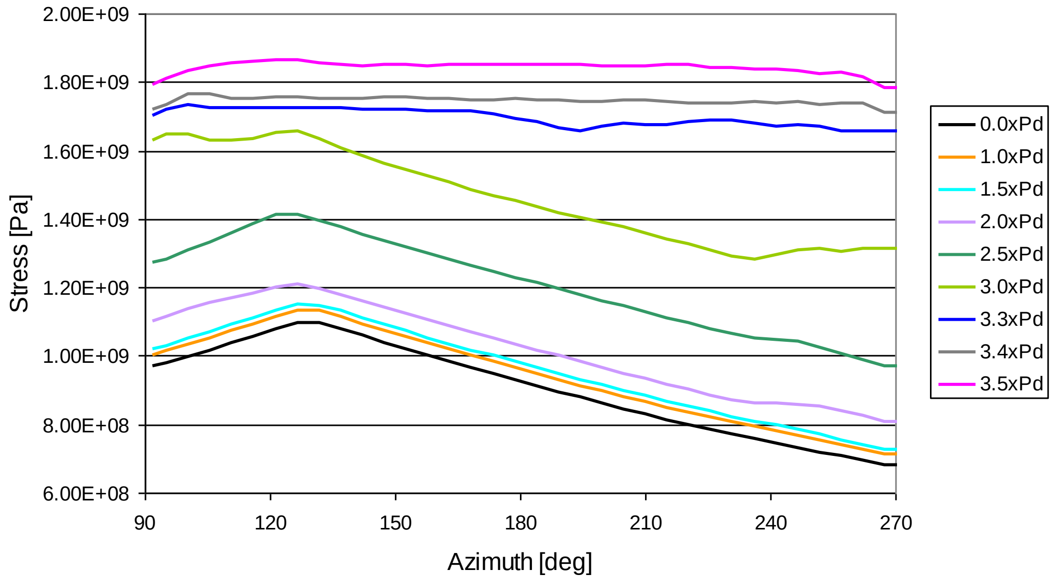
Deformation 3.5xPd
(scale x 10)



Model1: Results (2/2)



Tendon after prestressing



Stress with increasing pressure

Fortum

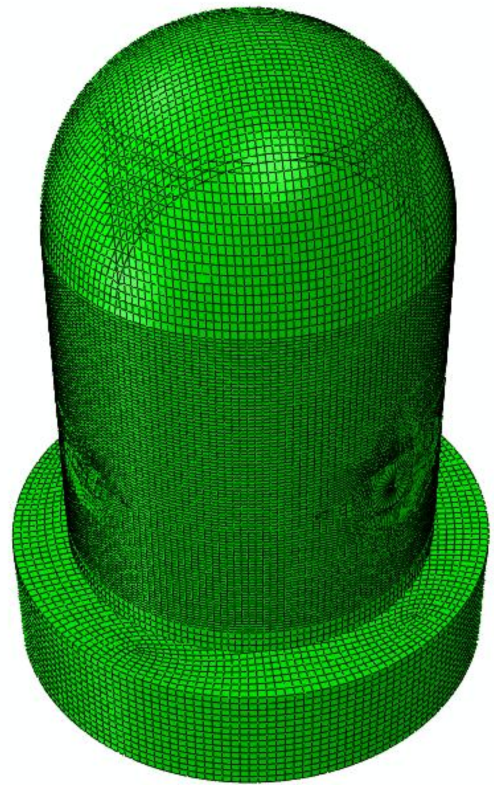
Model1: Conclusions

- The behaviour of the model is consistent with the test results.
- Slot connectors are able to model the tendon-concrete interaction.

Fortum

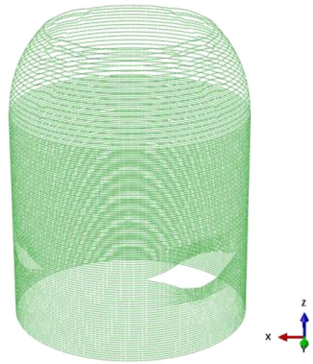
Model3: General

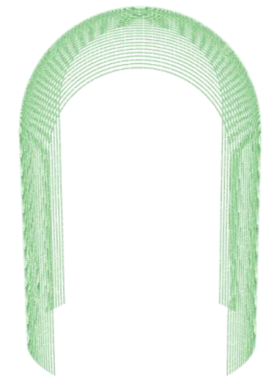
- Modeling with Abaqus-6.10
  - Implicit dynamic analysis. Much better convergence than using static solver.
  - Loads applied slowly (quasi-static).
- 175603 nodes and 257580 elements.
- Containment with shell elements. Basemat with solid elements. Tendons with truss elements.

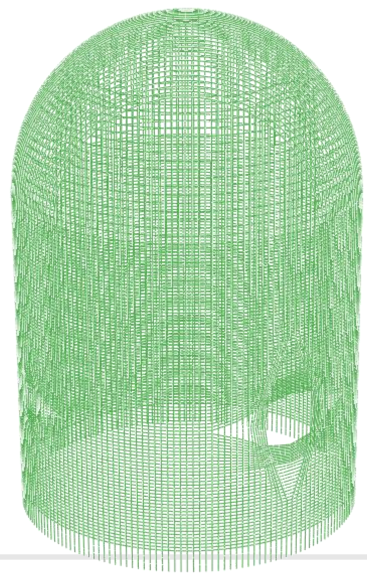


Model3: About tendons

- 3 parts
  - Horizontal
  - Vertical-1
  - Vertical-2
- Slot connector interaction between tendon and concrete node.







Model3: Rebars and Liner

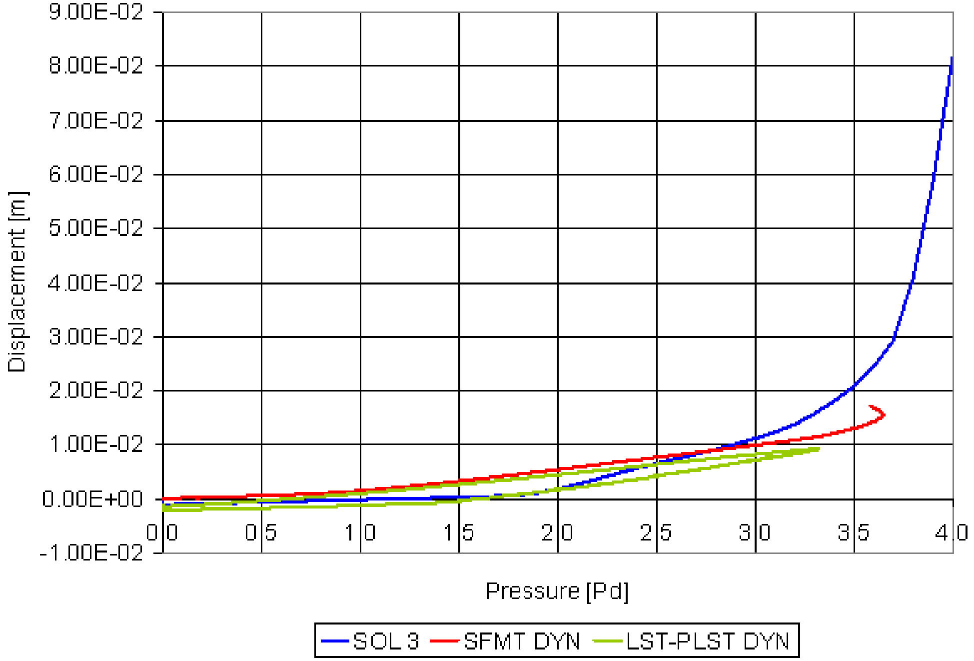
- Rebars with rebar layer shell property.
- Liner as a skin reinforcement.

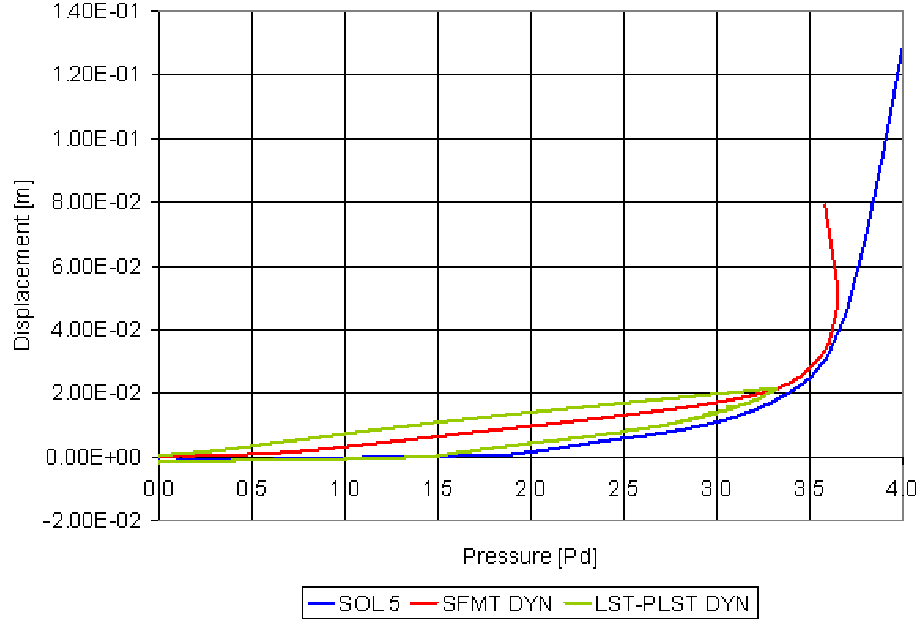
Model3: Tendon Prestressing

- Force guided pretension and seating loss.
- Locking of the prestressing connectors achieved using temperature dependent connector plasticity:

```
*CONNECTOR BEHAVIOR,
NAME=ZZZV2-CONNSECT-END
*CONNECTOR ELASTICITY, RIGID
 1
*CONNECTOR PLASTICITY,
COMPONENT=1
*CONNECTOR HARDENING,
DEFINITION=TABULAR
 1.0E-15, 0.0, 0.0,0.0
 1.0E+15, 0.0, 0.0,1.0
```

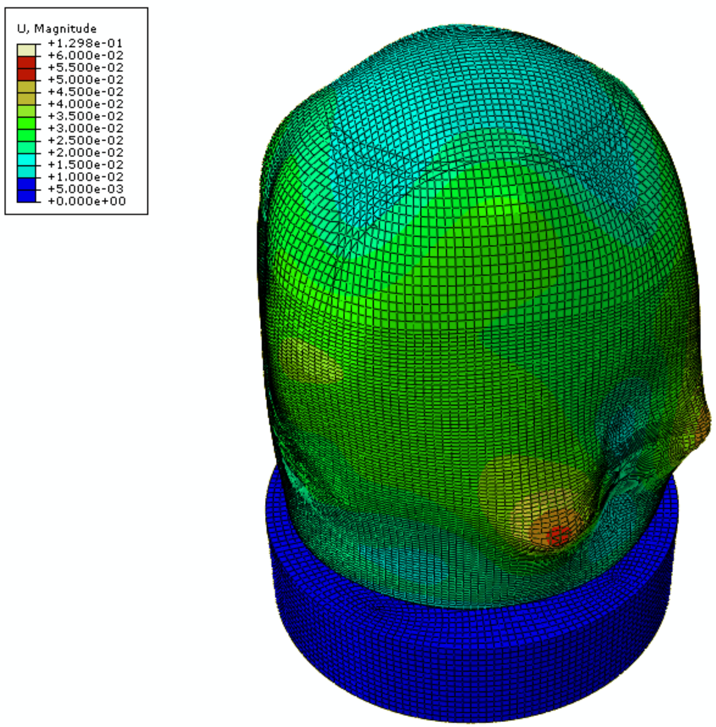
Model3: Some Selected Results

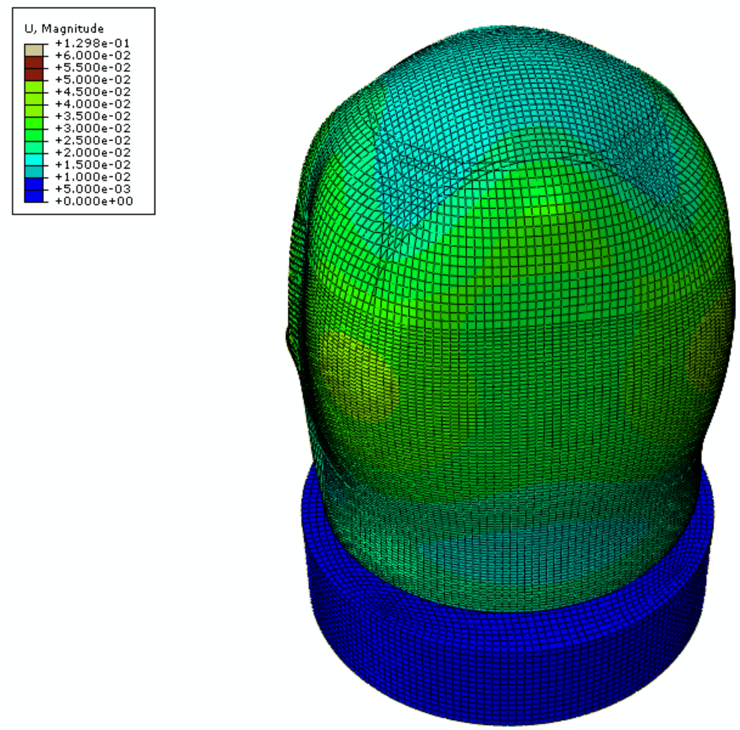




Model3: Results

Global deformation (x 50) at applied
pressure P = 3.5 x Pd





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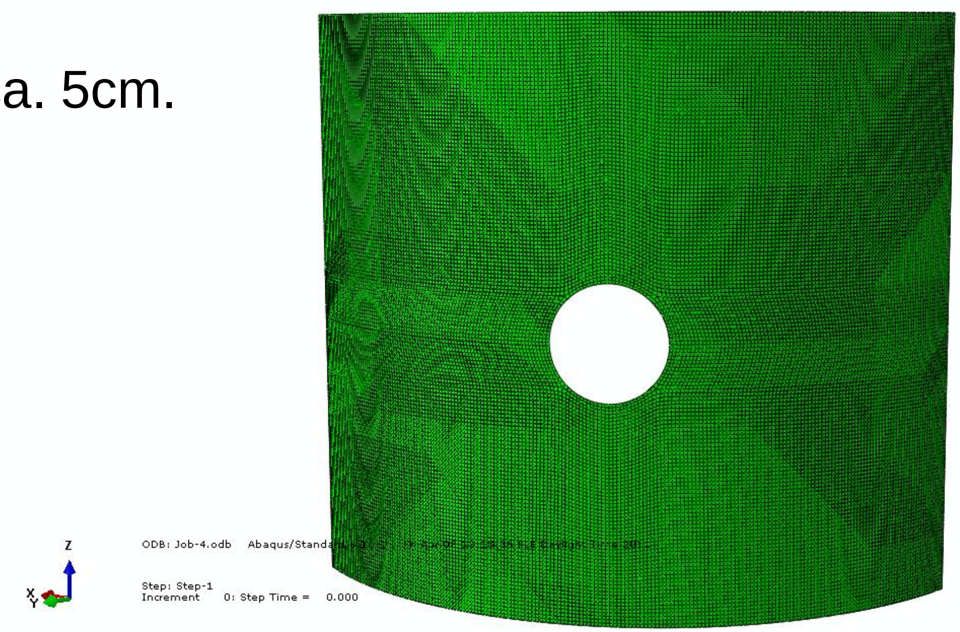
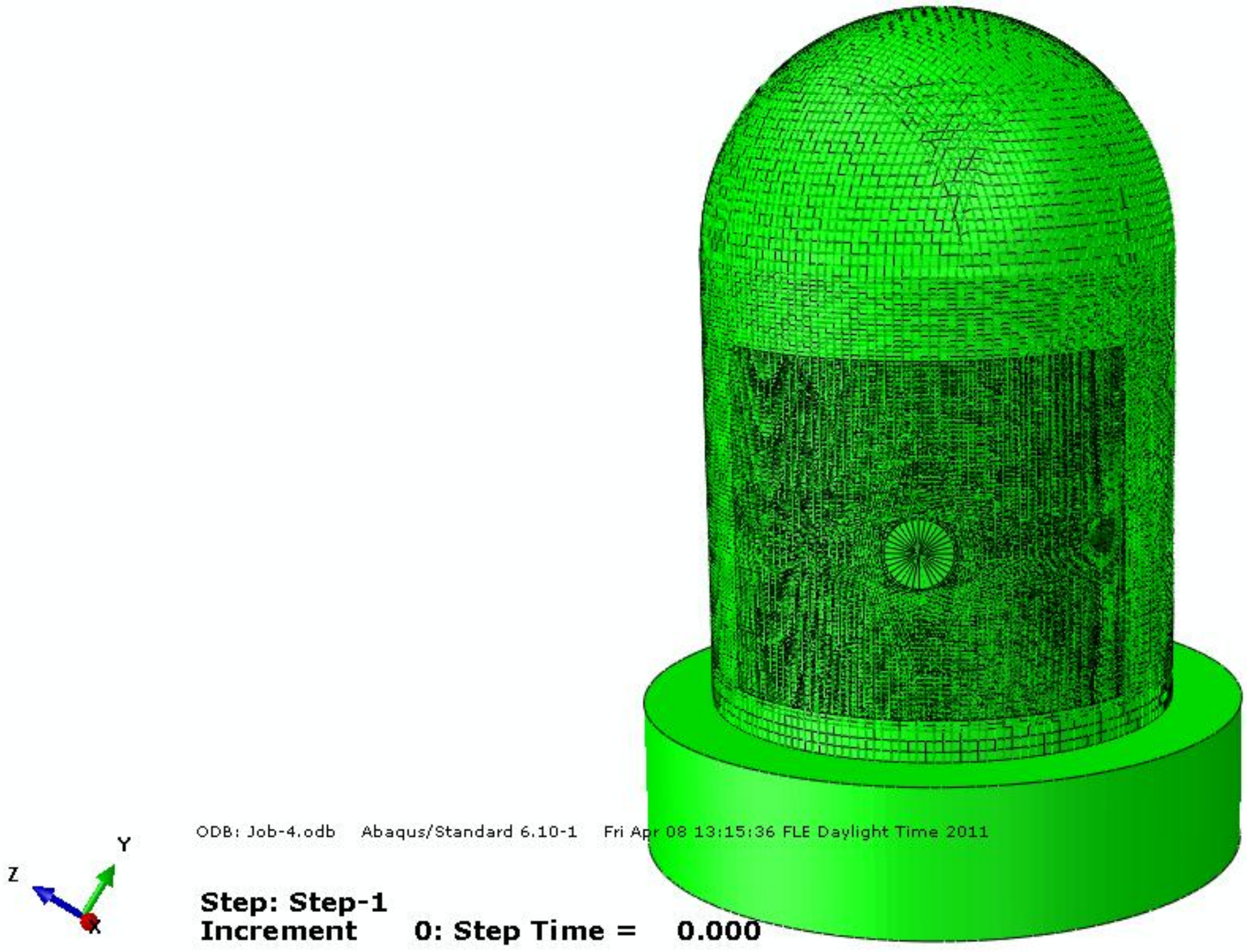
Some Fracture Mechanics of the Liner

- Sub model of the liner.
- Two layers of reduced integrated solid brick-elements.
- Element side length ca. 5cm.

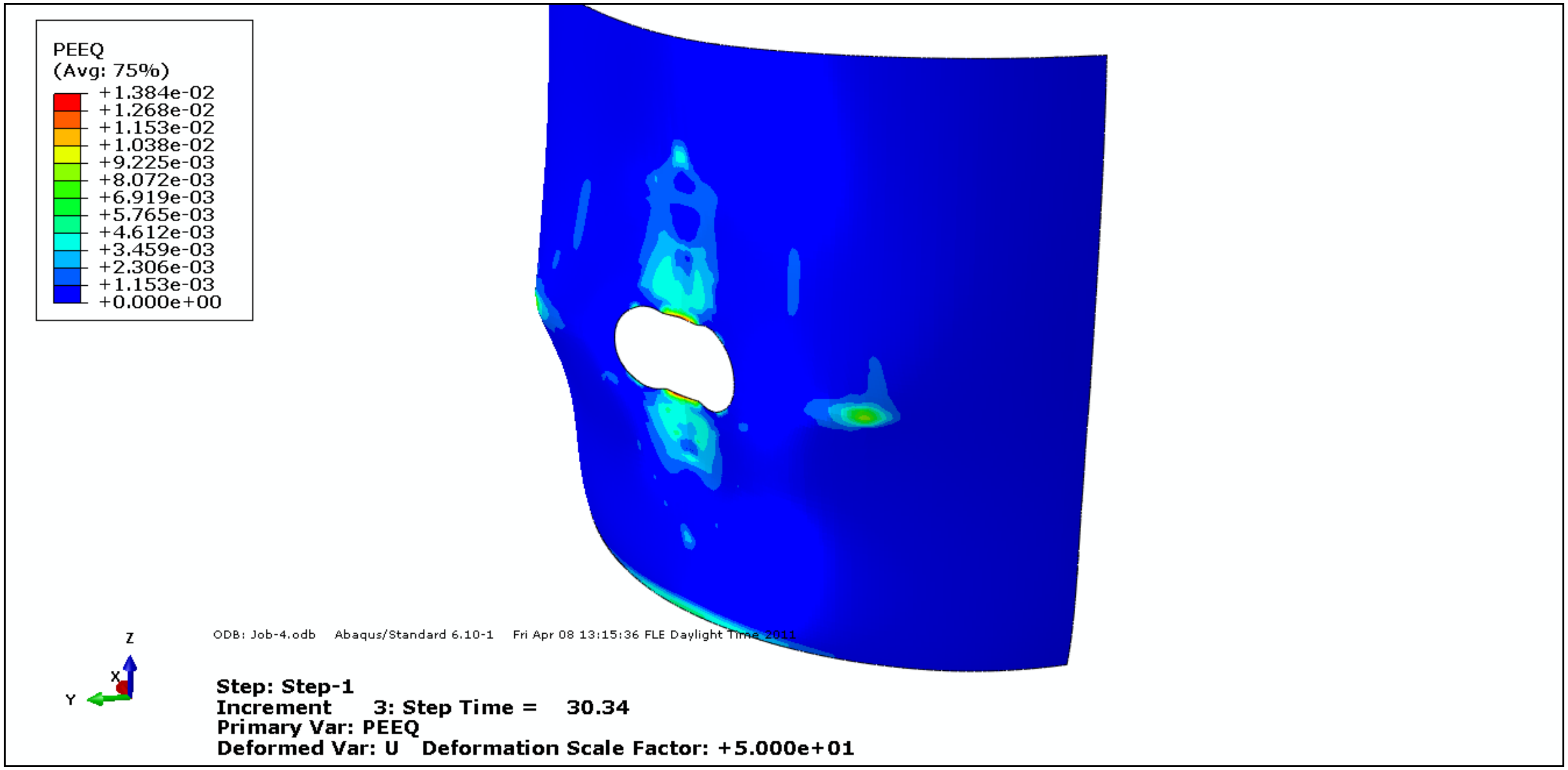


Overlay Plot of the Sub Model



Does the Sub Model Work?

P = 3.034Pd, Deformation x 50

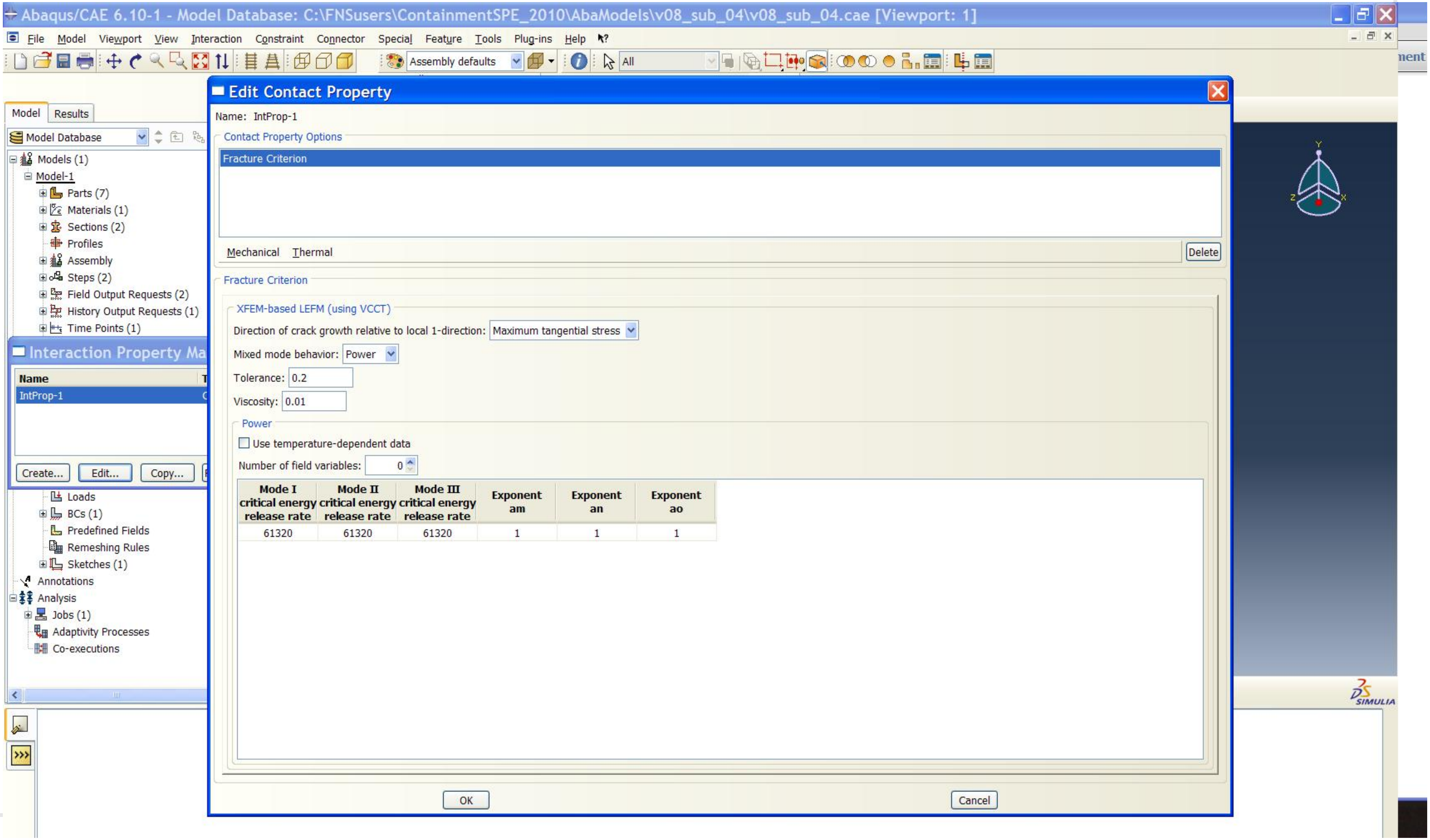


Fortum

Setup

- The global model drives all the sub model dofs.
- Use of extended finite element method (XFEM) available in Abaqus.
- Crack initiation when max. principal strain = 0.03.

Crack Growth Criteria (1/2)

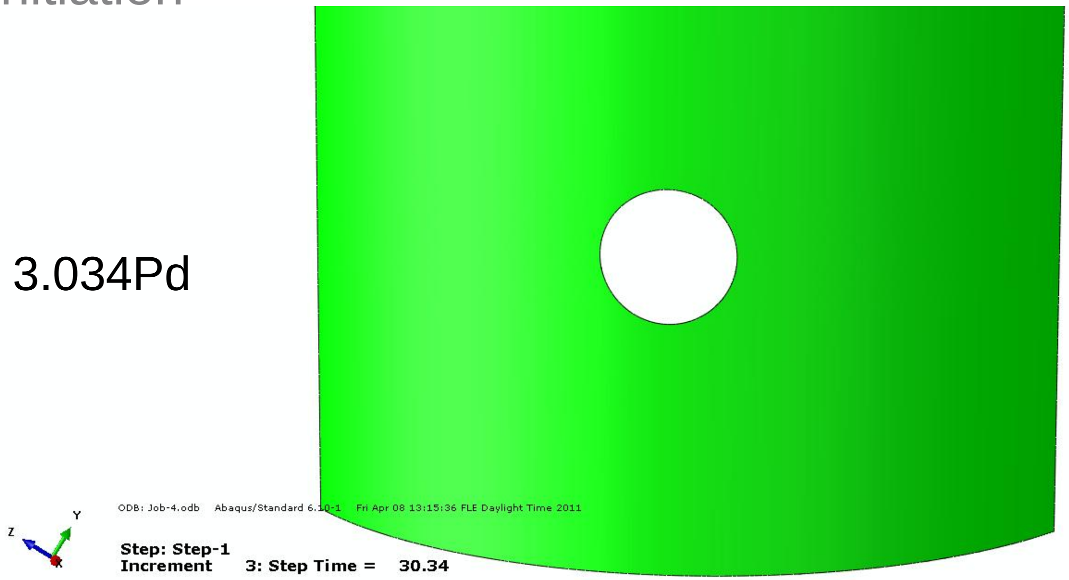


Crack Growth Criteria (2/2)

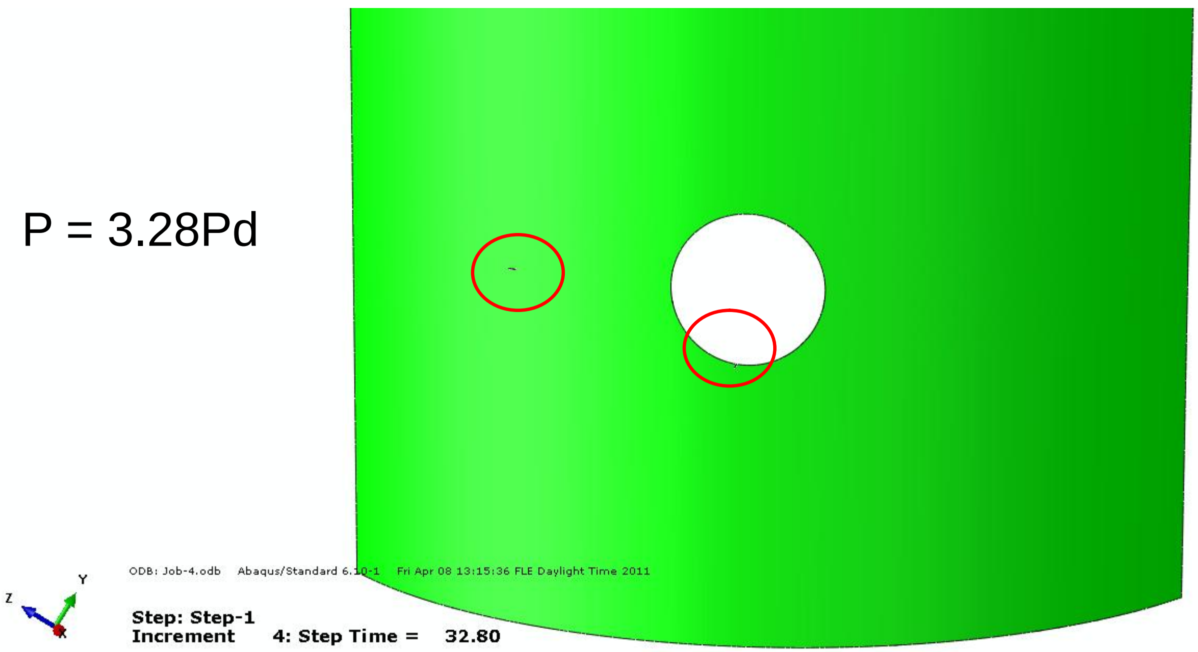
- Critical energy release rate = J_{ICr} = 61.32 kJ/m^2
- Same critical energy release rate used for modes II and III.
- Power law assumption: $(J_I / J_{ICr})^1 + (J_{II} / J_{IICr})^1 + (J_{III} / J_{IIICr})^1 \leq 1$

Results: Crack Initiation

P = 3.034Pd



P = 3.28Pd



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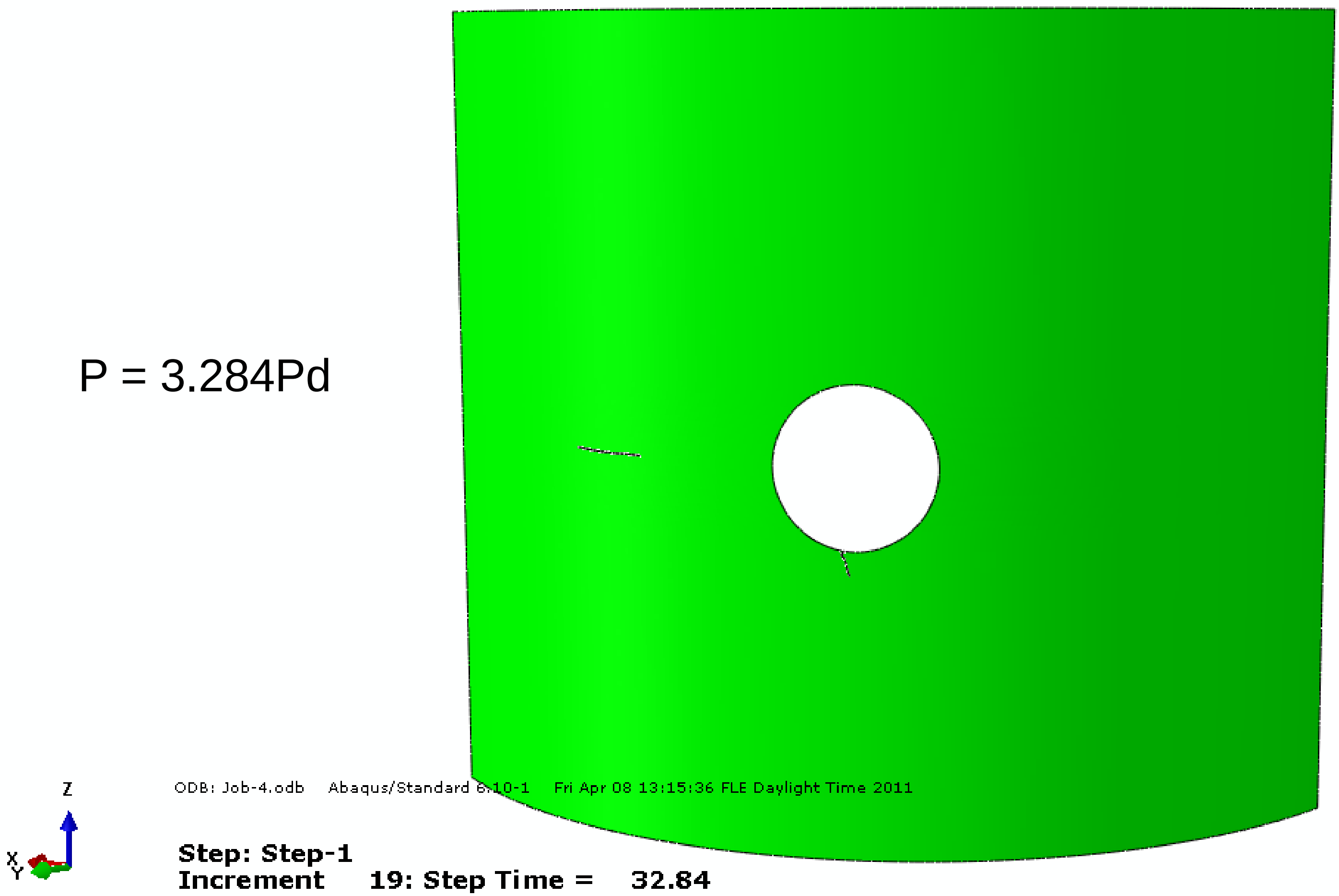
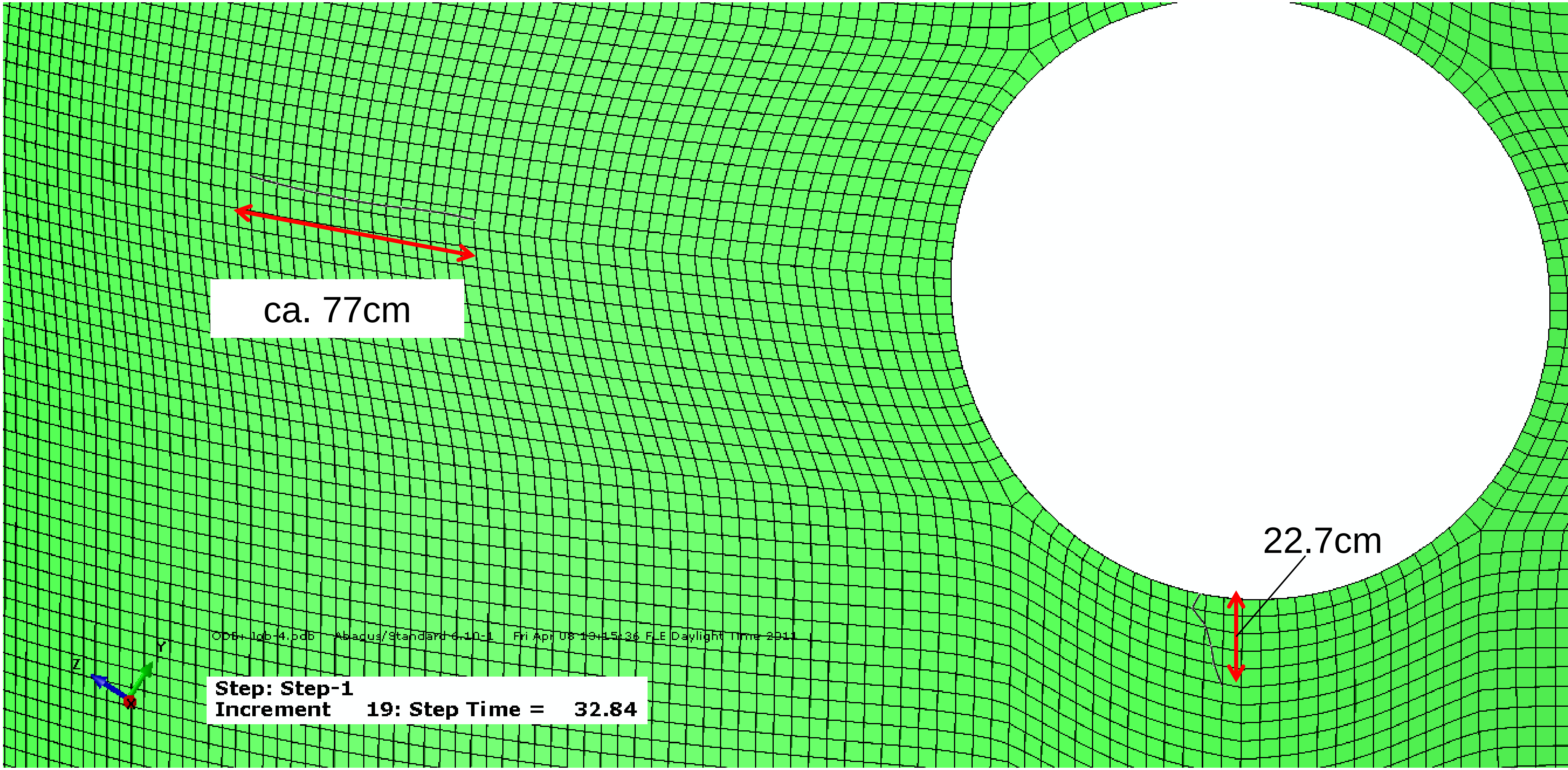
Results: Crack Propagation (1/2)

P = 3.284Pd



Results: Crack Propagation (2/2)

P = 3.284Pd



Thank you for your attention !