SAND2012-10195C

OECD WGIAGE Expert Meeting on

Post-tensioning Methodologies for Containment Building: Analytical Methods for Evaluating Corrosion in Grouted and Ungrouted Systems

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Villeurbanne, France

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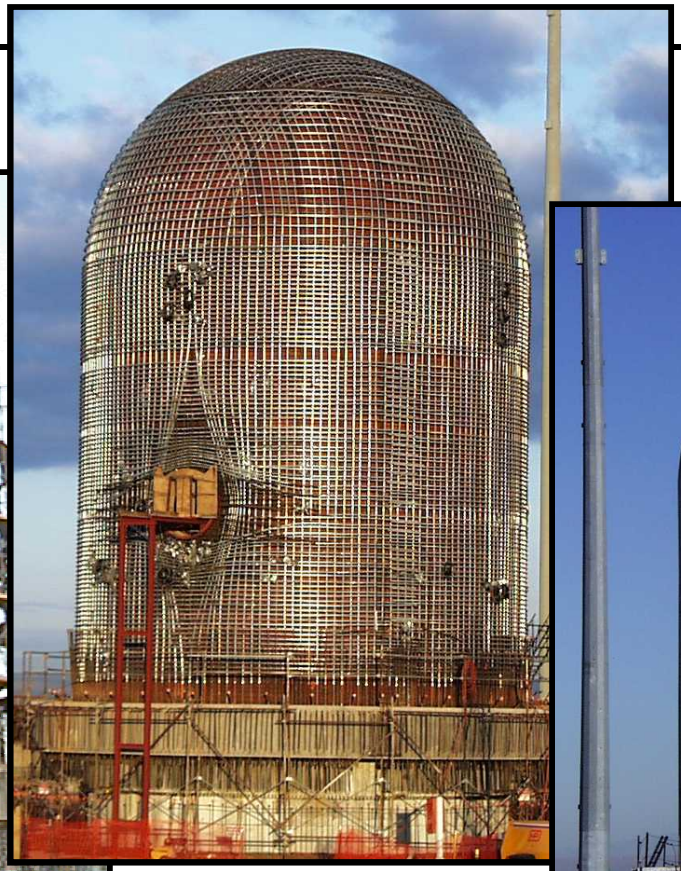
Long-Term Corrosion Protection Methods for Grouted and Ungrouted Systems

- Background
- FEA Modeling of Corrosion
  - Effective Area of Tendons Reduced
  - Corrosion Initiation
    - Before Grouting and/or Pressurization
    - After Vessel Pressurization
- Analysis Results
  - Comparison of grouted vs. ungrouted with corrosion
  - Effects of location of corrosion

Background

- USNRC investigating use of grouted versus ungrouted tendon systems in PCCV
  - Prior to 2010, only 1 operating containment in U.S. with grouted tendons
  - New plant applications requesting the use of grouted tendon systems
- Three topics to explore
  - investigation and comparison of structural behavior of PCCVs with grouted and ungrouted tendon systems
  - comparison of post-tensioning and in-service inspection methods
  - assessment of the durability and long-term corrosion protection for grouted and ungrouted tendons
- FEA used to model structural behavior
  - Behavior due to corrosion (assessing durability means assessing structure performance if corrosion were to occur
  - Comparing grouted vs. ungrouted for corroded tendons

FEA Studies Continuing to Utilize NUPEC/NRC/Sandia 1:4 Scale PCCV Model



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3D FE Modeling of Corrosion

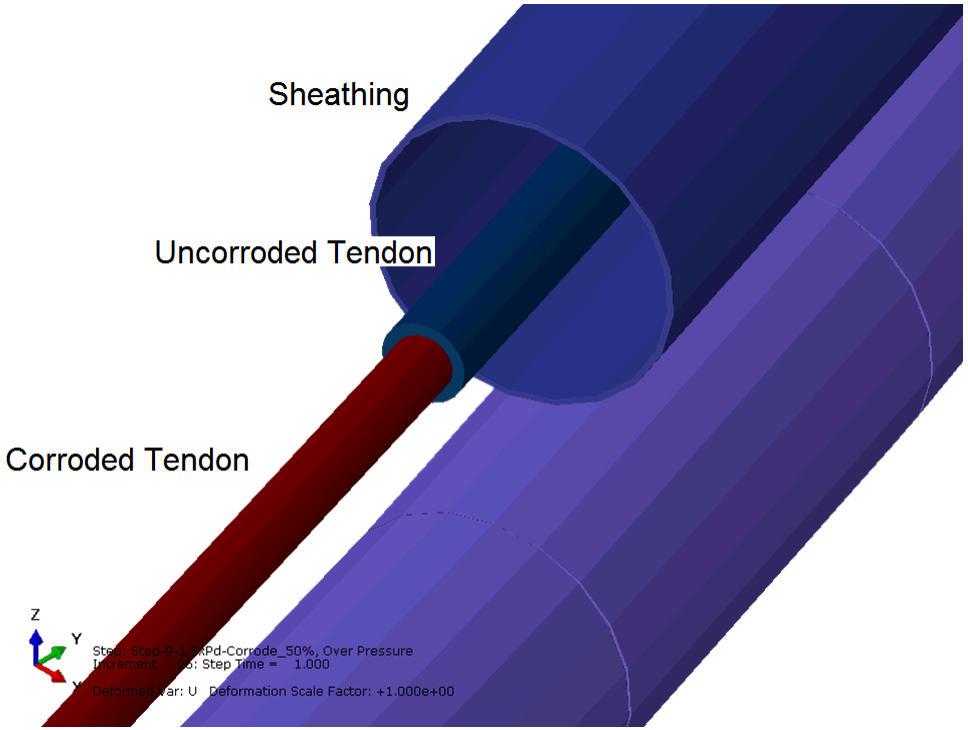
- Two potential corrosion cases postulated:
  - Near the wall-basemat juncture
  - Near the equipment hatch
- Certain areas of the vessel might suffer tendon corrosion, over time, and prior to occurrence of a severe accident.
- Simulation:
  1. Dead Load and Prestressing Loads applied to structure ("new structure")
  2. Certain tendon groups/regions down-sized to a smaller (corroded) tendon cross-sectional area; involves eliminating and replacing certain segments of tendon elements as an additional analysis step; structure equilibrium is re-established at the end of this step. Note that other "aging" conditions could be introduced, such as creep of concrete, steel tendon relaxation, aging of concrete properties; these have not been introduced in current study
  3. Severe accident pressure applied

Add'l Background – Prior FEA Studies

- **Current work is adding to the research and findings of Cherry and Smith.**
  - **J. A. Smith, "Capacity of Prestressed Concrete Containment Vessels with Prestressing Loss," Sandia Report, SAND2001-1762, Sept. 2001.**
  - **Cherry, B.W., and Price, S.M. 1980. "Pitting, Crevice and Stress Corrosion Cracking Studies of Cold Drawn Eutectiod Steels," *Corrosion Science*, Vol. 20, 1163–1183.**
- **Smith's research noted certain forms of corrosion influence the tendons in additional ways, other than section loss; i.e., reduction in ductility, reduction in effective ultimate strength.**
- **Current work distinction: 3D FEA representation. Previous studies used either sector or axisymmetric models so conclusions about behavior and failure mode were axisymmetric.**
  - **3D global FEA (enabled by current computational facility) can show non-axisymmetric behaviors and "early" failures associated with them.**

Modeling Corrosion

Corrosion modeled by reducing the effective area of the tendon elements.



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Modeling Corrosion

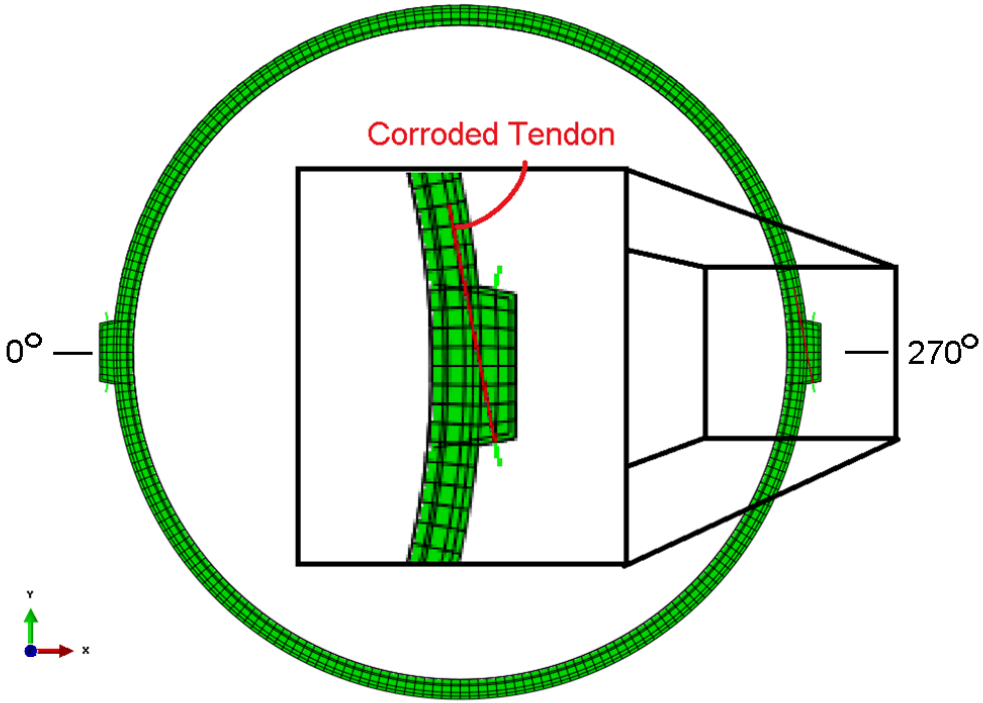
Two corrosion sequences investigated

- **Model 1:**
  - **Corrosion occurs after internal pressure at various milestones. Grouting, if done, is applied before pressurization.**
  - **This allows the analyst to verify the expected behavior.**

- **Model 3:**
  - **Corrosion occurs on unpressurized vessel on ungrouted tendons. Tendons are then grouted or left ungrouted, and internal pressure increased.**
  - **This captures the global structural response.**

Analysis Results

Model 1 – Corrosion Initiated after Pressurization of Vessel - Ungrouted



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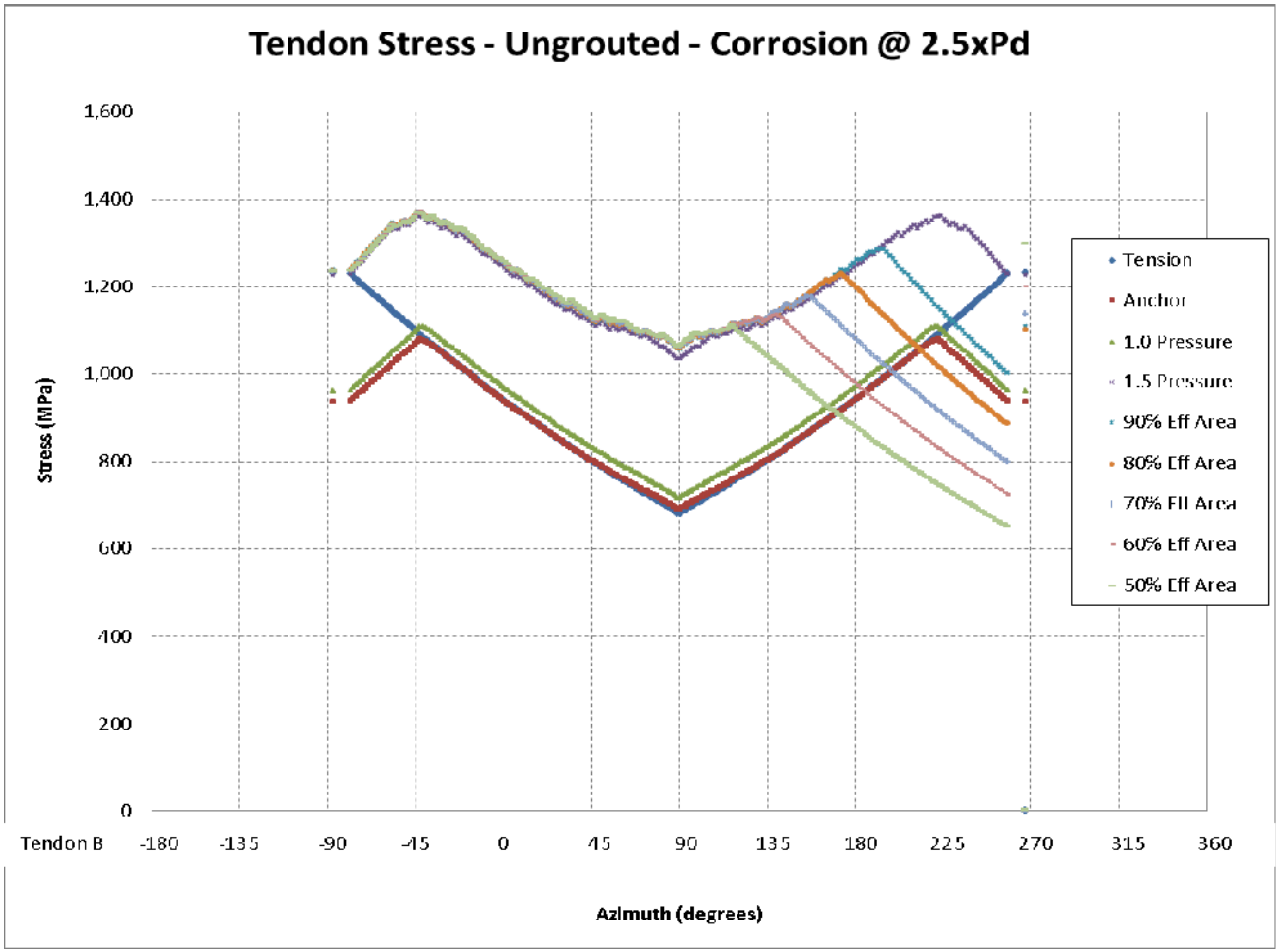
Analysis Results

Typical Tendon Anchored at 270°Buttress



- This is the affected tendon from the previous slide.
- The reduction in stress extends over several tens of degrees

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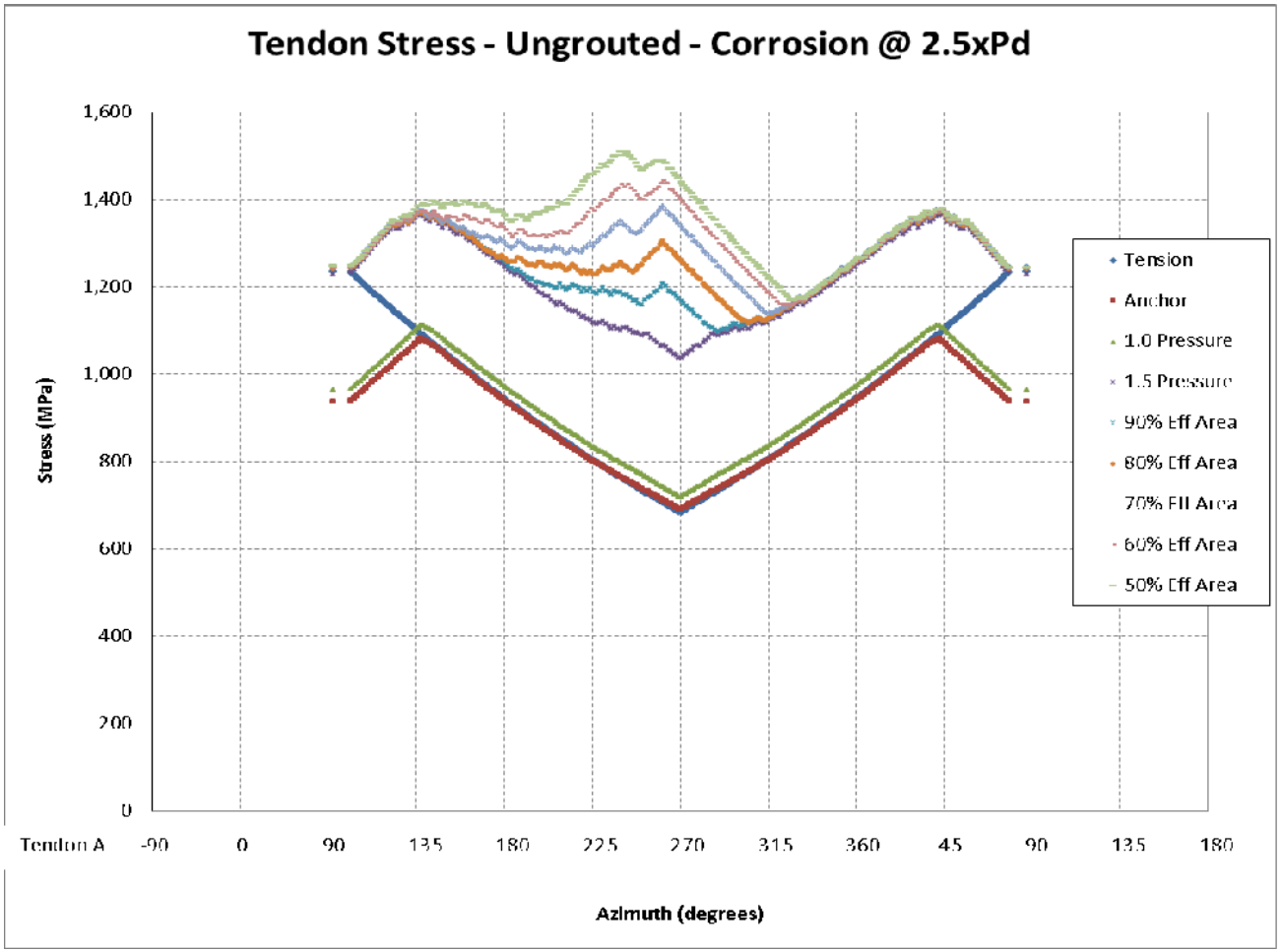
Analysis Results

Typical Tendon Anchored at 90°Buttress



- This is the unaffected, adjacent tendon.
- This tendon carries the load that the corroded tendon dropped.

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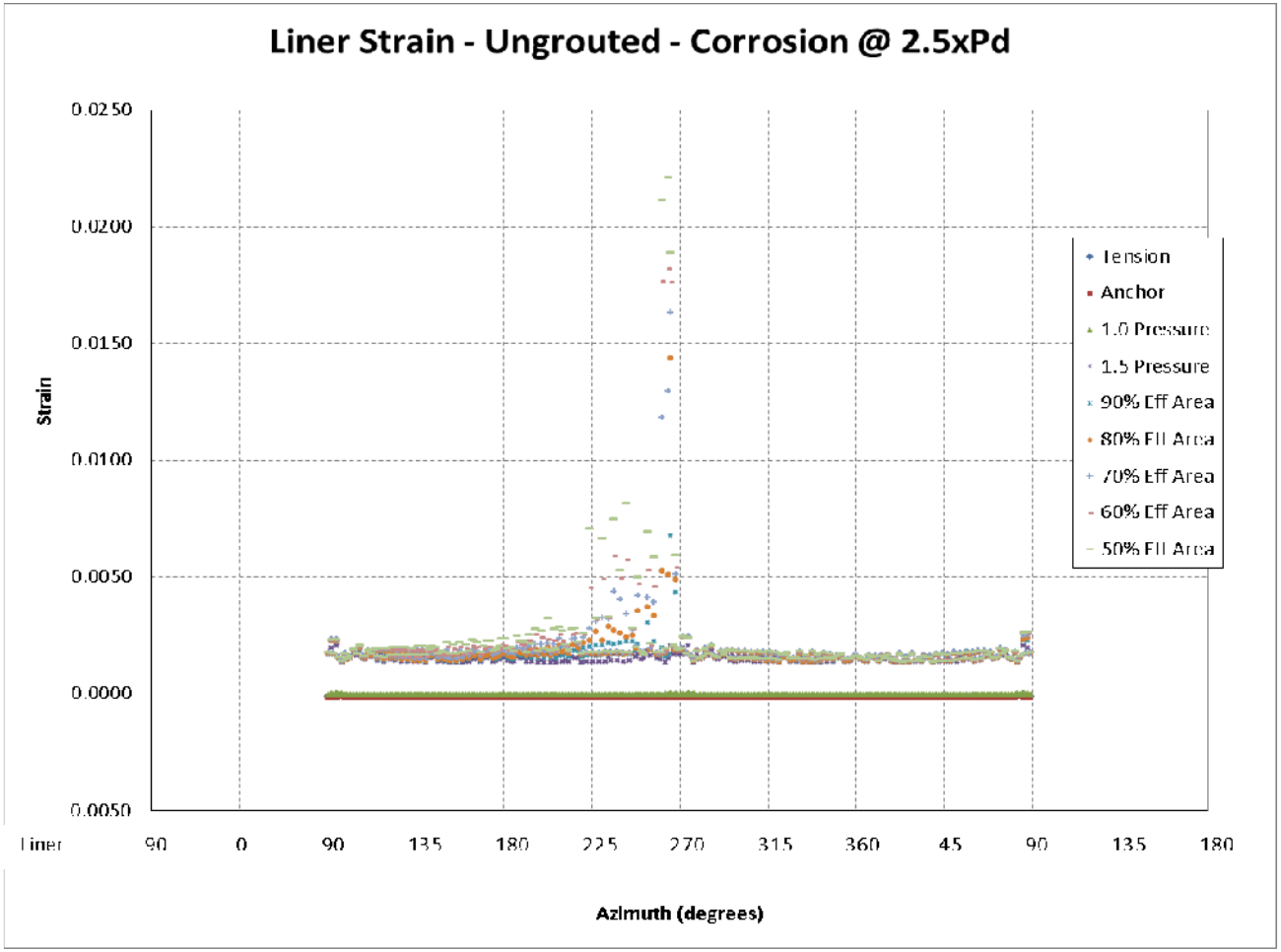
Analysis Results



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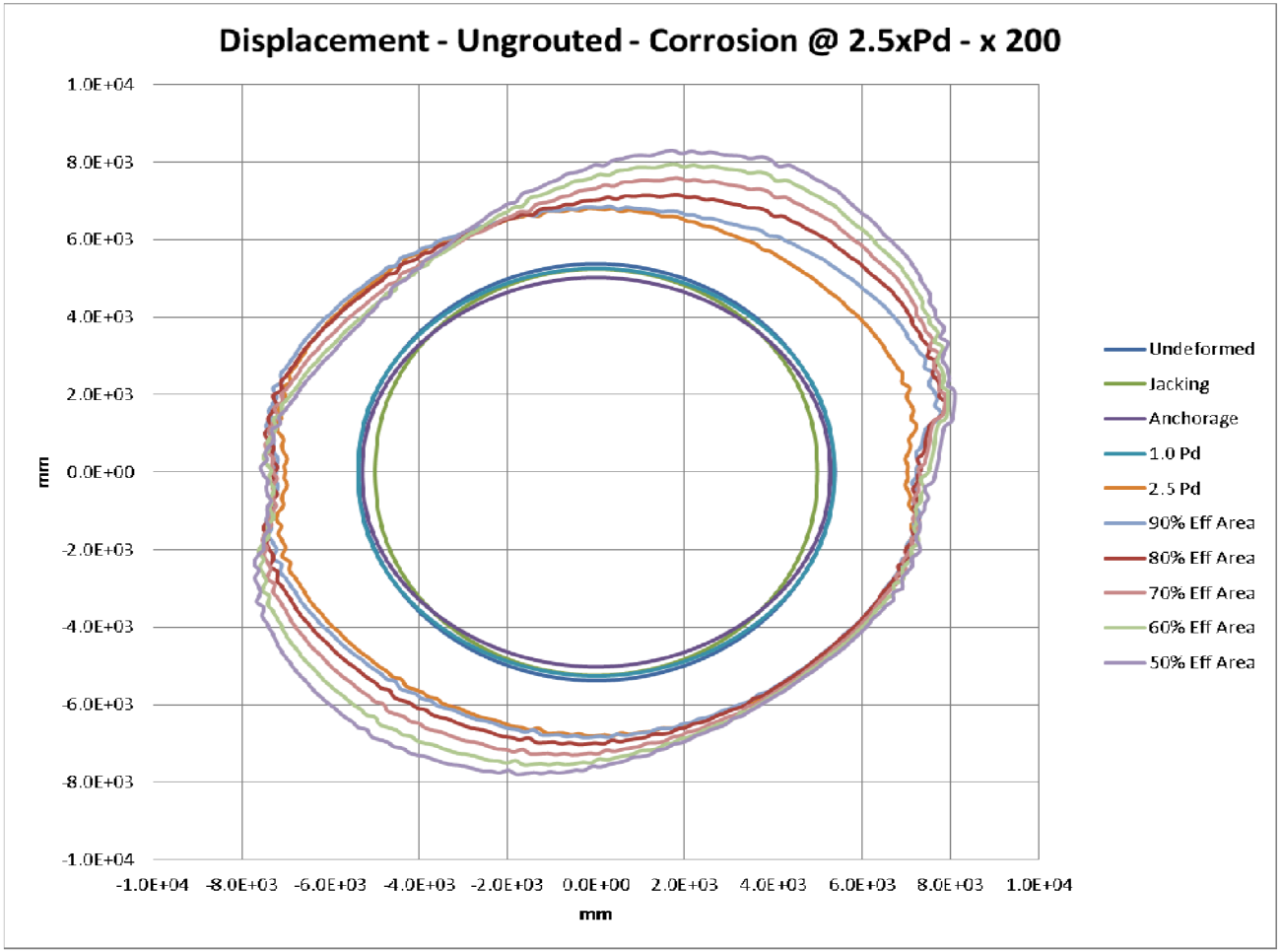
Analysis Results



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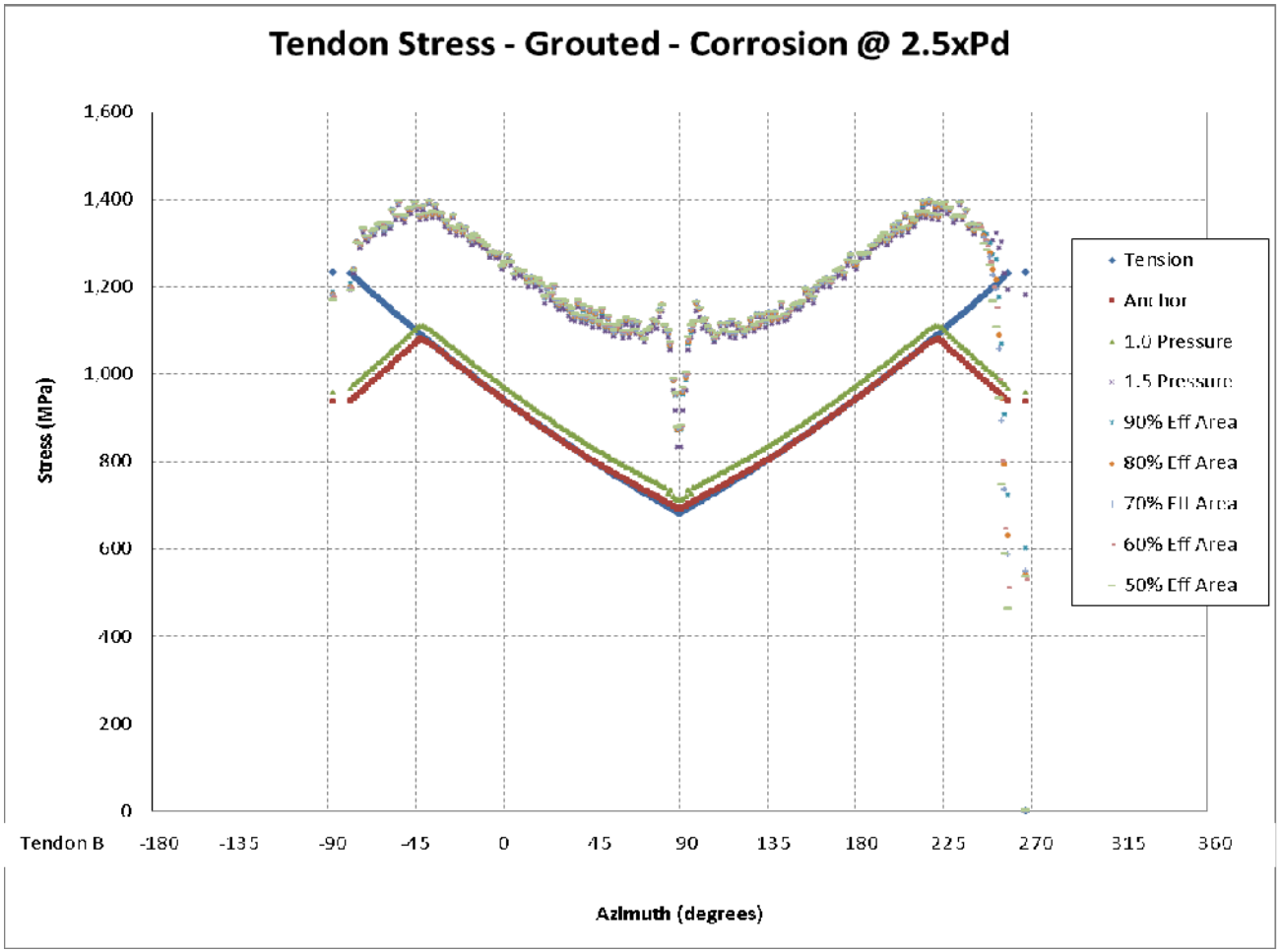
Analysis Results

Model 1 – Corrosion Initiated after Pressurization of Vessel - Grouted

Analysis Results

Tendon Anchored at 270°Buttress



- This is the corroded tendon.
- The reduction in stress is much more localized for the grouted case.

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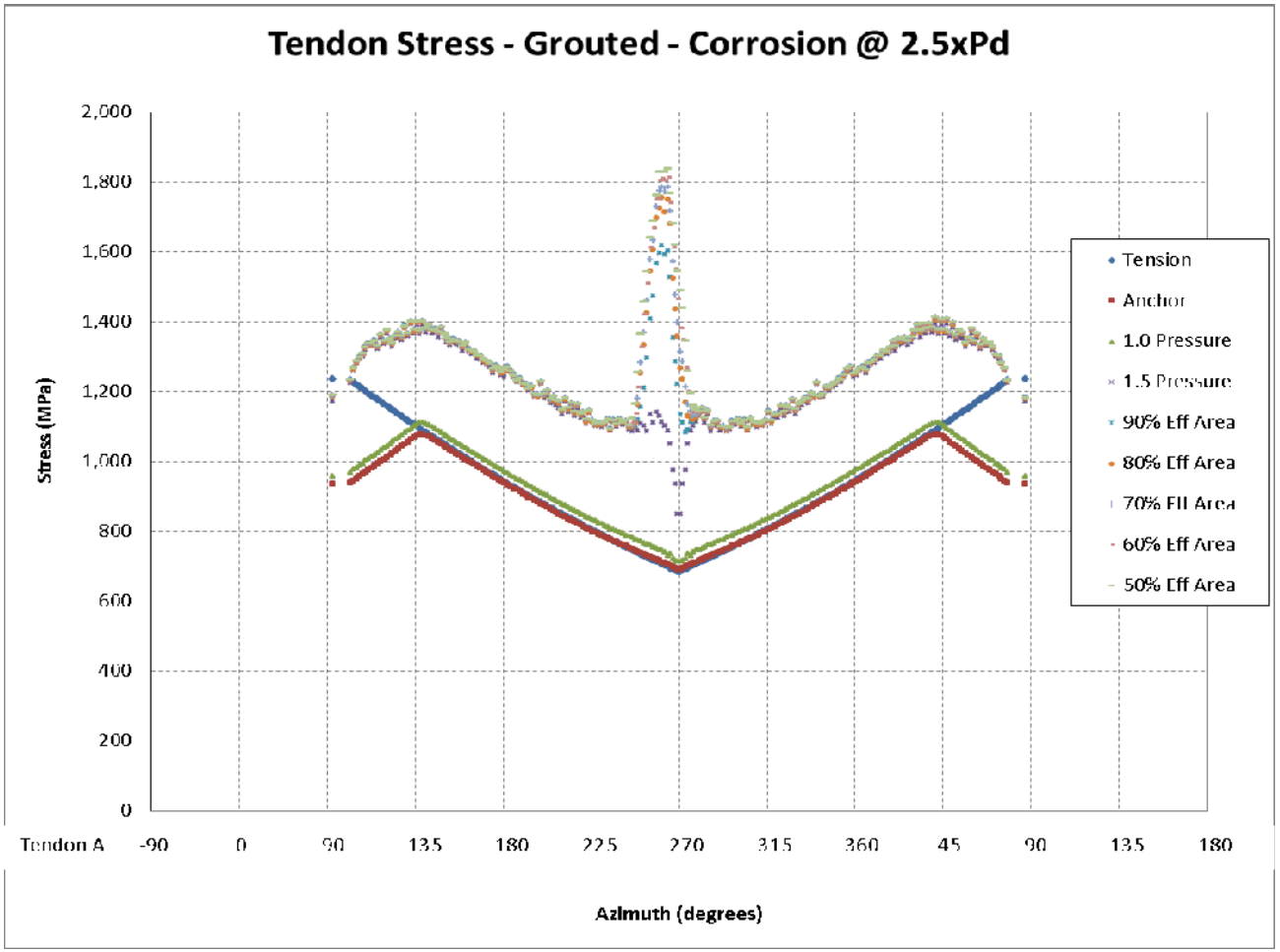
Analysis Results

Tendon Anchored at 90°Buttress



- This is the un-corroded tendon.
- As for the ungrouted case, the adjacent, unaffected tendon carries the load from the corroded one.
- The affected region is more confined.

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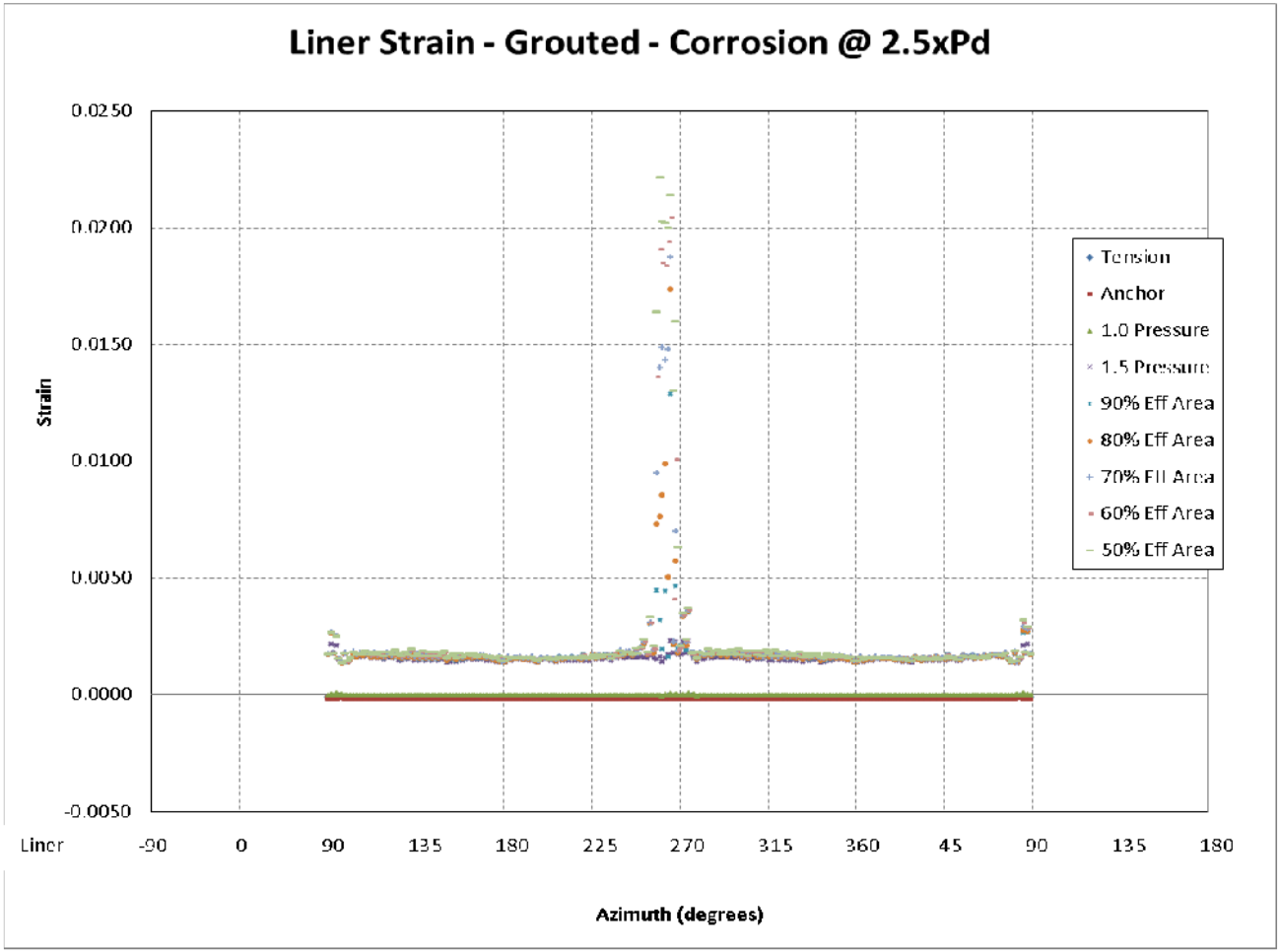
Analysis Results



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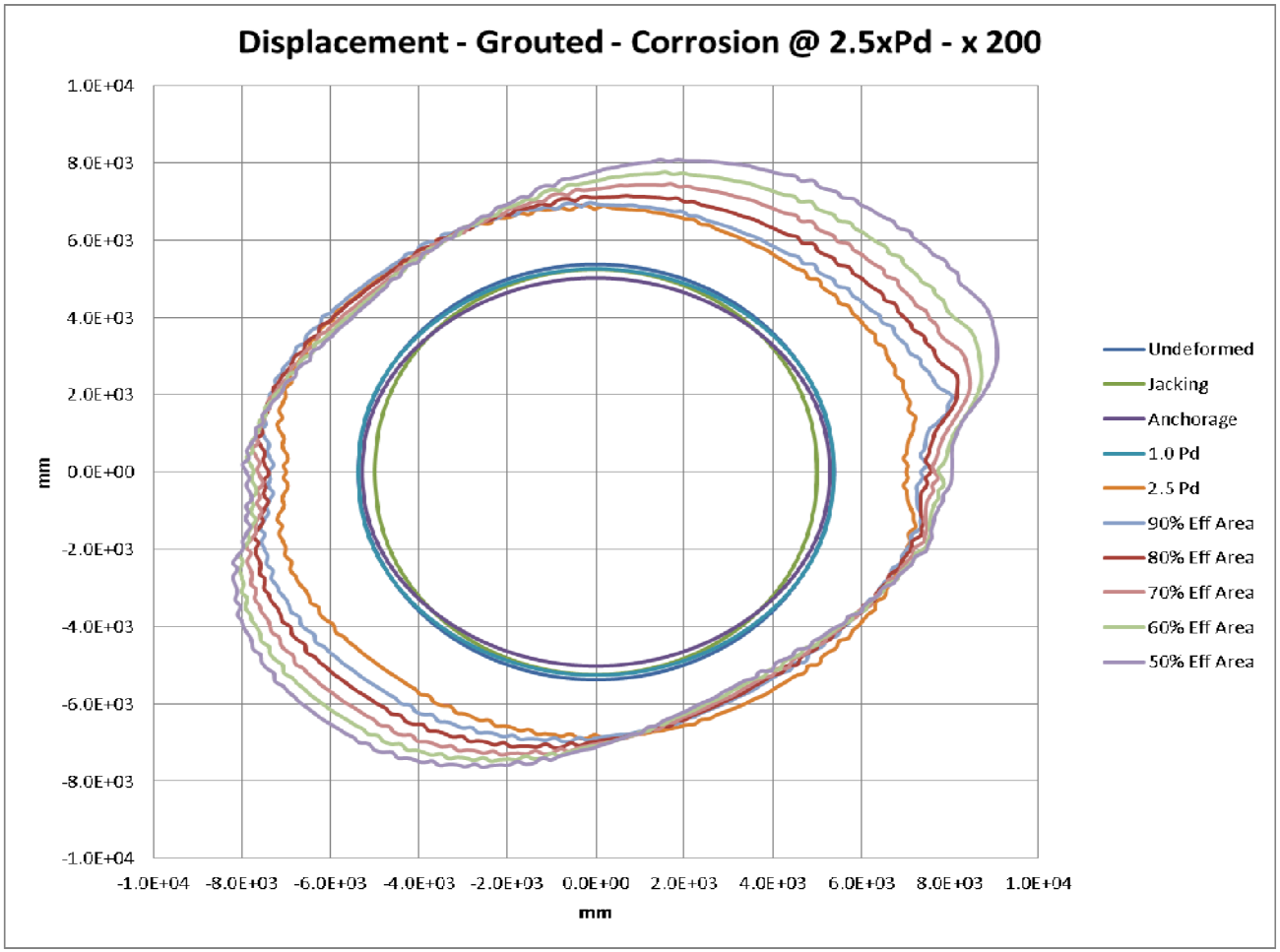
Analysis Results



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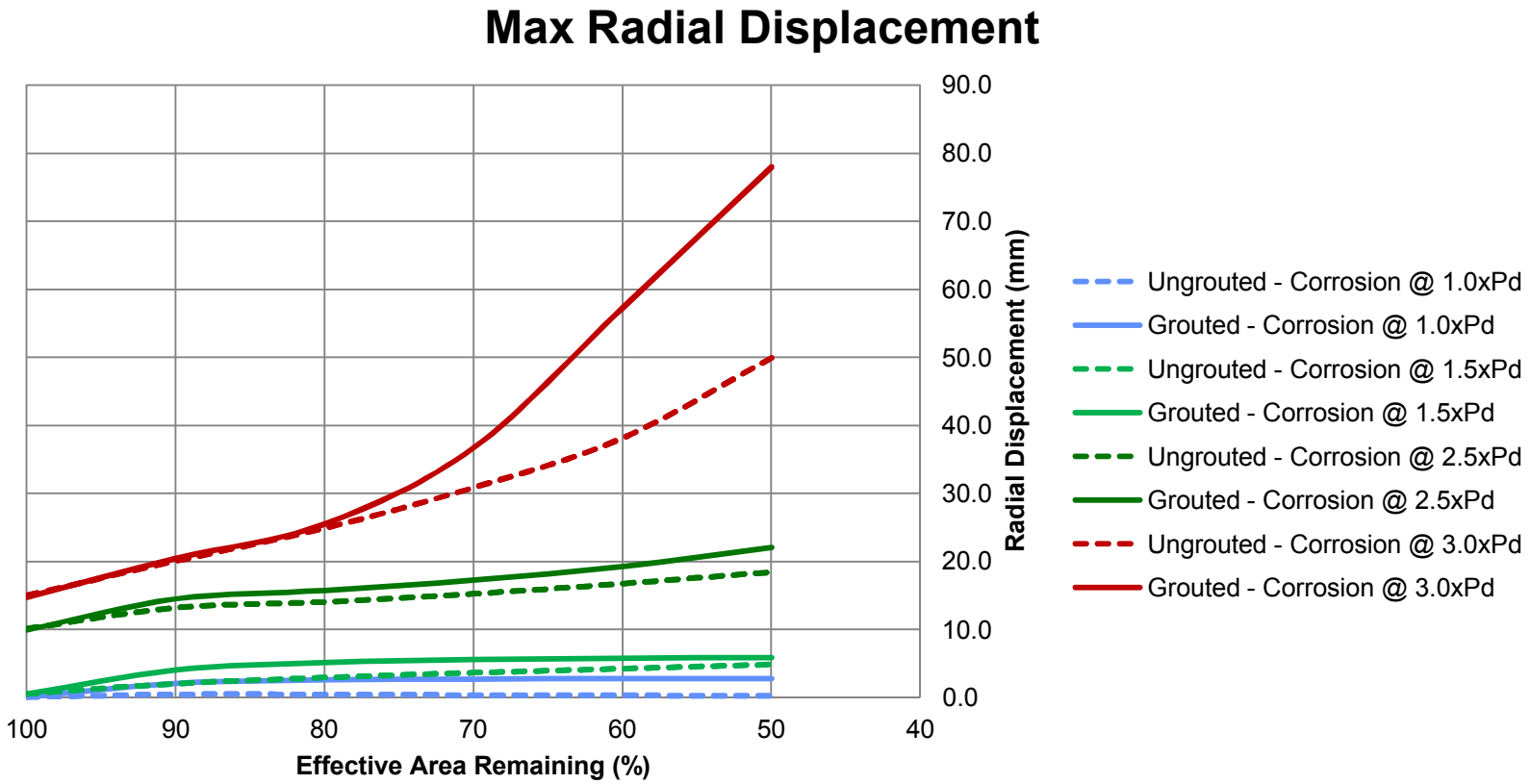
Analysis Results (Using Model 1)



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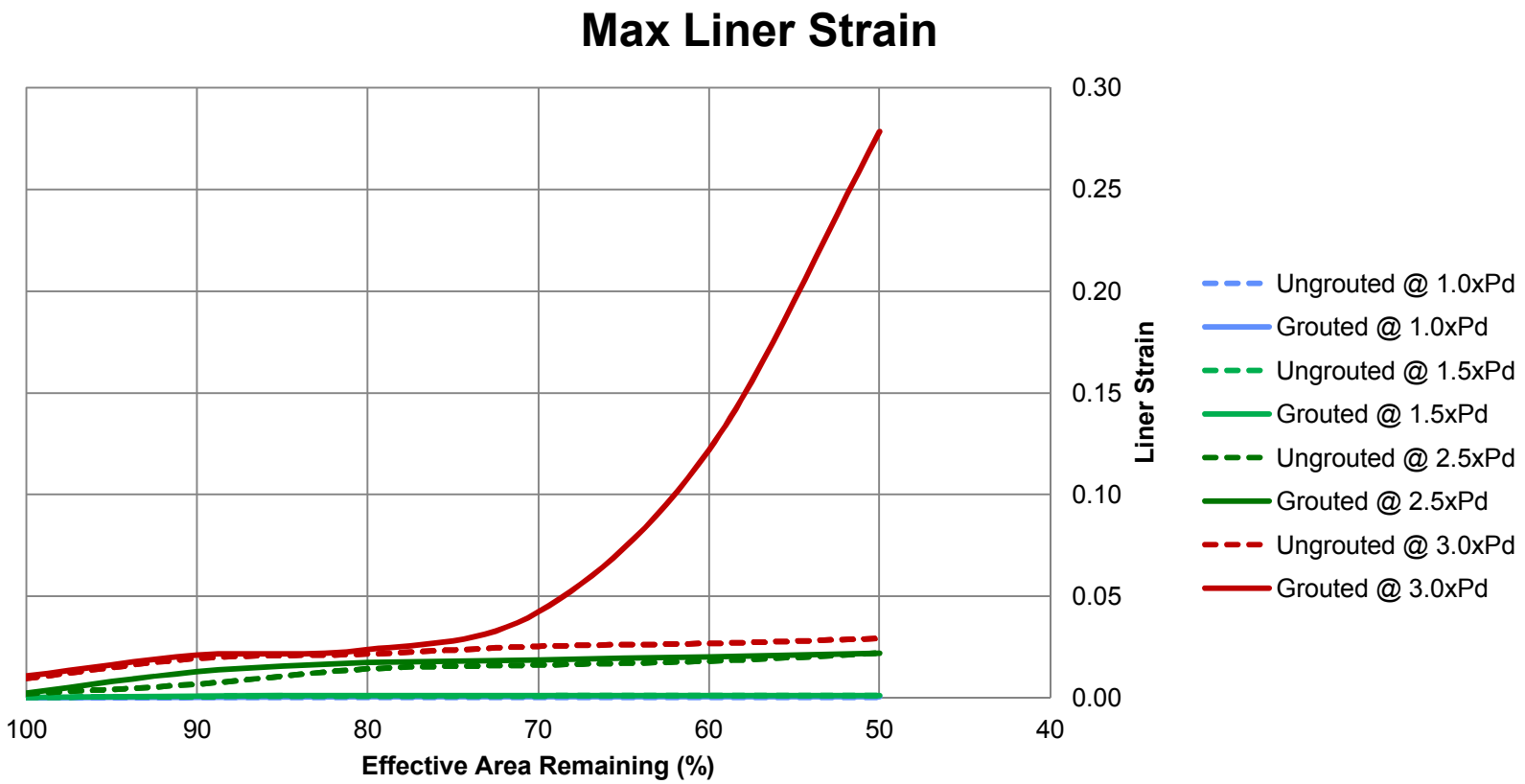
Analysis Results (Using Model 1)



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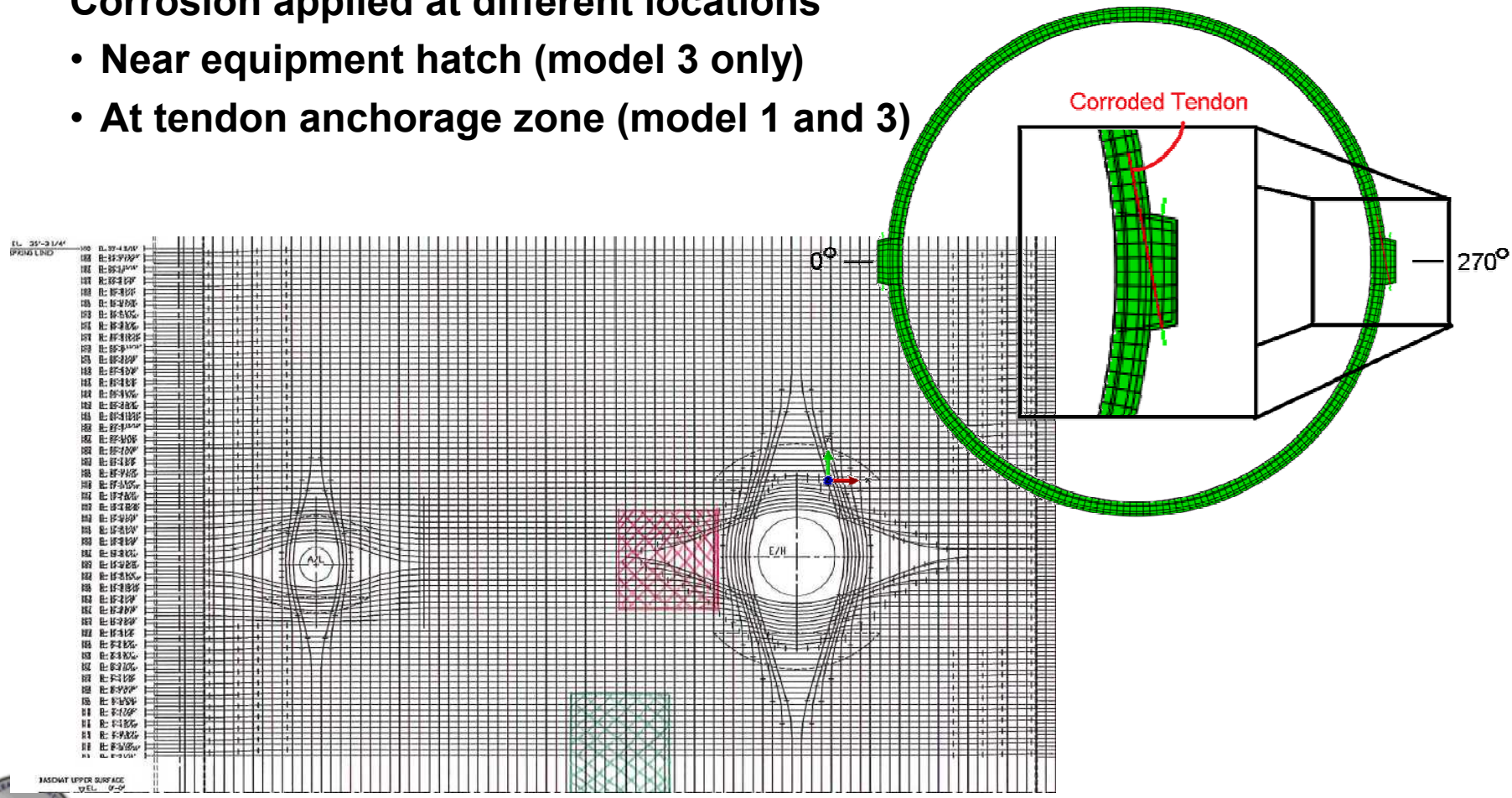
Modeling Corrosion

Corrosion applied at different locations

- **Near equipment hatch (model 3 only)**
- **At tendon anchorage zone (model 1 and 3)**



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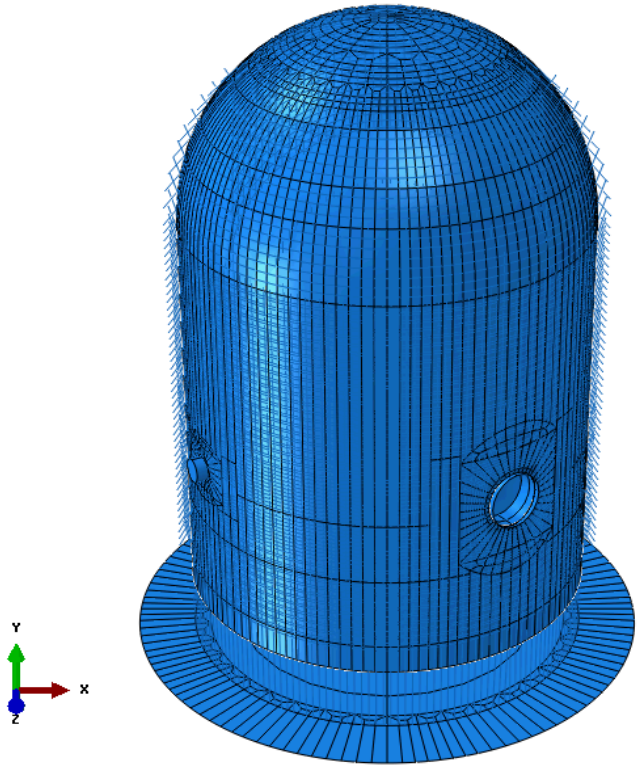
Analysis Results

Model 3 – Corrosion Initiated before Pressurization of Vessel

Case 1-Corrosion of the vertical tendons near the basemat-wall juncture



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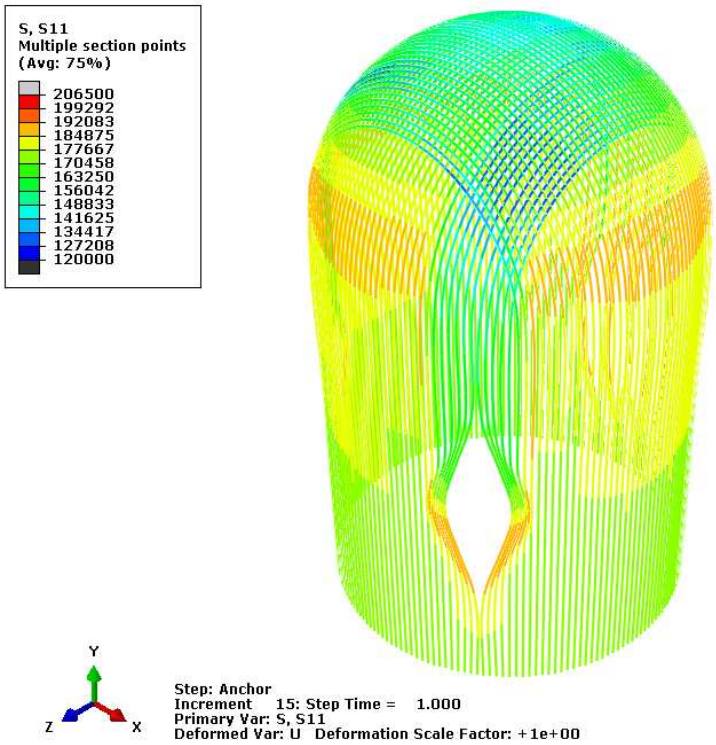
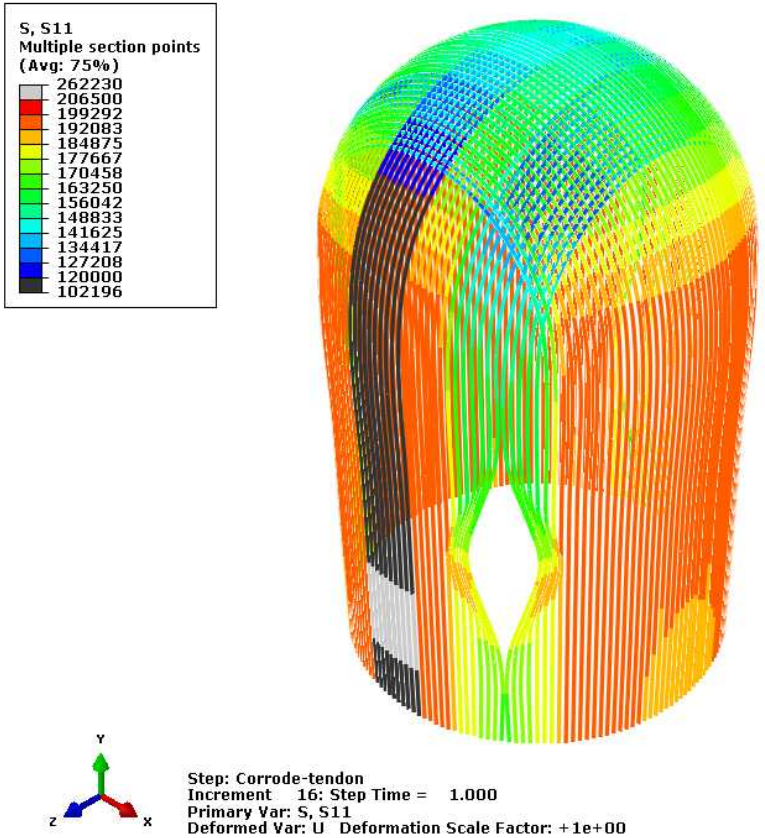
Analysis Results

No Corrosion



Corrosion with 40% Section Loss



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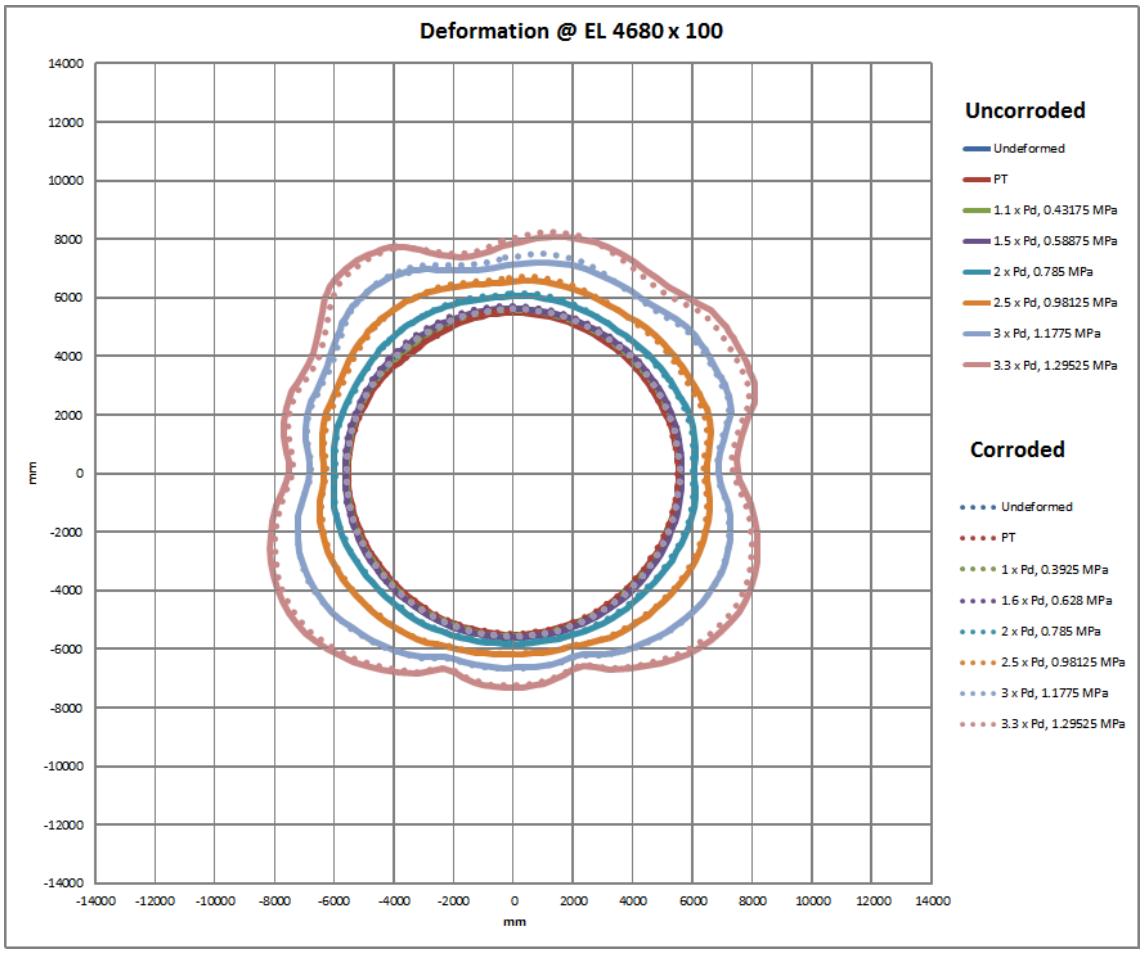
Analysis Results (Model 3 Midheight)

Ungrouted



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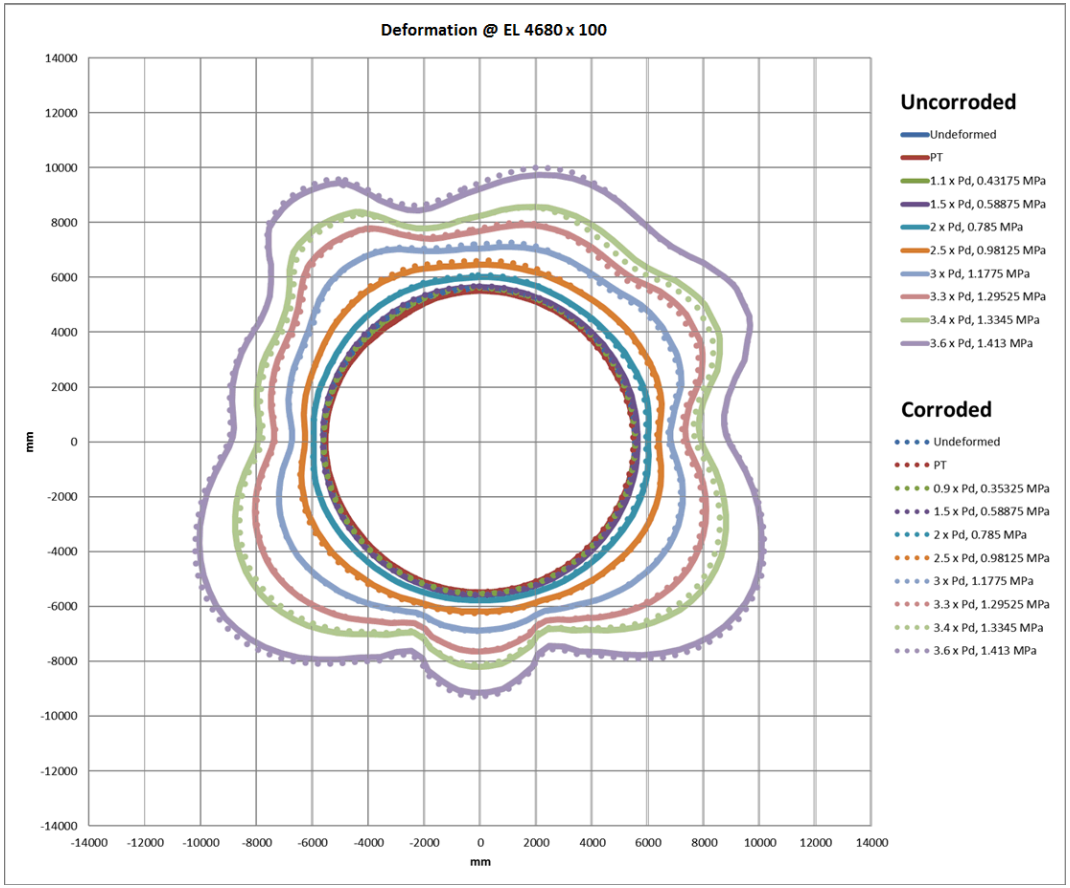
Analysis Results (Model 3 Midheight)

Grouted



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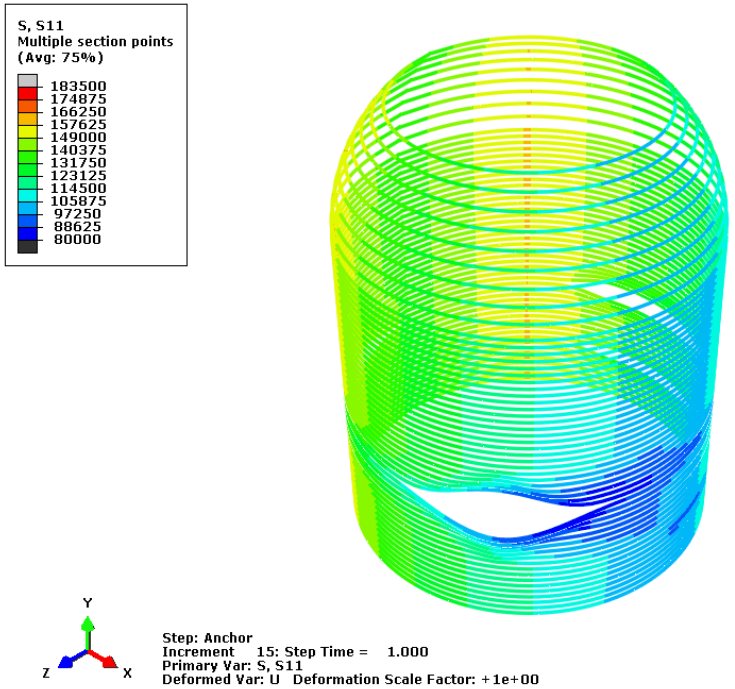
Analysis Results

Model 3 – Corrosion Initiated before Pressurization of Vessel

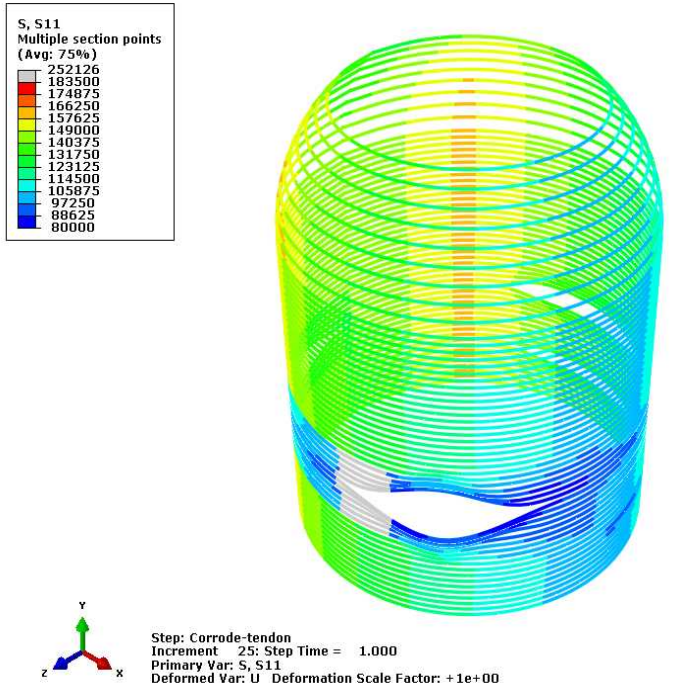
Case 2 – Corrosion of the hoop tendons near the equipment hatch

Analysis Results

No Corrosion



Corrosion with 40% Section Loss



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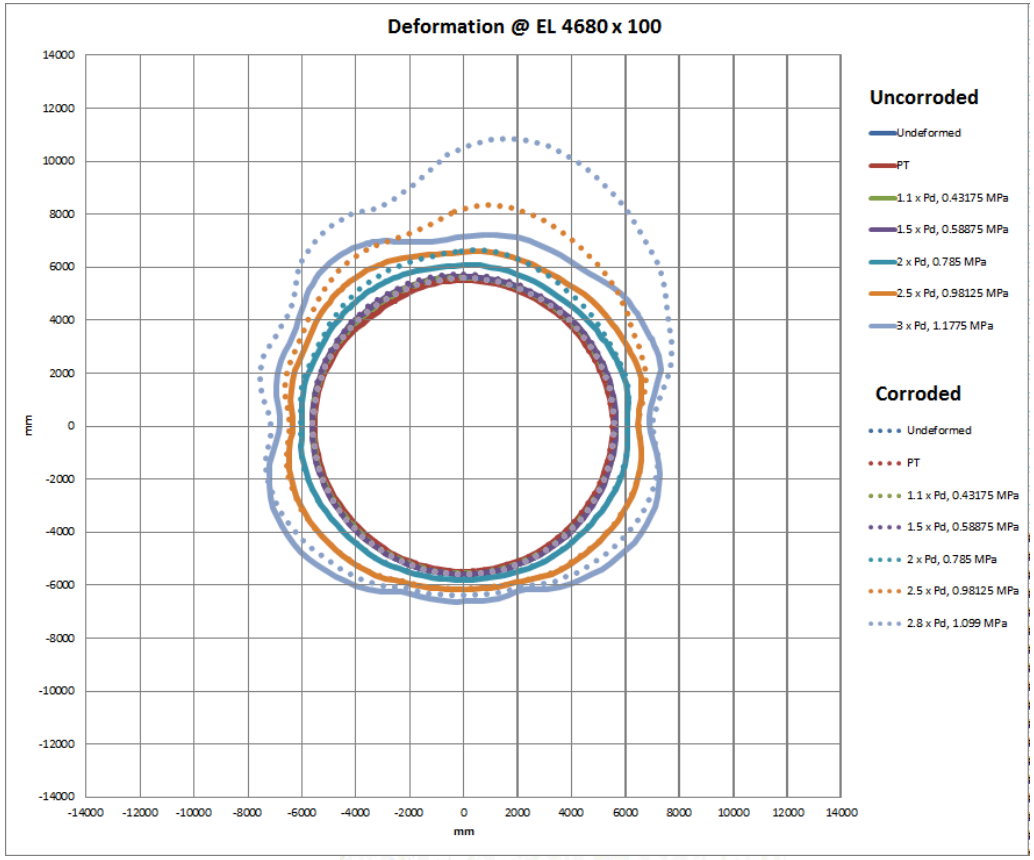
Analysis Results (Model 3 Midheight)

Ungrouted



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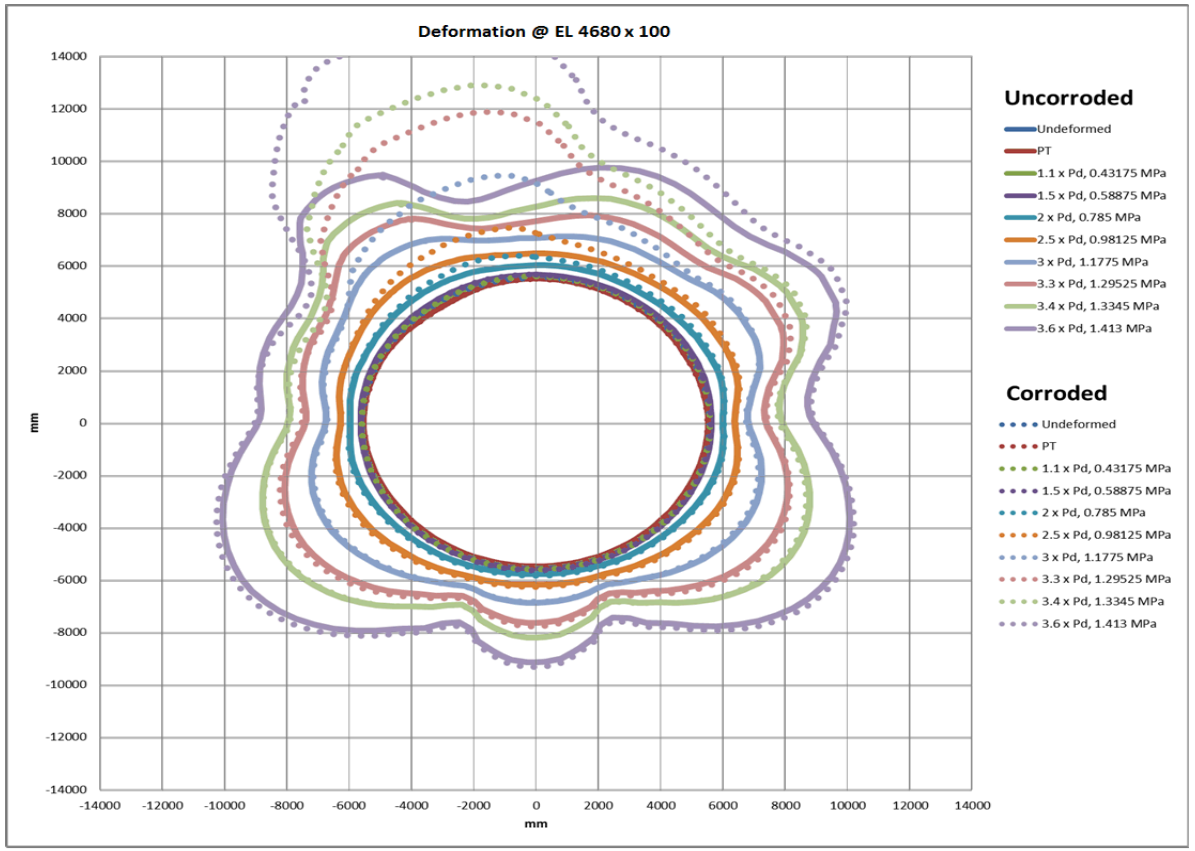
Analysis Results (Model 3 Midheight)

Grouted



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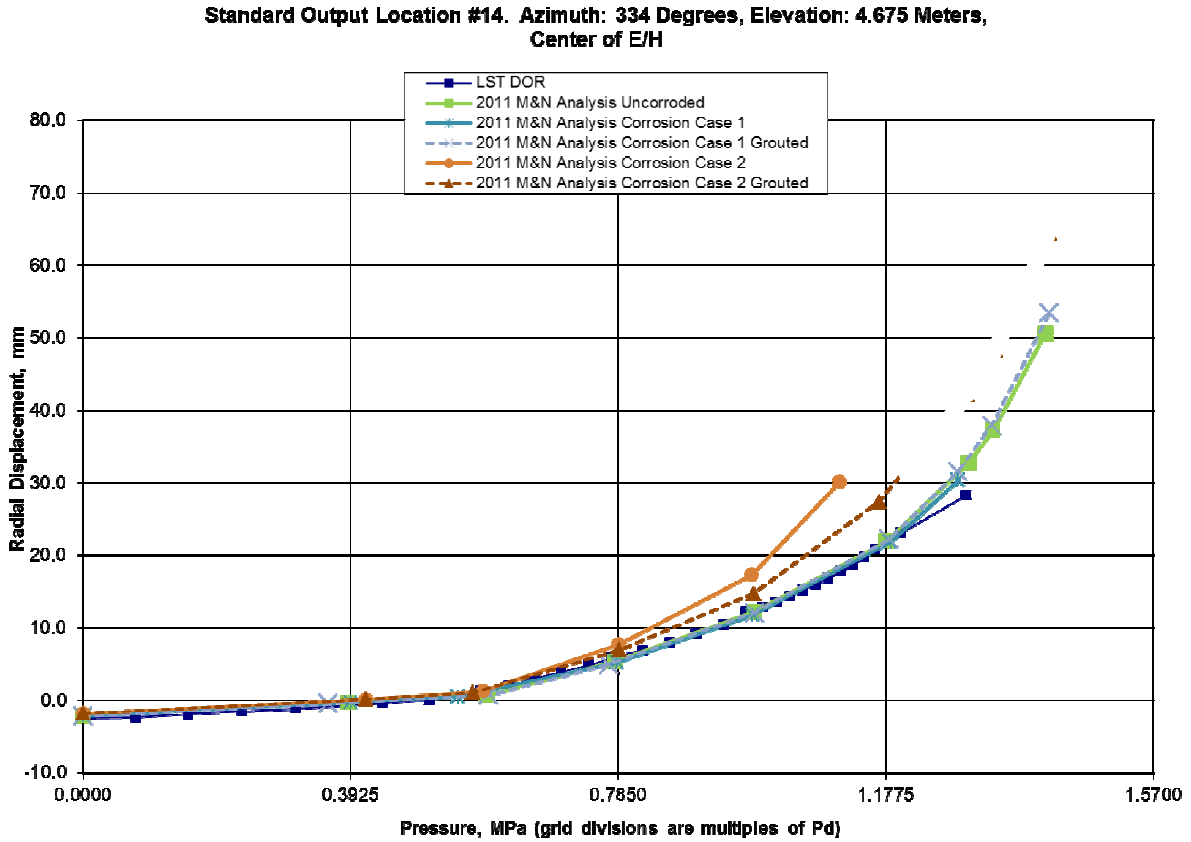
Analysis Results



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Conclusions From Corrosion Simulation (Unbonded Tendons)

- **Analysis Limitations: Reduction of area of about 40% was obtainable, but area reduction of 50% or more failed to converge, i.e., the structure has difficulty redistributing the prestress when 50% is lost along a substantial bank of tendons**
- **In general, bonded or grouted tendon cases (especially Case 2 for hoop tendons) result in significantly larger peak strains, but these strains are much more localized**
- **At this point, no conclusions as to the ultimate pressure capactiy of the corrosion affected vessels are made**
- **These analyses assume equivalent probability of corrosion for grouted and ungrouted systems and no conclusions as to corrosion protection are made**