Sanity Checks and Self-Checking of Finite Element Models

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Outline of Presentation

- Words of wisdom from R.D. Cook
- Quality Control vs Quality Assurance
- Where does Sanity Checks Fit with QA/QC
- Working definition of sanity checks
- Types of sanity checks
- When should sanity checks be performed
- Goals and benefits of sanity checks
- Importance of performing sanity checks
- Examples of sanity checks in practice for concrete structure

Words of Wisdom from R.D. Cook

- Seasoned practitioners stress that *reliable* results are obtained only when the analyst understands?
  - The problem and how to model it
  - Behavior of finite elements
  - Assumptions and limitations built into the software
  - Input data formats

Words of Wisdom from R.D. Cook

- Older engineers complain that younger engineers have a naive faith in computer programs and value computer skills over analytical skills and lack the ability to produce “ballpark” answers.
- Analytical skills can be developed by analyzing problems for which results are available and reliable and troubleshooting models until results align.
- Crude methods may be employed for more complex problems.

Quality Control vs Quality Assurance

- **Quality Control (QC) and Quality Assurance (QA) are related but not the same:**
  - **Quality Assurance** (QA) (Merriam-Webster): program for the systematic monitoring and evaluation of the various aspects of project, service, or facility to ensure that standards of quality are being met.
  - **Quality Control** (QC) (Merriam-Webster): aggregate of activities (such as design analysis and inspection for defects) designed to ensure adequate quality, especially in manufactured products
- **ISO 9000 family of standards**:

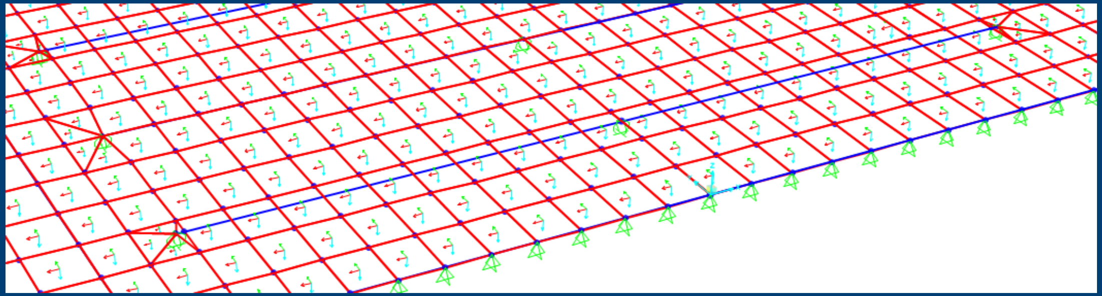
Quality Control is a part of quality management focused on fulfilling quality requirements, whereas

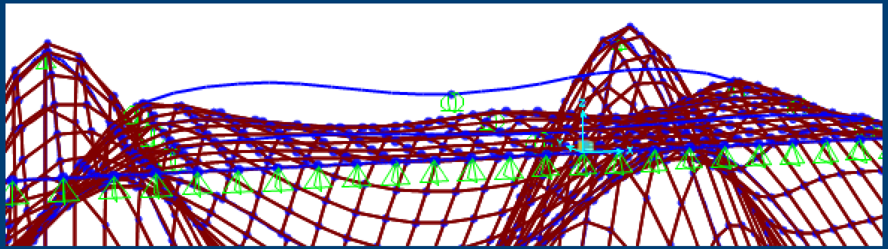
Quality Assurance is a part of quality management focused on providing confidence that quality requirements will be fulfilled.

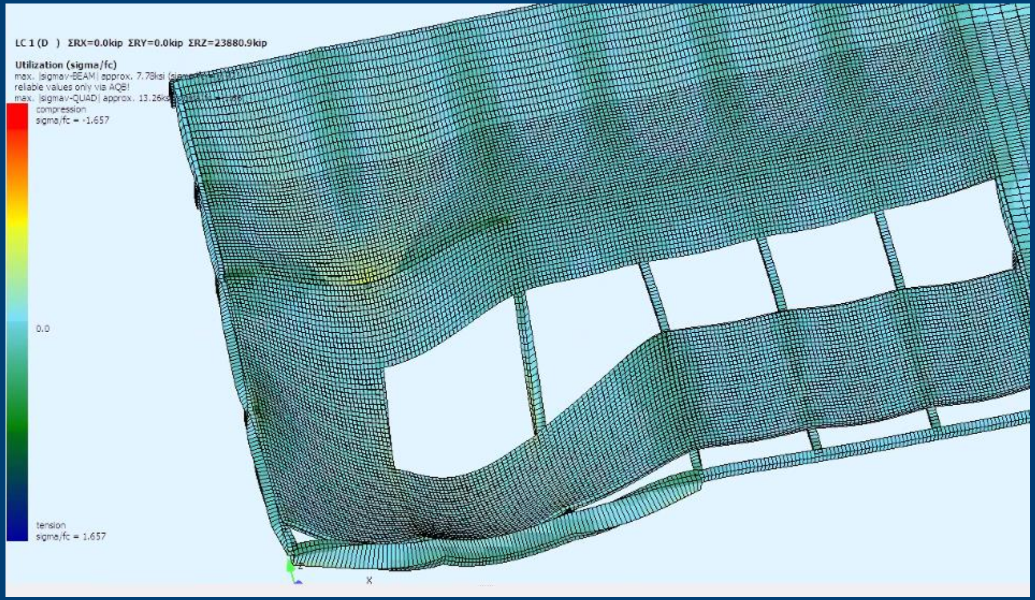
•Reference: TEQC 18: Quality Assurance vs Quality Control: What's the Difference? (engineeringmanagementinstitute.org)

Sanity Checks:

- Are a basic test used to quickly evaluate a finite element model to confirm whether the results represent realistic behavior.
- Ensure that the model is working as expected.
- Confirms whether the model is providing results that make sense.
- Involve engineers evaluating results at important features and critical model locations and comparing them to their understanding of expected structural behavior to identify potential errors.
- Require engineering judgment and a practical understanding of what they expect from the model in advance of the analyses.







Connectivity and Behavior

EXAGGERATED DISPLACED SHAPE

Sanity Checks are NOT

- Detailed verifications.
- Detailed tests or checks of inputs or other modeling decisions.
- A sanity check does not take the place of comprehensive quality control and quality assurance.
- The point of a sanity check is to rule out certain classes of obviously false results, not to catch every possible error or validate the solution.

Where do Sanity Checks Fit in QA/QC Process

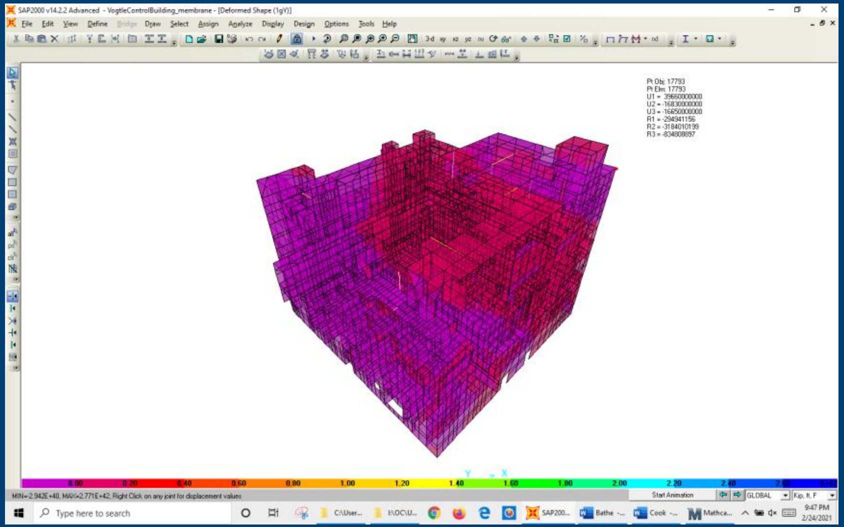
- An integral part of a Quality Control process for finite element modeling.
- All Quality Assurance programs should make sure that sanity checks are occurring.

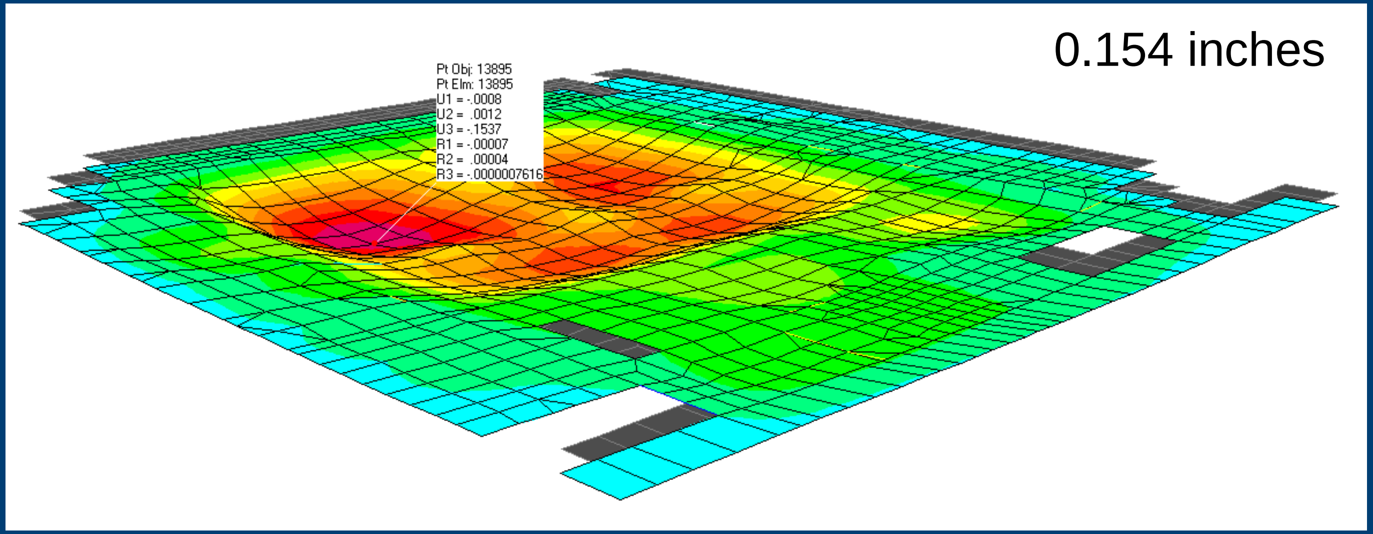
Working Definition of Sanity Checks for FEA of Concrete

- A sanity check is a basic test to quickly evaluate whether a claim or the result of FEA can possibly be true. It is a simple check to see if the produced material is rational (that the material's creator was thinking rationally, applying sanity). The point of a sanity check is to rule out certain classes of obviously false results, not to catch every possible error or validate the solution. A sanity check introduces intuition into the analysis and can give confidence in the model before more complexity is added. Sanity checks should be performed early and often. Sanity checks do not take the place of verification.

Types of Sanity Checks for FEA

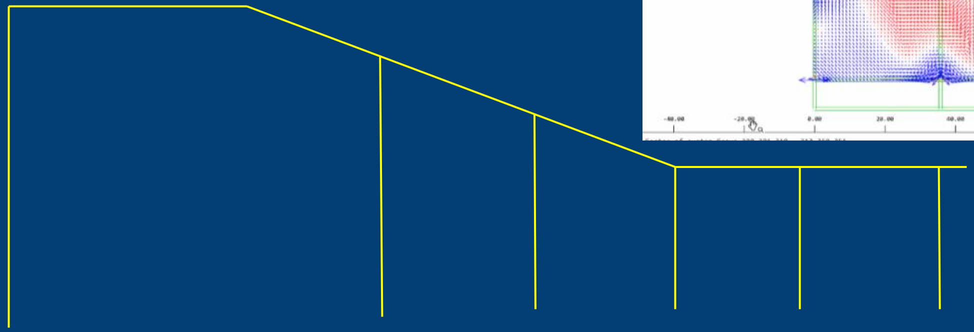
- Investigate exaggerated displaced shapes.
  Look for overall displacements.
  Look for discontinuities in displacements.
- Investigate mode shapes and natural frequencies.
  Look for local modes that indicate lack of connectivity.
- Investigate axial forces and confirm they are appropriate.
- Investigate torsion and confirm releases are correct.
- Sum overall base reactions and those that the designer believes are primary reactions.
- View principal stress contours and trajectories.
- Run total static moment checks
- Rule-of-thumb or back-of-the-envelope calculations.

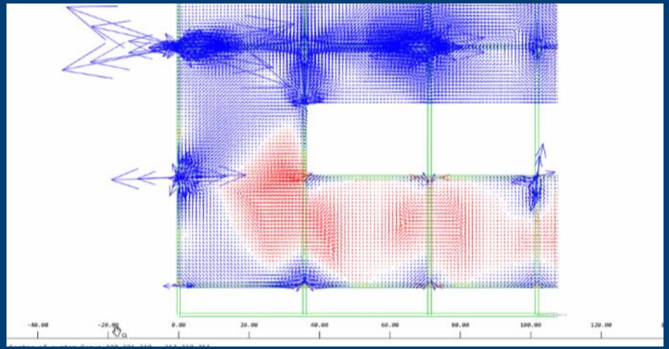


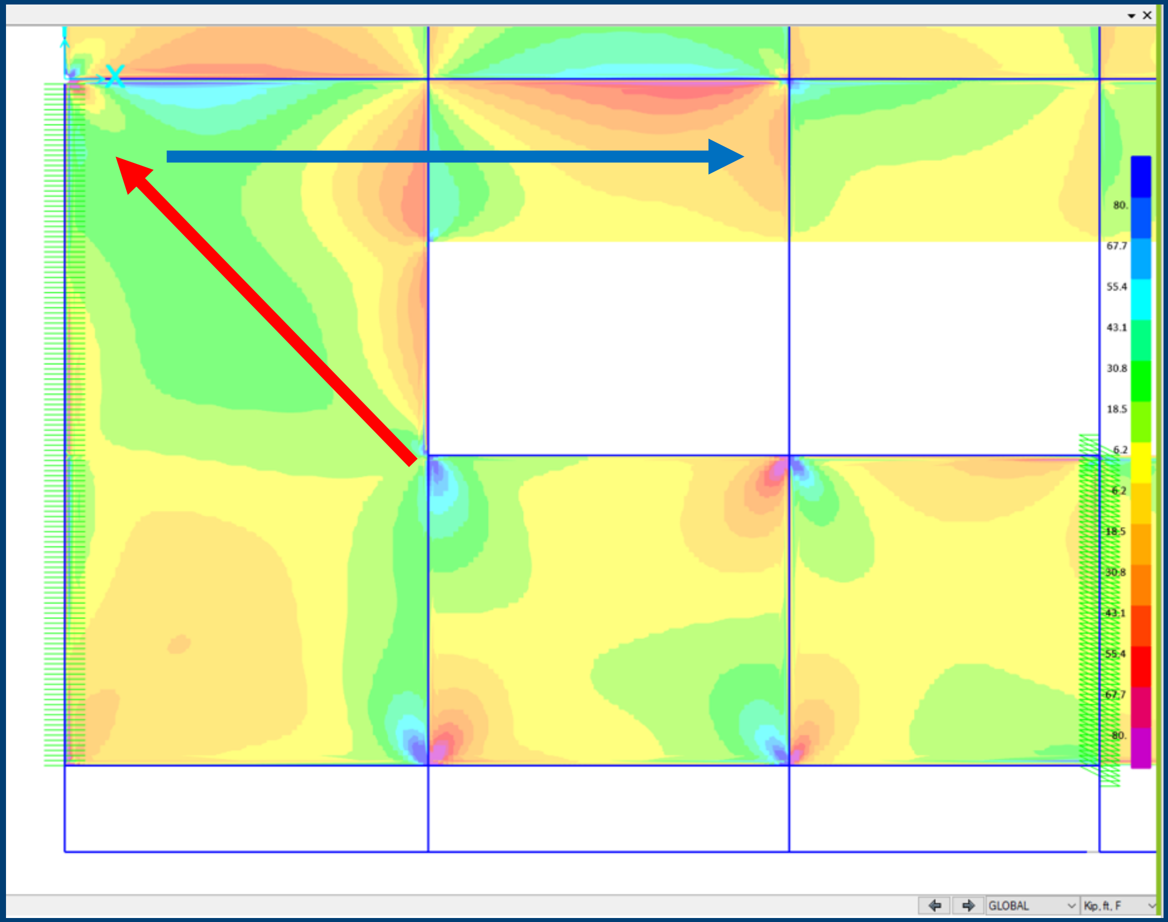


What is a reasonable slab vertical displacement? Consider serviceability limits.

STATIC 1G ANALYSIS

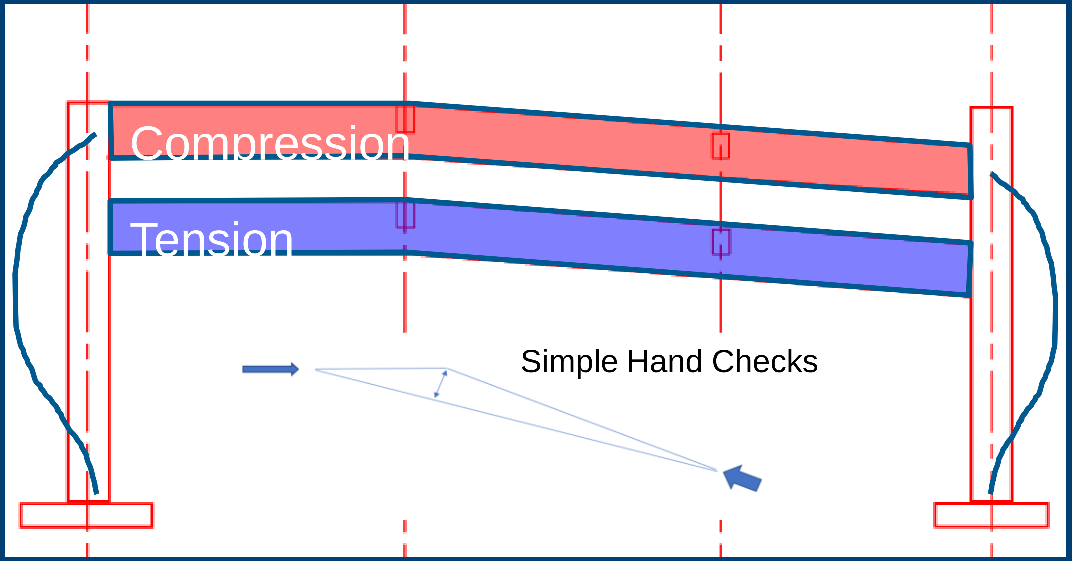






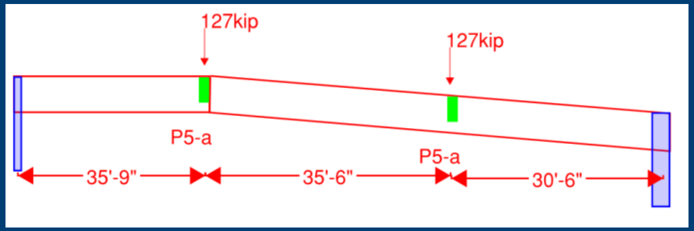
Strut and Tie Action for Ramp Landing

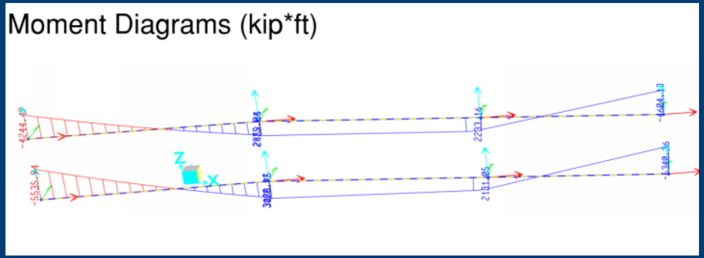
Principal Stresses & Stress Trajectories

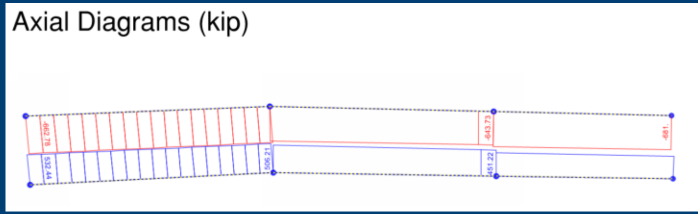


Compatibility of Displacements
Looking at All DOF-TENSION

Axial Forces Check





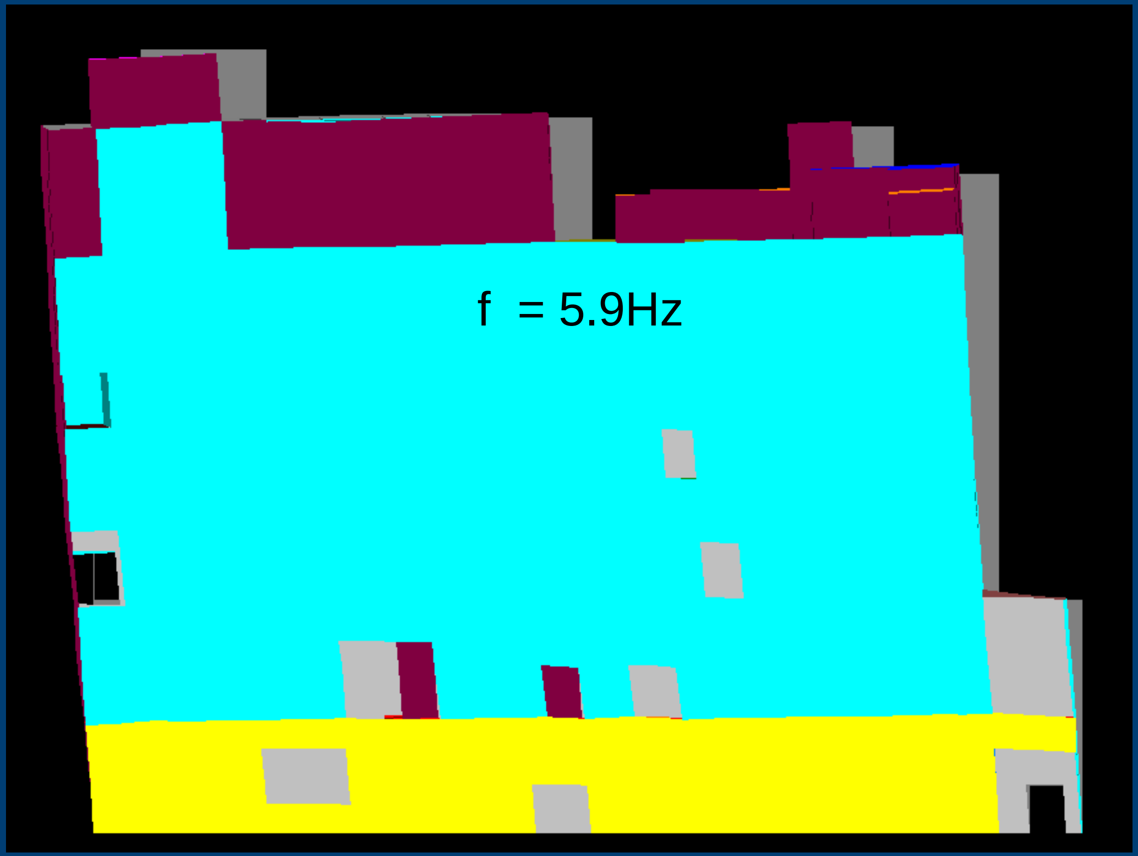


$$E := 4.978 \cdot 10^{8}\,\text{psf} \qquad G := \frac{E}{2\cdot(1 + 0.25)} = 199120\,\text{ksf}$$

$$H := 120\text{ft}\cdot\frac{2}{3}$$

$$m := 6159.56\text{kip}\cdot\frac{\text{sec}^{2}}{\text{ft}} = 8.989 \times 10^{7}\,\text{kg} \qquad k := \frac{3532\text{ft}^{2}\cdot G}{1.2\cdot H} = 7.326 \times 10^{6}\,\frac{\text{kip}}{\text{ft}}$$

$$f := \frac{1}{2\cdot\pi}\cdot\sqrt{\frac{k}{m}} = 5.489\,\text{Hz}$$



MODAL ANALYSIS

Is your first mode a translational mode?

Is the frequency consistent with establish metrics?

Quick hand calculation to estimate frequency of fundamental mode.

When Should Sanity Checks Be Performed

- Early and often during model development.
- Before performing detailed review.
- Prior to performing detailed QA/QC checks.
- Before and after complexity is added to a model.

Goals and Benefits of Sanity Checks

- Define expected performance expectations of model.
- Save time and cost by fixing modeling errors quickly and throughout the process.
- Quickly evaluates some basic functions of the model.
- Introduces intuition into the analysis and can give confidence in the model before more complexity is added.
- Makes sure the engineers understand the model output.
- Validate reliability of newly added modeling complexity.

Importance of Performing Sanity Checks

- Sanity checking models:

  Forces engineers to understand what is being modeled.

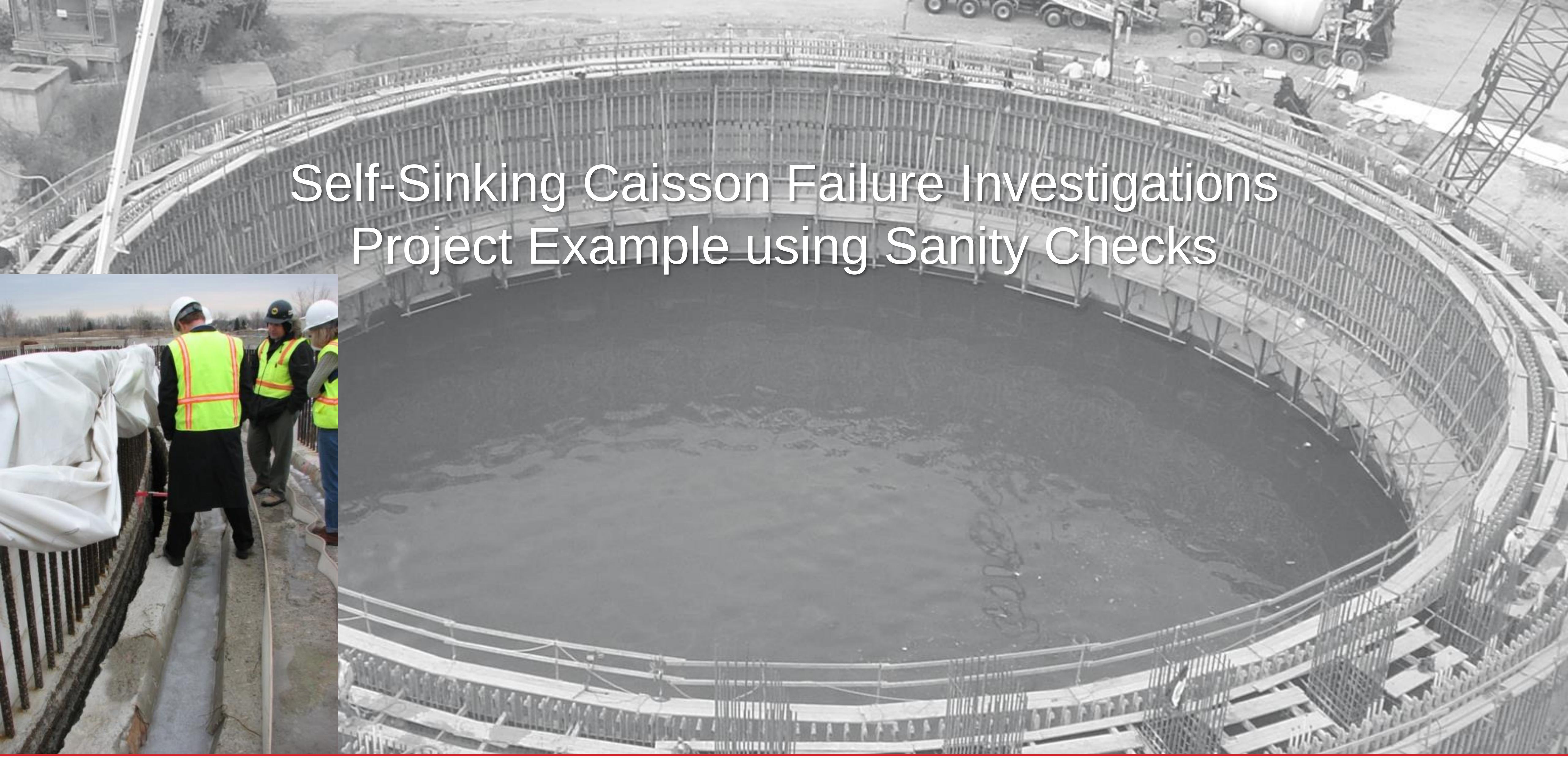
  Prevents engineers from making gross modeling errors that could lead to inappropriate designs.

  If done early can prevent making difficult to fix errors as complexity is added to a model.

  Guides engineers in the detailed QC checking process.

  Provides the highest value for the shortest effort in the checking process.

Self-Sinking Caisson Failure Investigations
Project Example using Sanity Checks



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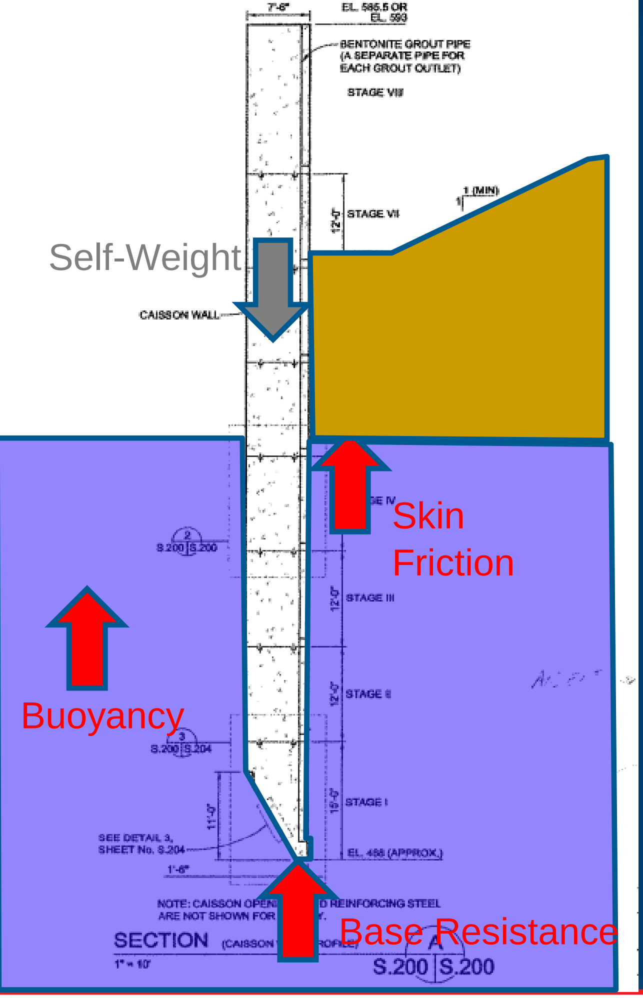
Stage 2 Reinforcement

Driving Forces vs. Resistance Forces for Sinking



- Loading during construction/sinking may govern the structural design.

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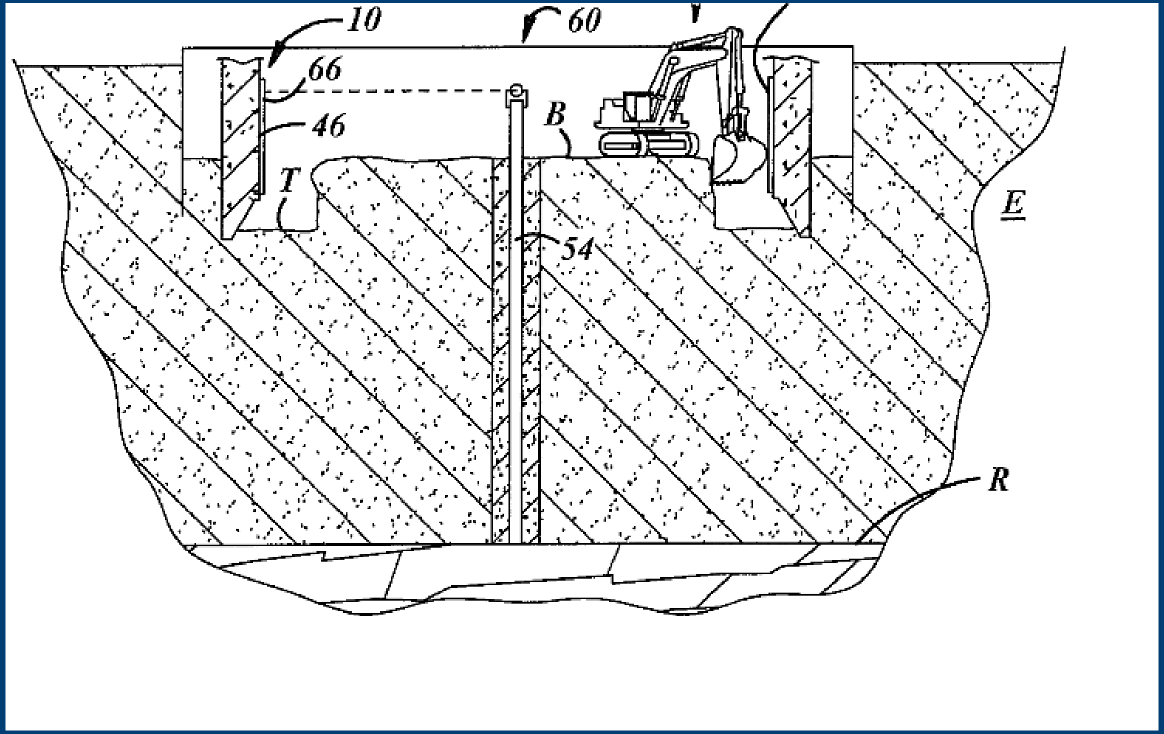
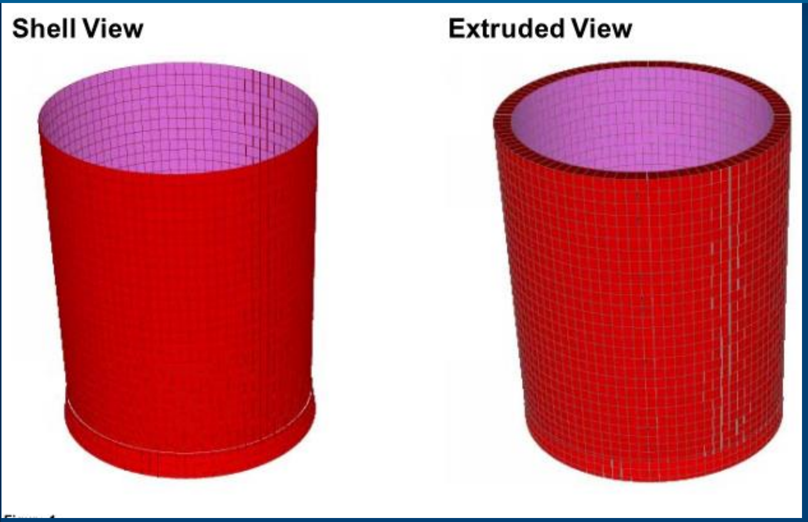
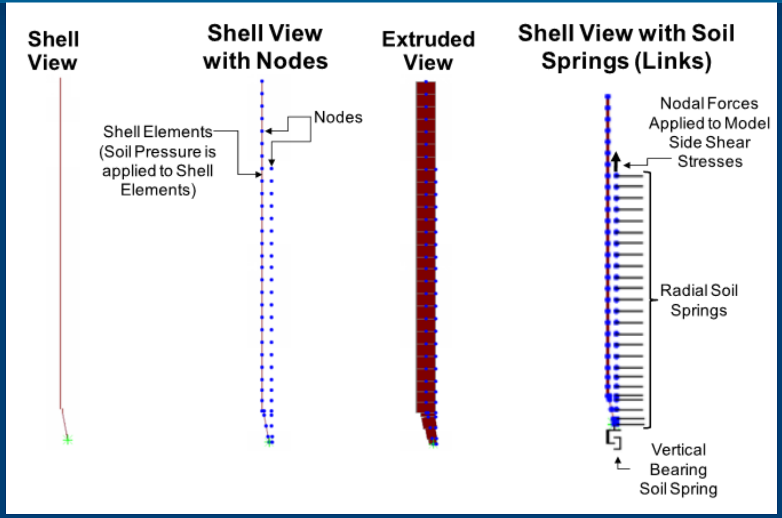
Typical Means & Methods for Sinking Caissons

Controlled Excavations Around Inside of Caisson Shoe to Induce Small Soil Failures

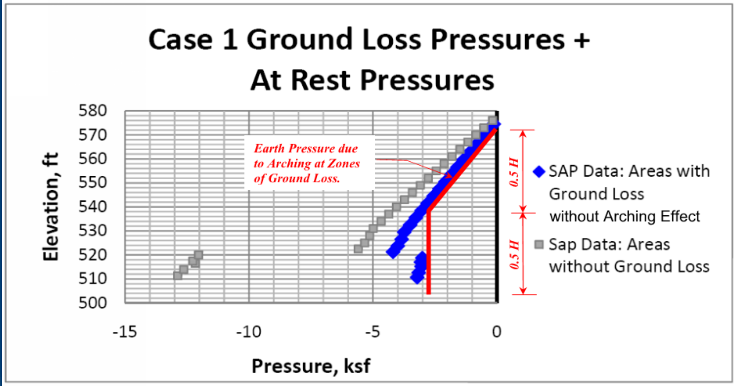


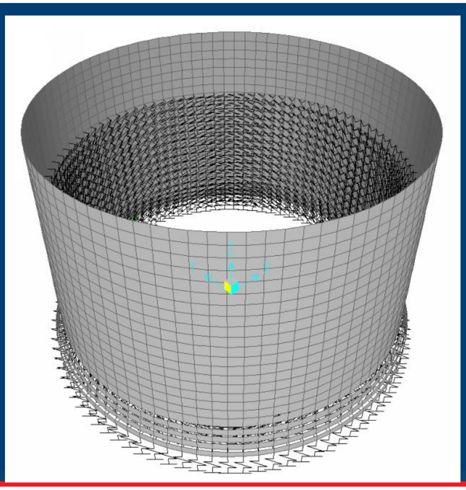
Modeling Approach

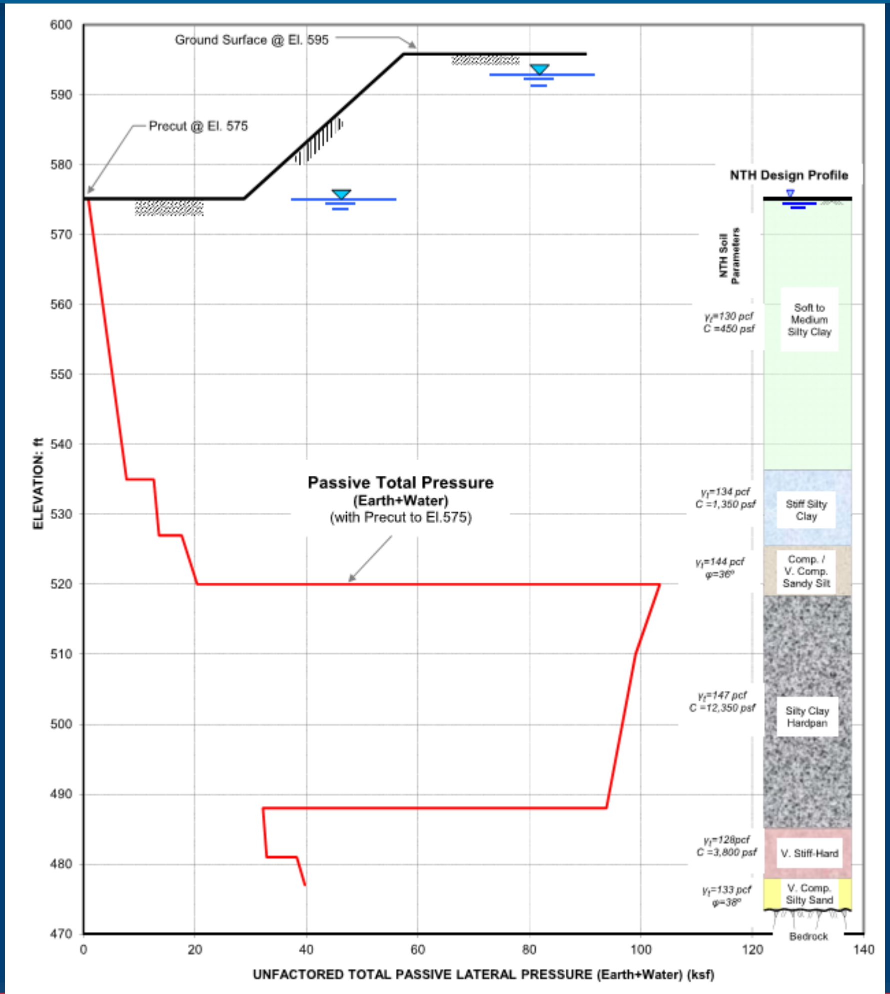




Use Graphs of Data to Check Sanity of Inputs

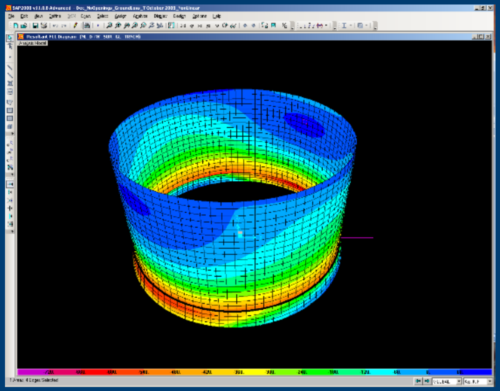


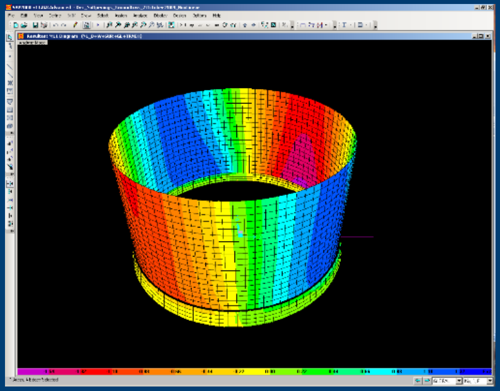


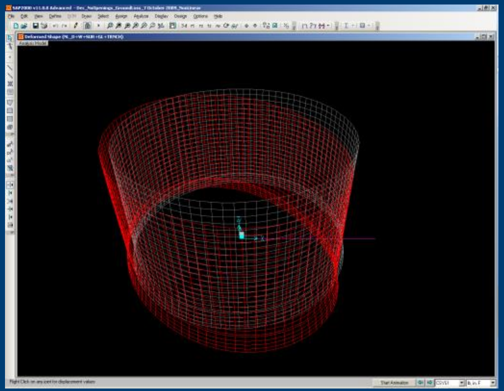


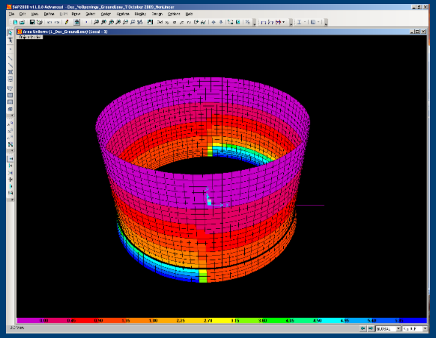
Ground Loss Load Case for Ovaling

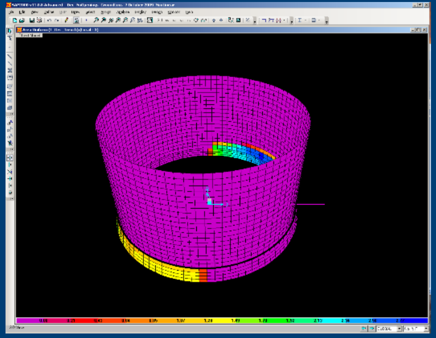
- Active Spring Stiffness and Active Soil Pressures (3:00 to 6:00 & 9:00 to 12:00)
- At Rest Spring Stiffness and At Rest Soil Pressures (12:00 to 3:00 and 6:00 to 9:00)
- Effects included in analysis:
  - Water Inside and Out
  - Trenching
  - Pre-cut Elevation
  - Soil Disturbance for a Out-of-Round Deformation of the Caisson

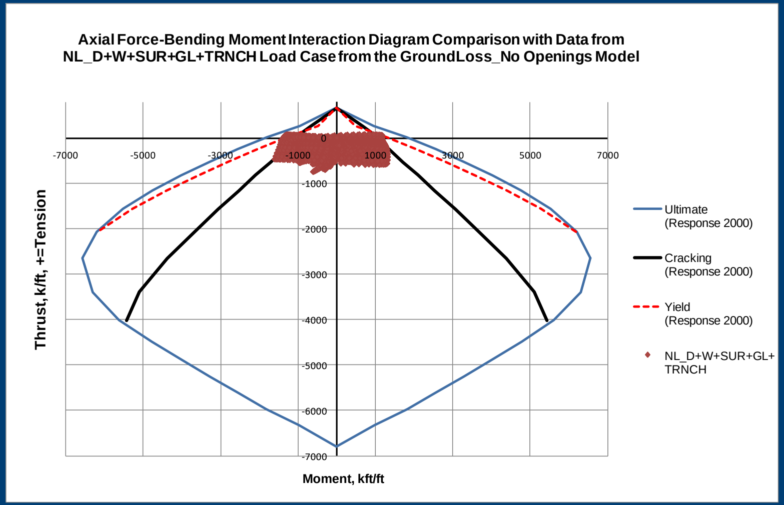


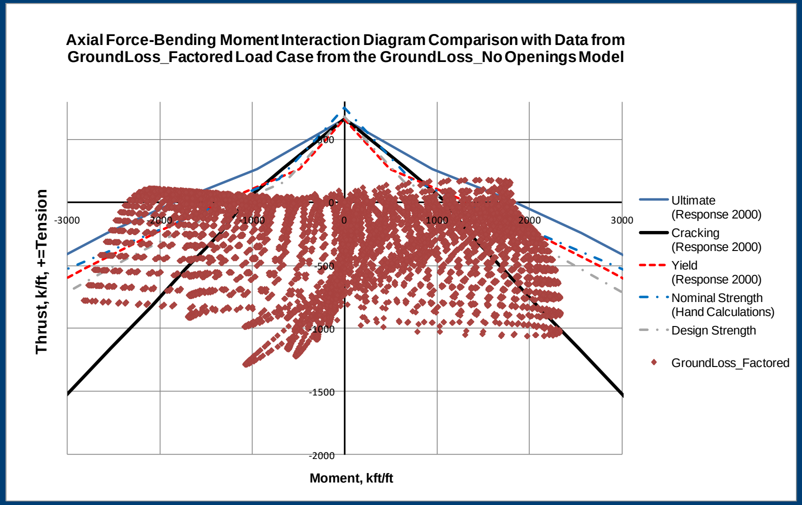






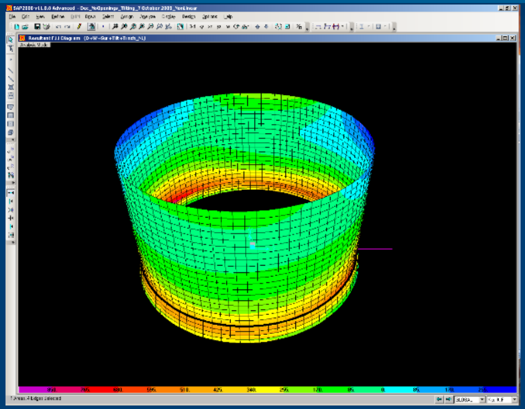


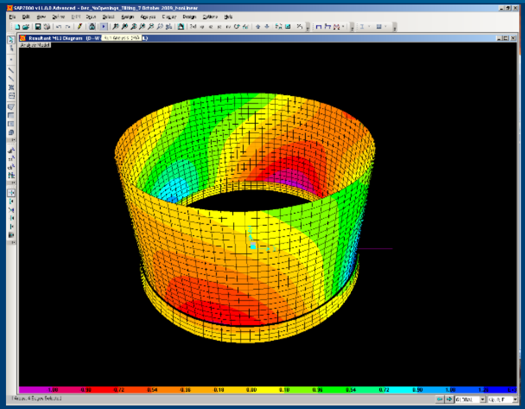


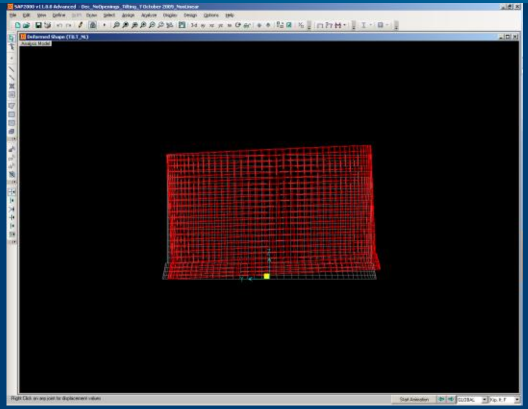


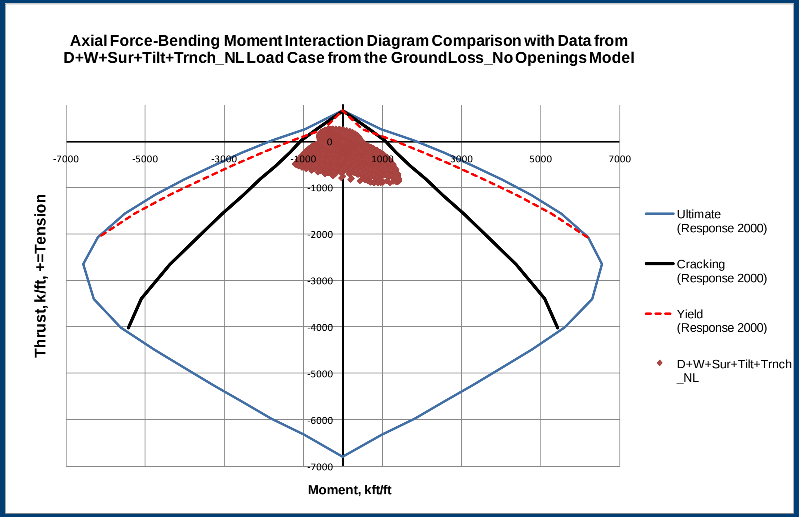
Ground Loss Load Case for Tilting

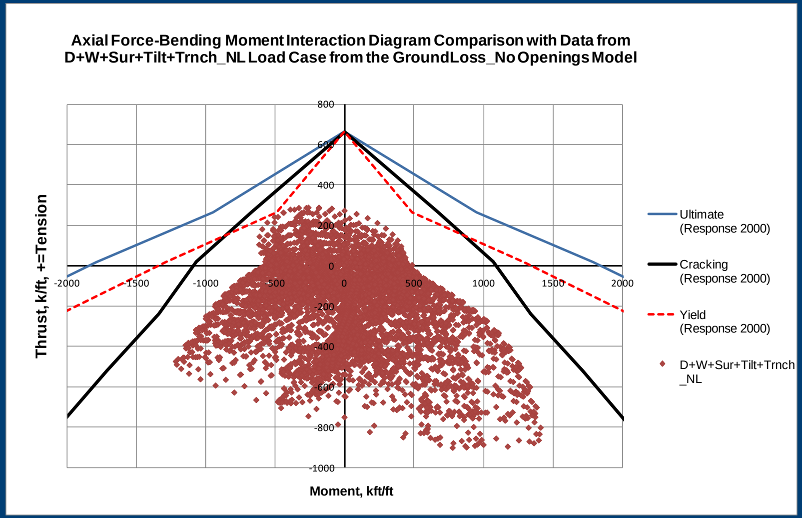
- Active Spring Stiffness and Soil Pressures from (3:00 to 9:00)
- At Rest Spring Stiffness and Soil Pressures from (9:00 to 3:00)
- Effects Included in analysis:
  - Water Inside and Out
  - Trenching
  - Pre-cut Elevation
  - Soil Disturbance for a Tilting Deformation of the Caisson

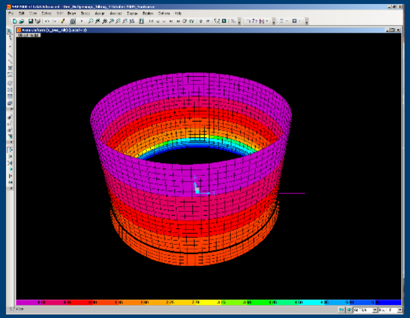


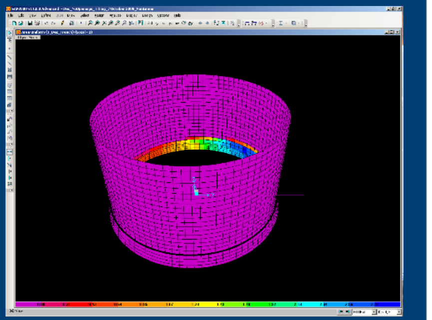












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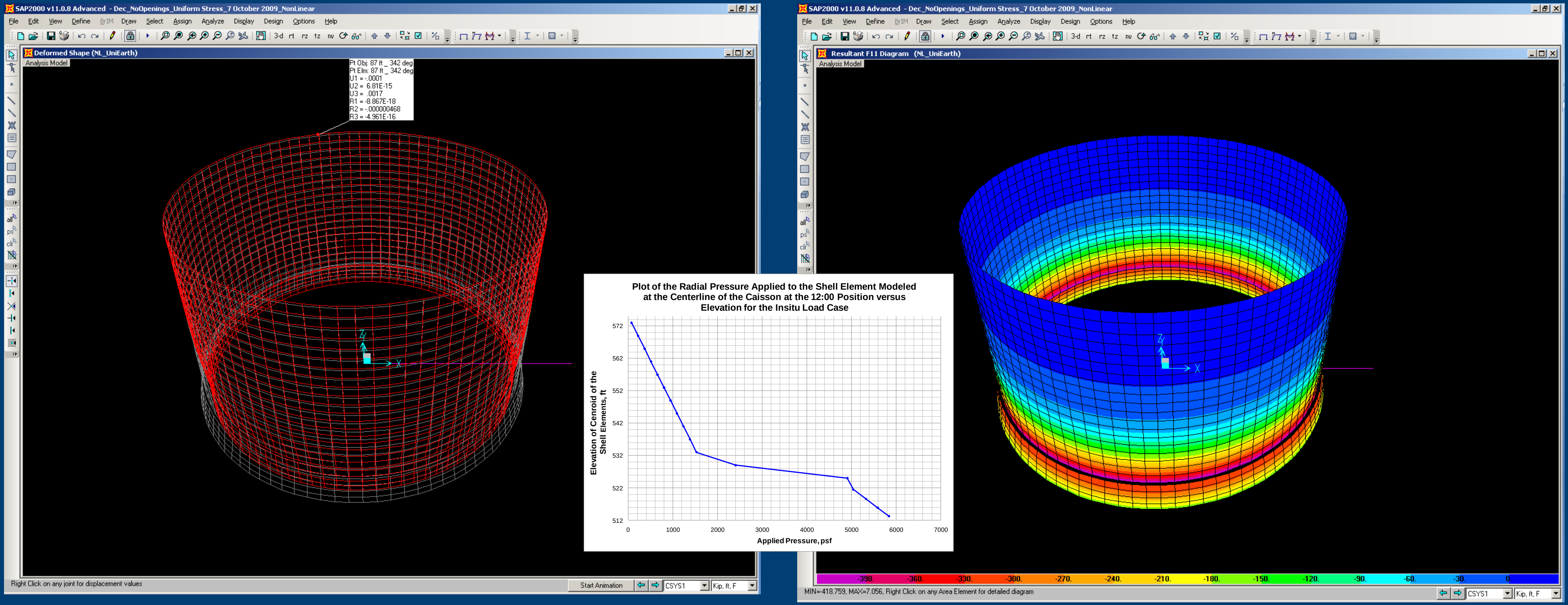
Pinching at Base



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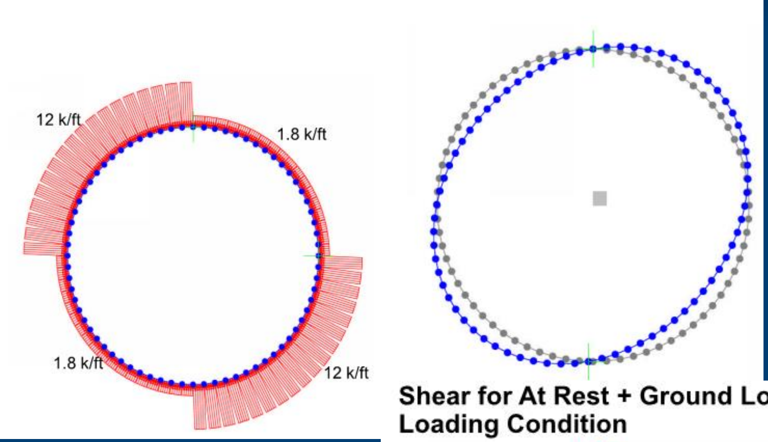
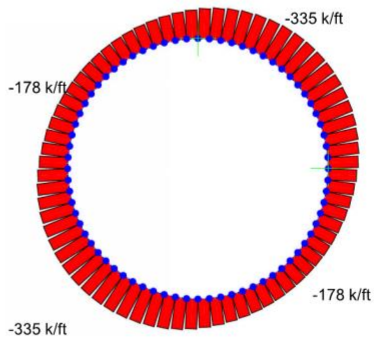
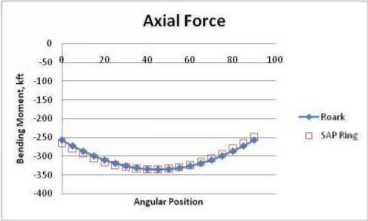
Isolated Ring Modeling Approach



Thrust for At Rest + Ground Loss Loading Condition

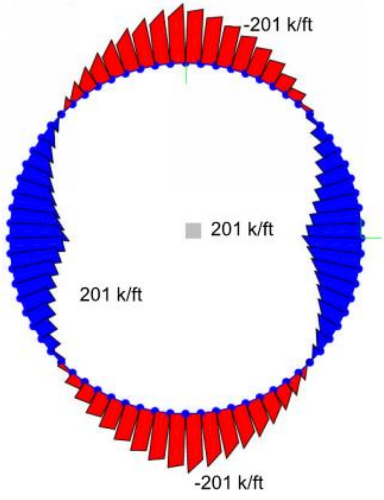
Plot Comparing Roark and SAP Ring

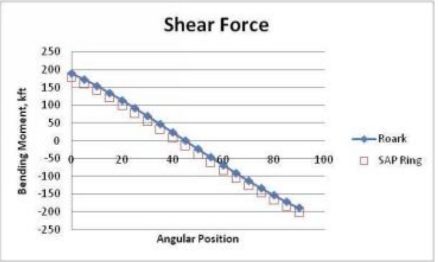




Shear for At Rest + Ground Loss Loading Condition

Plot Comparing Roark and SAP Ring

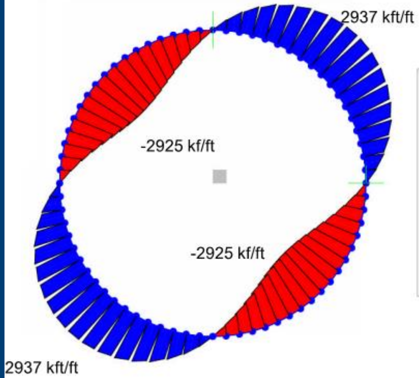


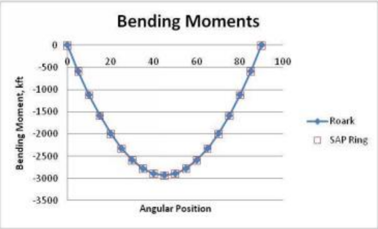


SAP Ring Analysis Output_Case 2 Ovaling

Moment for At Rest + Ground Loss Loading Condition

Plot Comparing Roark and SAP Ring Analysis





Questions for Audience

- What sanity checks do you perform in practice?

Thank you

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