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VERCORS
Vérification réaliste du confinement des réacteurs

SAND2018-9070C

OECD

Workshop "VeRCoRs – 2018" : 27-29 August 2018, EDF Paris-Saclay

VeRCoRs 2018 Benchmark Theme 2: Mechanical Behavior of the Containment during Pressurization Tests

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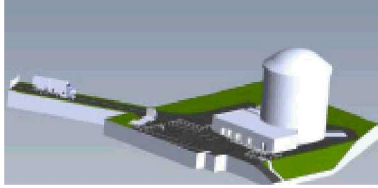
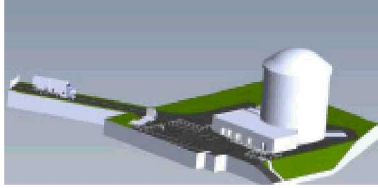
Outline



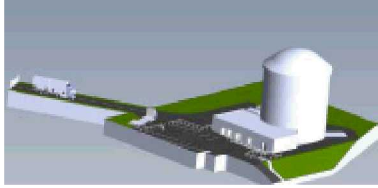
- Model Geometry and Mesh Overview
- Material Properties and Models
- Simulation Load History
- Finite Element Analysis (FEA) Computational Information
- Selected Results

Model Geometry



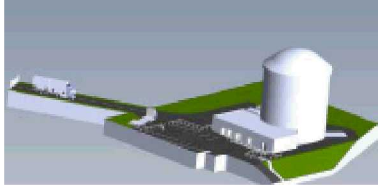
- Containment vessel concrete and posttensioning tendon geometries and mesh were provided by EDF and used as received
- Rebar geometry and mesh were created utilizing Cubit
- Rebar size and spacing were determined from drawings provided by EDF
- Rebar layers were added to the simulation as surface elements
- Surface elements in ABAQUS have orthotropic properties depending on reinforcement ratios in each direction

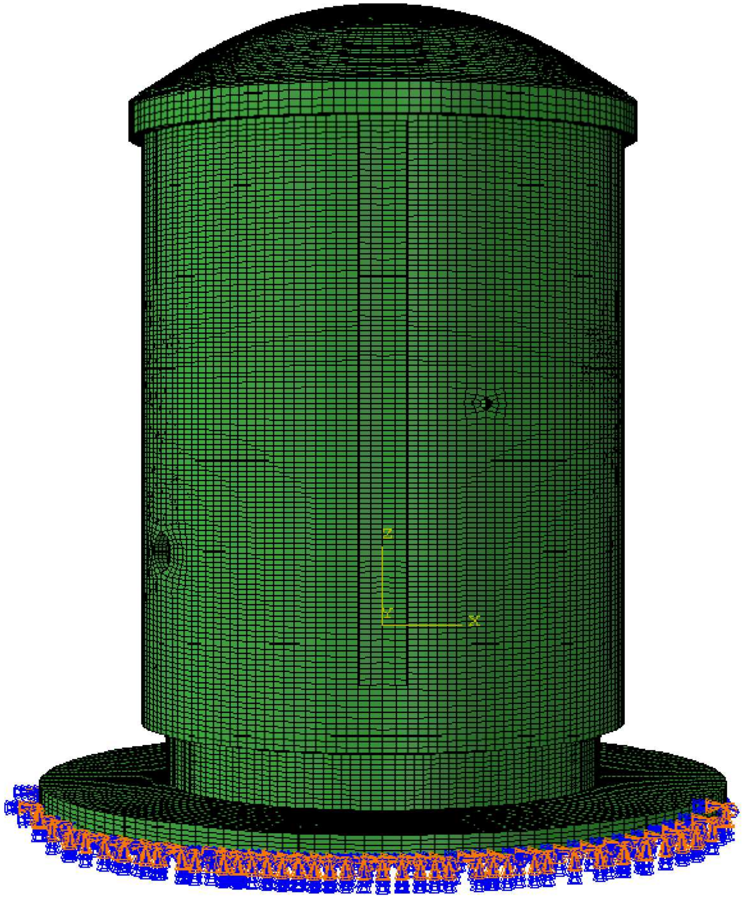
Element Information

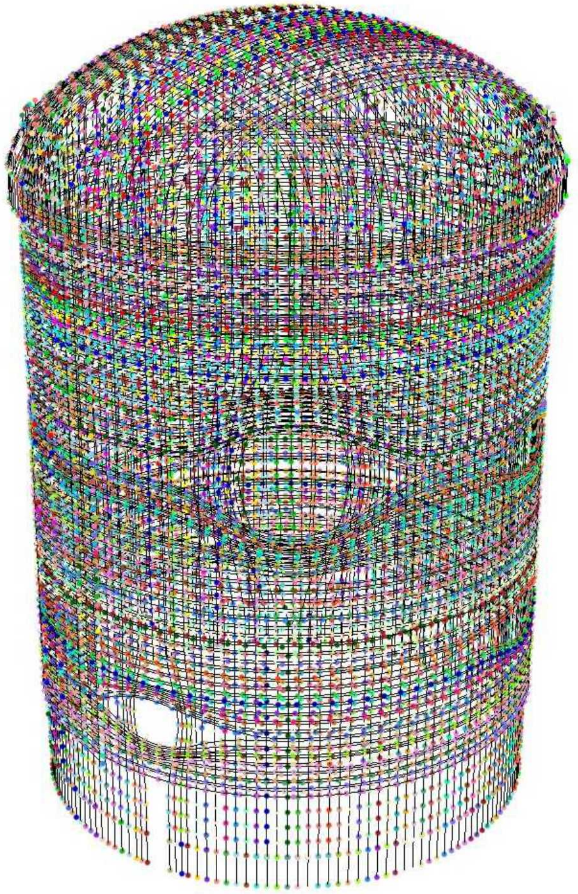


- Containment vessel:
  - 292,336 elements
  - 8-noded hexahedrons
  - 3 elements through thickness of the containment vessel wall
- Rebar:
  - 35,172 elements
  - 4-noded surfaces
- Tendons:
  - 44,466 elements
  - 2-noded bars

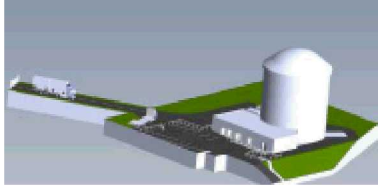
Concrete and Tendon Geometry and Boundary Conditions

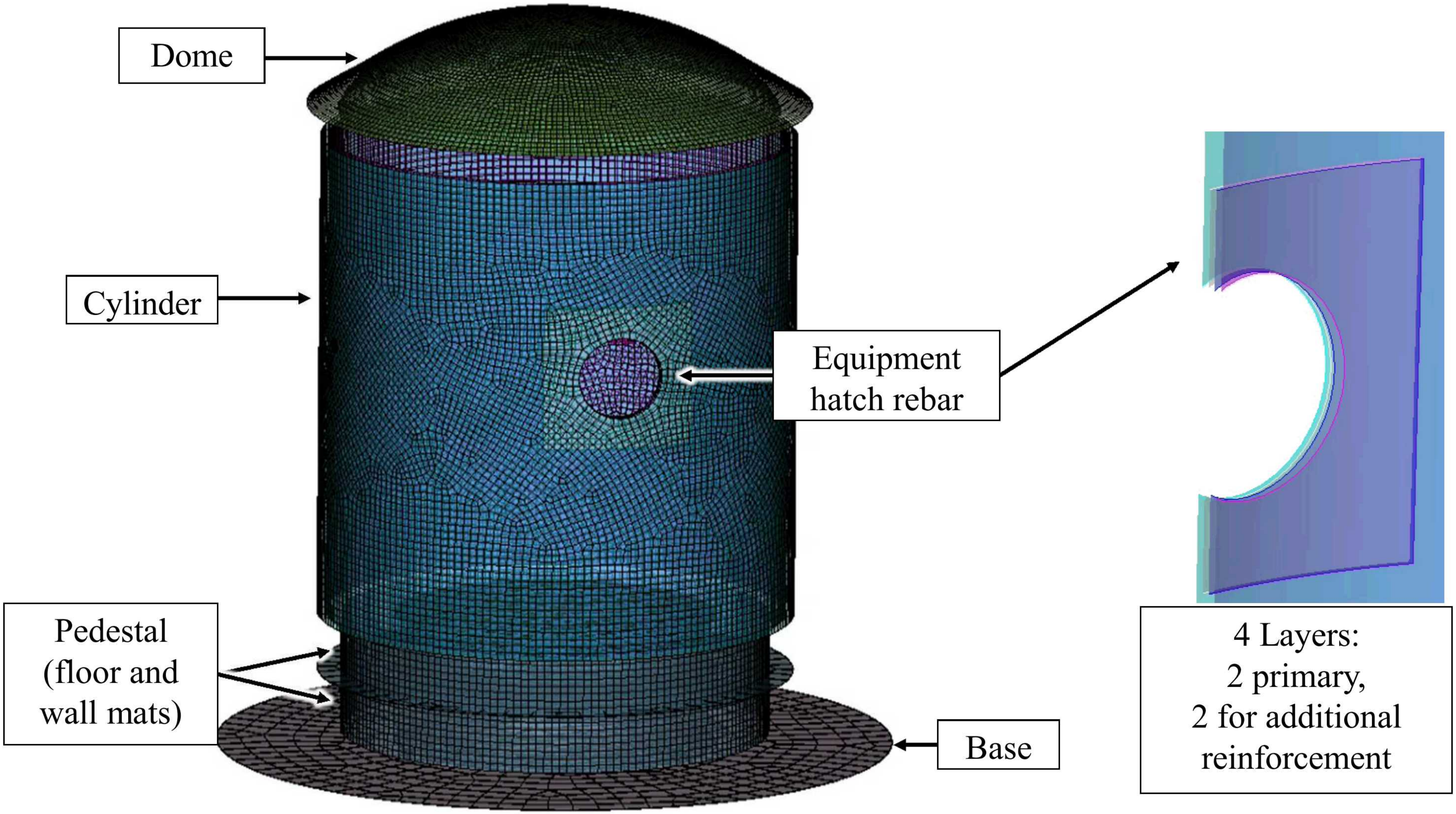






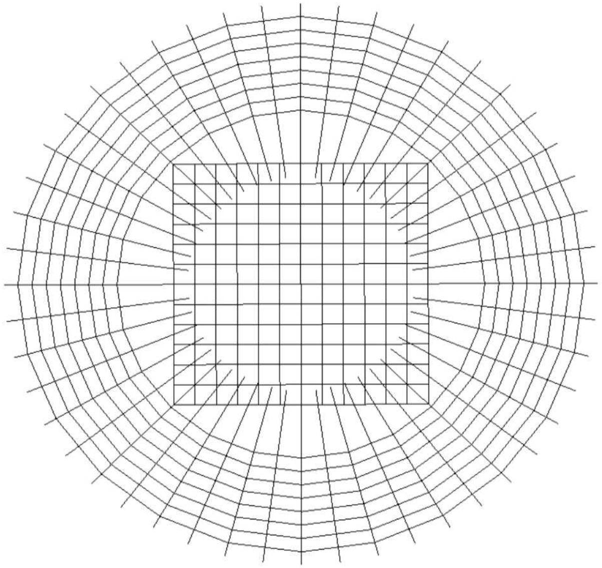
Rebar Mesh Overview



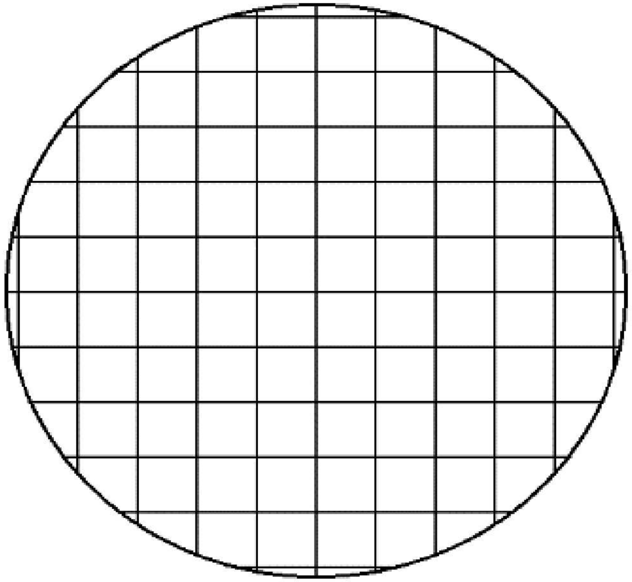


Rebar Floor Mat Geometry

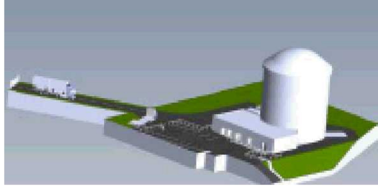
As Constructed
(schematic)



ABAQUS Representation
(schematic)

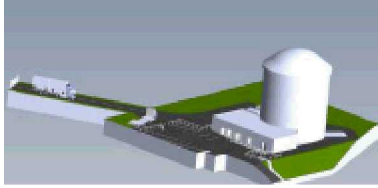


Tendon Posttensioning Stress



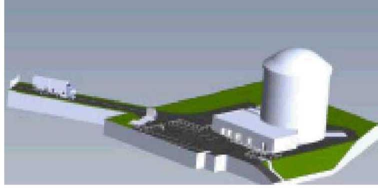
- All tendons given a single initial posttensioning stress calculated using given information
- Using the jacking force, elastic recovery, and relaxation losses (ρ_{1000}), the long-term stresses at the jacking location for the tendons were calculated:
  - Hoop tendons: 1418 MPa
  - Dome/vertical tendons: 1359 MPa
- Initial tendon applied stress (all tendons): 1400 MPa
  - Note: tendon stresses were seen to change over time due to concrete creep

Material Properties and Models



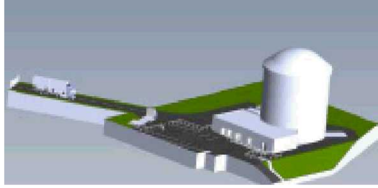
- Concrete:
  - Homogeneous linear viscoelastic
  - Young's modulus = 34.3 GPa, f'_c = 50 MPa, ν = 0.20
  - Prony series used to replicate creep behavior
- Rebar:
  - Linear elastic
  - Young's modulus = 200 GPa, f_y = 500 MPa, ν = 0.30
- Tendons:
  - Linear elastic
  - Young's modulus = 190 GPa, f_y = 1620 MPa, ν = 0.30
- No steel is expected to stress beyond yield
- All models (visco)elastic, so only Young's modulus and ν were required

Simulation Load History



- Simulation history begins on 17 Aug 2015, the date when posttensioning completed
- 10 seconds used to ramp gravity and posttensioning loads in simulation
- 77 days dormant period between posttensioning completion and zero-strain reference date (2 Nov 2015)
- Pressurizations modeled: Pre-op, VC1, VD1, VD1-bis, VD2
- Date end: 4 Apr 2018

FEA Computational Information

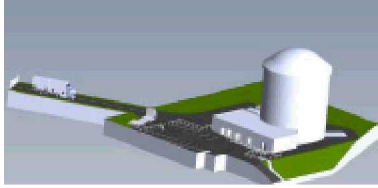


- Implicit time integration scheme
- FEA Code: ABAQUS
- Time step: varies
- Simulation run time on 10 processors: 17.7 hours

ABAQUS time step increments:

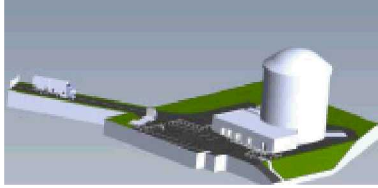
Step	Initial Time Step	Minimum Time Step	Maximum Time Step
Initialization	2.0 seconds	0.01 seconds	10.0 seconds
Pressurization	1.5 hours	0.5 hours	3.0 hours
Dormant period	5.0 days	0.25 days	50.0 days

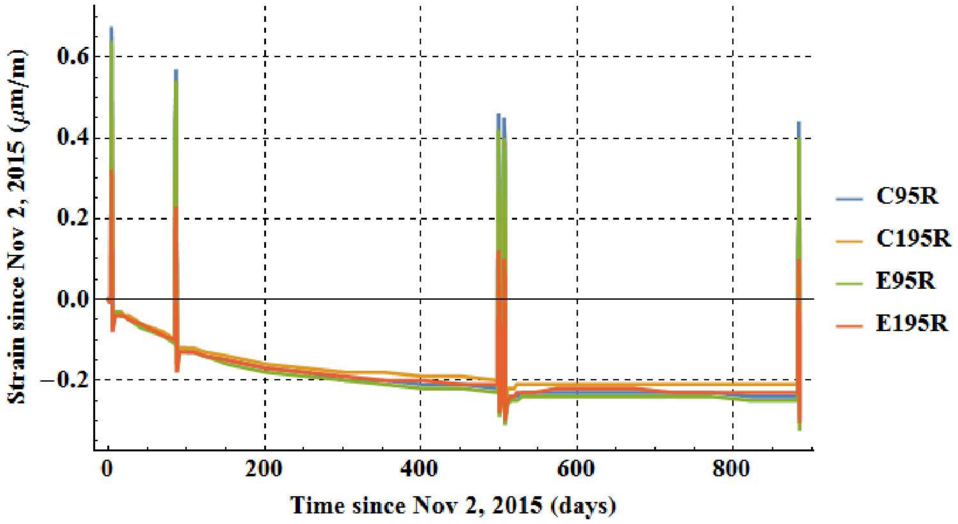
Simulation Animation

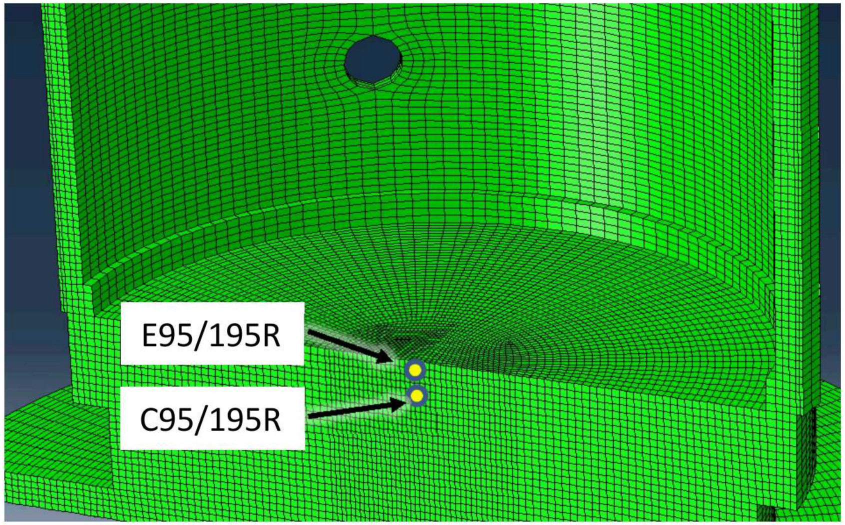


Deformation Scale: 2000

Strain Gages in Mass Concrete in Pedestal

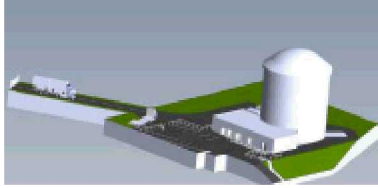


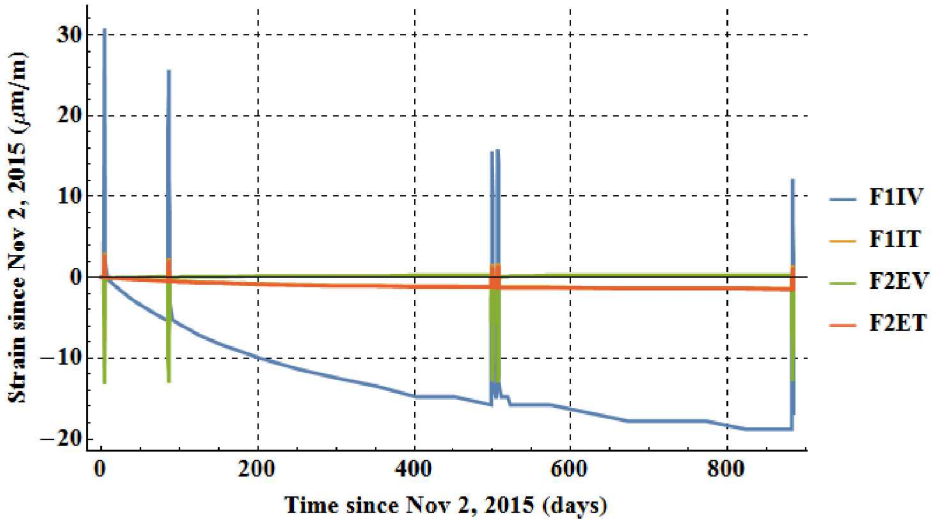


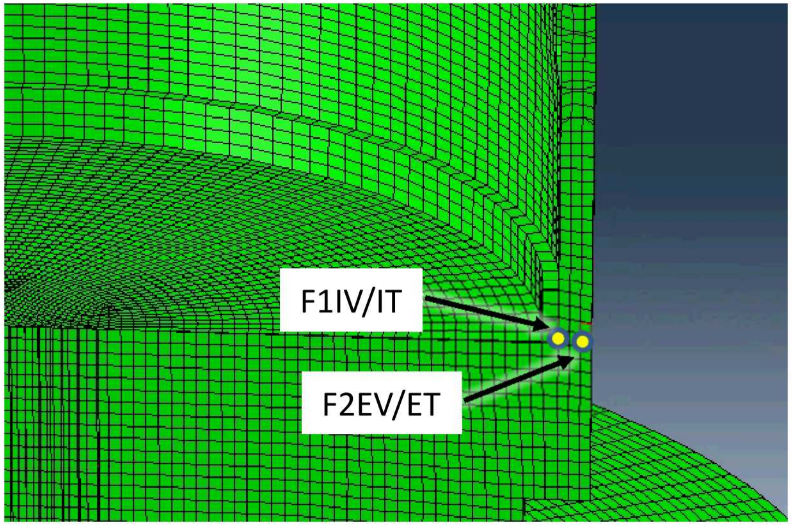


Experienced low strains relative to other gages, but creep effects were readily apparent.

Strain Gages on Gusset

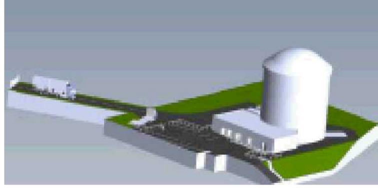




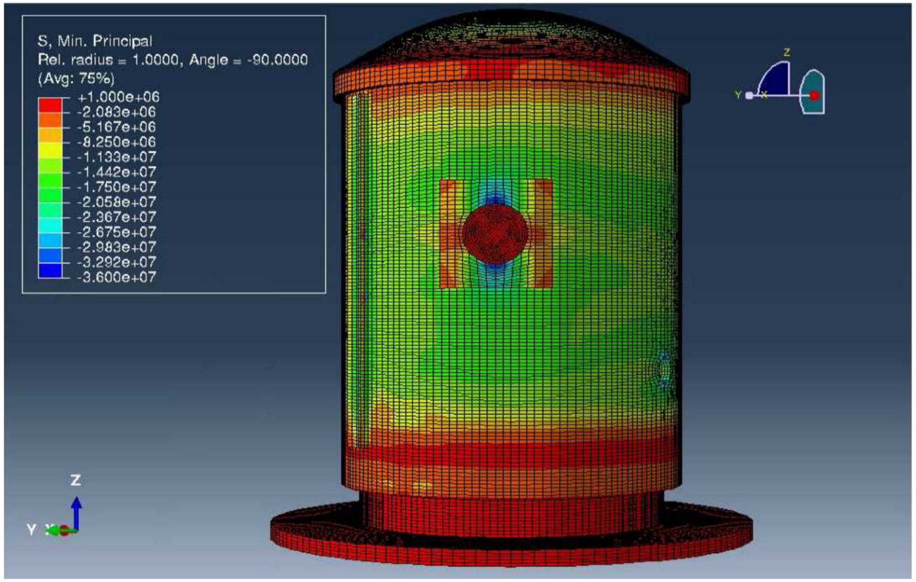


F1IV is located near the inner surface of the CV where the cylinder meets the base; this location is subject to large compressive strains during posttensioning, and is subsequently subject to large creep strains.

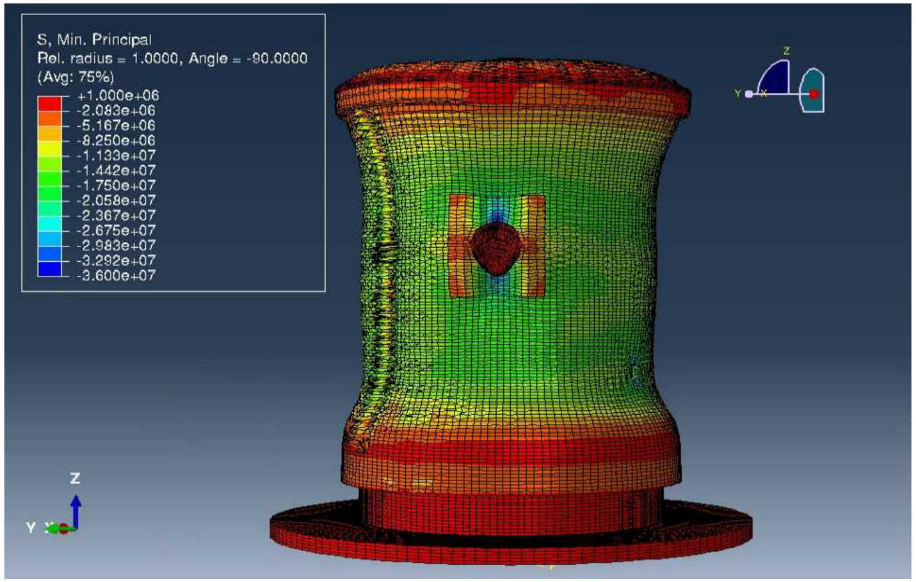
Maximum CV Compressive Stresses



Undeformed Shape

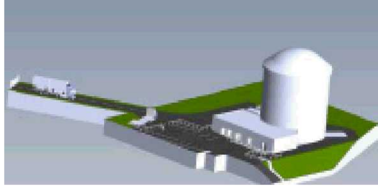


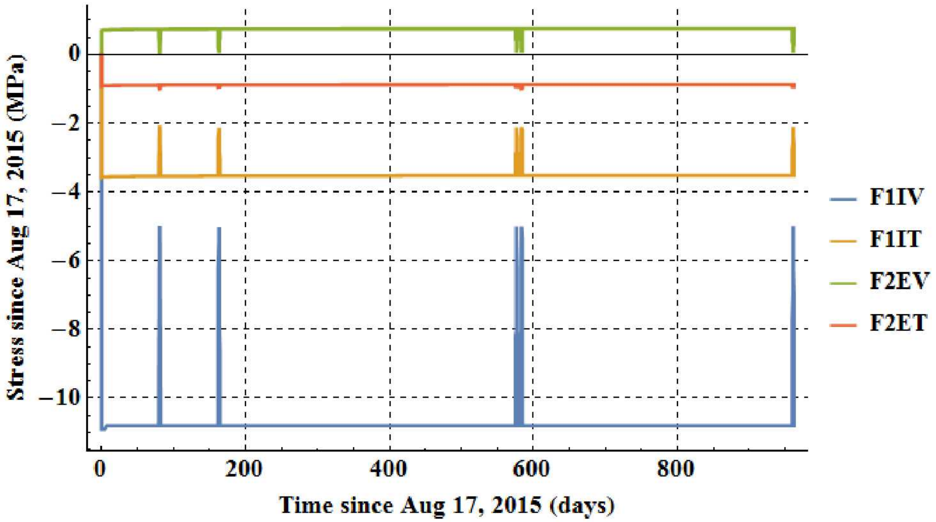
Deformed Shape

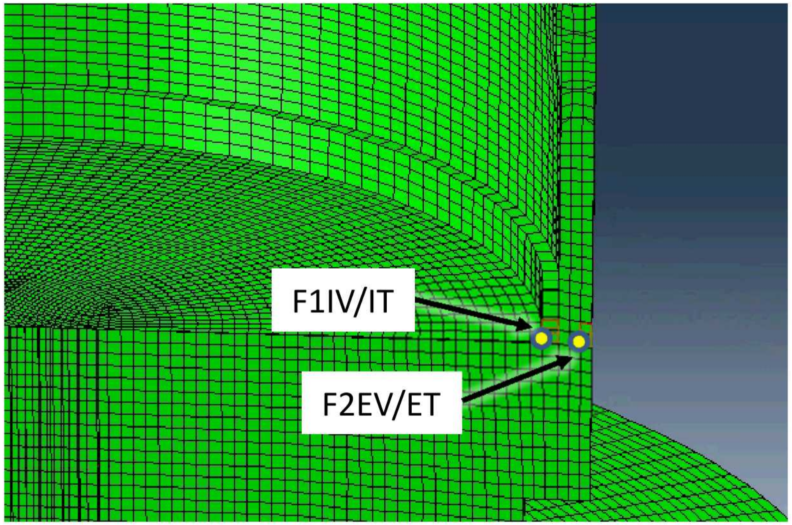


Deformation Scale: 2000

Stresses on Gusset

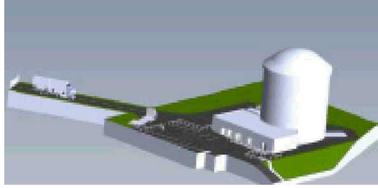


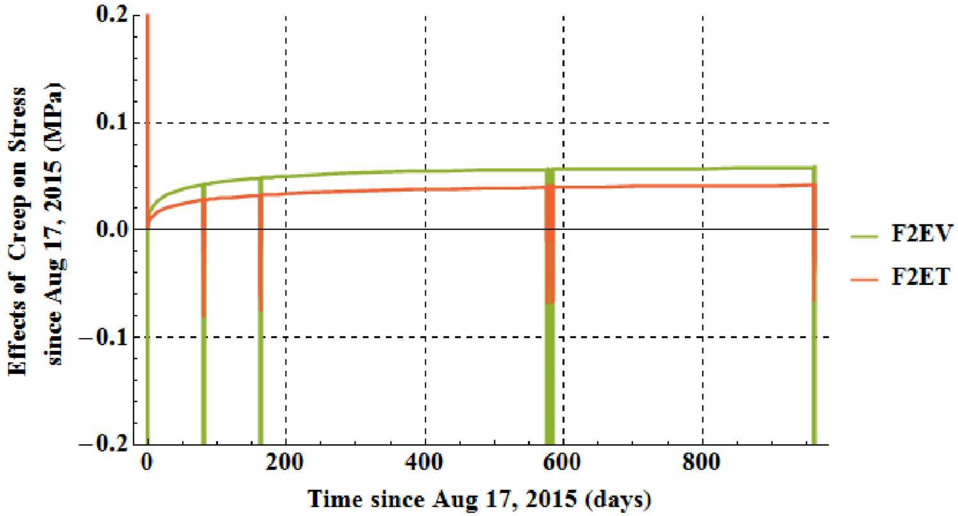


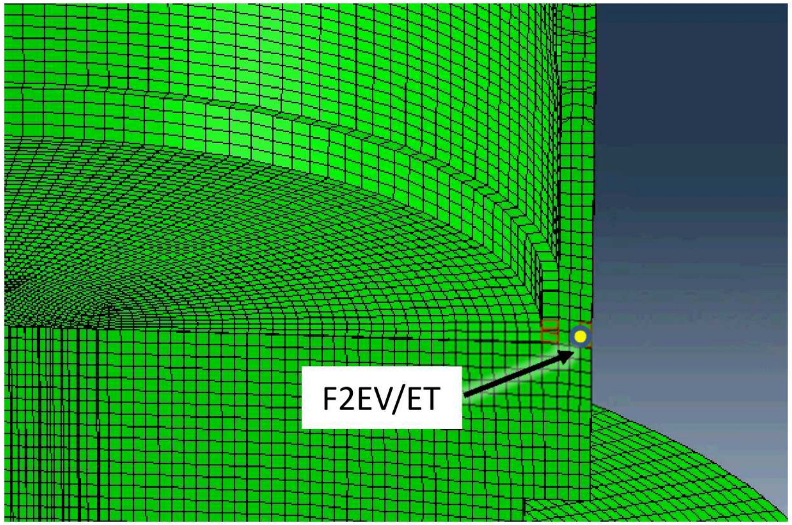


Strain gage F2EV experienced tensile stresses due to being on the outside of the CV where the cylinder meets the base. Neither posttensioning nor pressurizations increased stresses beyond yield, as expected.

Creep Stresses on Gusset

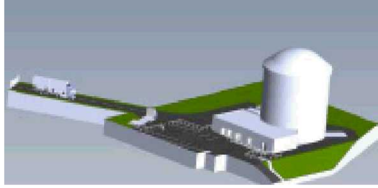






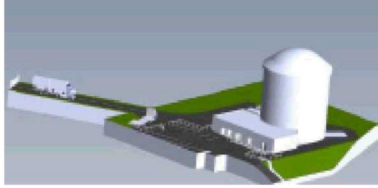
Concrete creep altered the stress by 7.8% and 4.8% for gages F2EV and F2ET, respectively.

Conclusions

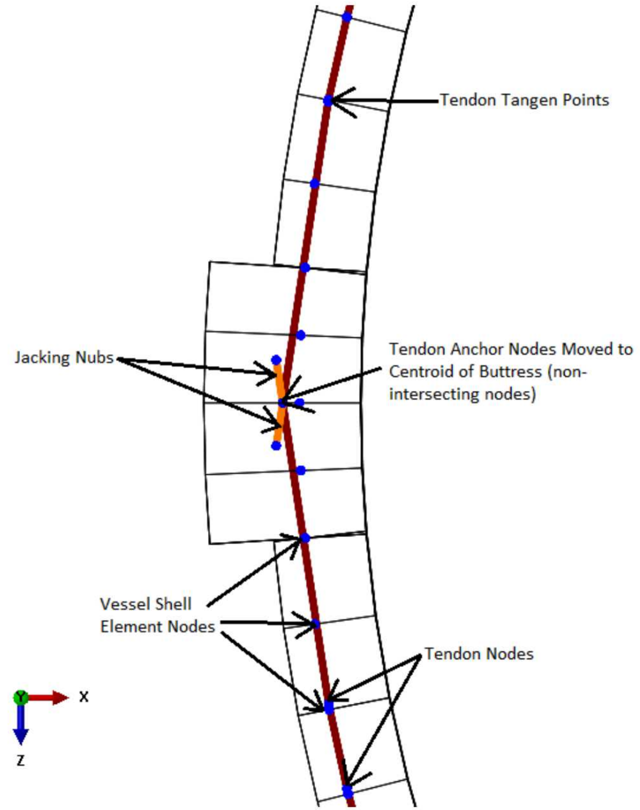


- The simulation captured posttensioning and creep effects. Future comparisons with experimental results will determine accuracy and/or precision of the simulation results.
- From these results, long-term creep strain is in the same range of strain magnitude that was caused by applied 4.2 bar internal pressurizations in posttensioned containment vessel.
- Pressurizations in the simulation did not create tensile stresses in the containment vessel. The region represented by gage F2EV actually reduced stress to almost zero during pressurization. All stresses were lower than the respective (tensile or compressive) concrete strength.
- Creep effects of concrete are predicted to alter stresses in the containment concrete as shown by strain gages F2EV and F2ET which had changes in stress of 7.8% and 4.8%, respectively, due to concrete creep.

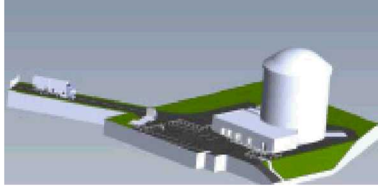
Future Plans

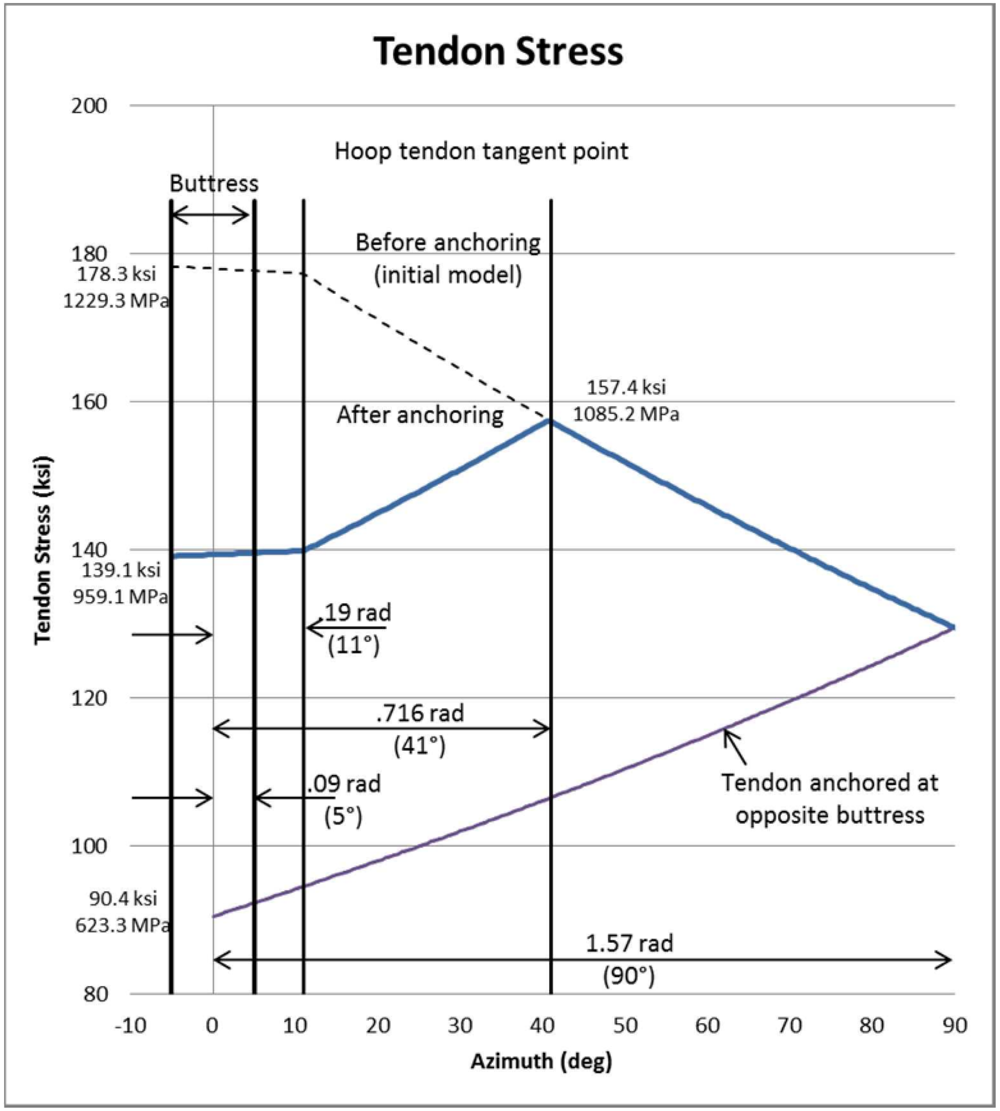


- Pull each tendon in order at jacking location
- Include friction effects
- Allow for concrete damage accumulation

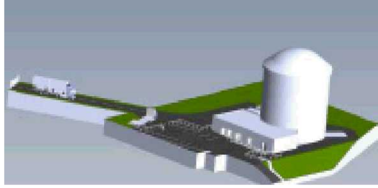


Allow for Varying Posttensioning





References



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