6/06/2025

Raghav Bhatt

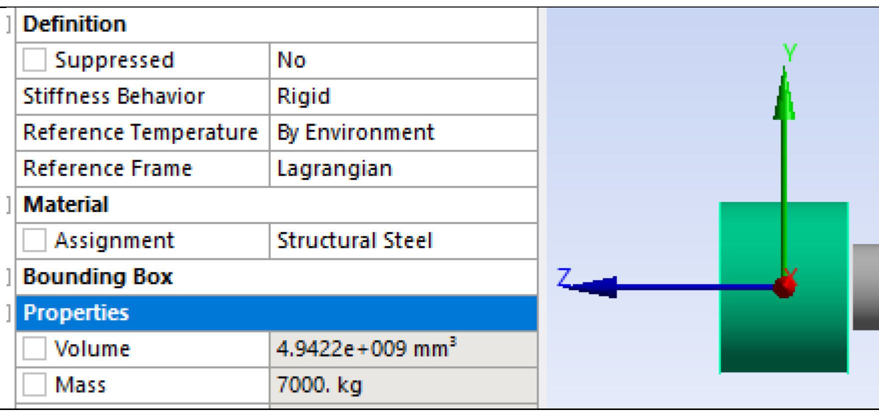
ME 478 Final Project

Problem 2:

The goal is to investigate the wave propagation in a 40-inch diameter, 90 ft. long pile with a wall thickness of 1 inch after it has been struck with a 7000 kg pile driving hammer at 7.8 m/s.

Assumptions:

- Pile: Structural Steel
  - Young Modulus: 200 GPa
  - Poisson Ratio: 0.3
- Pile Driving Hammer: Structural Steel
  - Young Modulus: 200 GPa
  - Poisson Ratio: 0.3
  - Density: 1416.4 kg/m^3
  - Mass: 7000 kg



Definition	
Suppressed	No
Stiffness Behavior	Rigid
Reference Temperature	By Environment
Reference Frame	Lagrangian
Material	
Assignment	Structural Steel
Bounding Box	
Properties	
Volume	4.9422e+009 mm^3
Mass	7000. kg

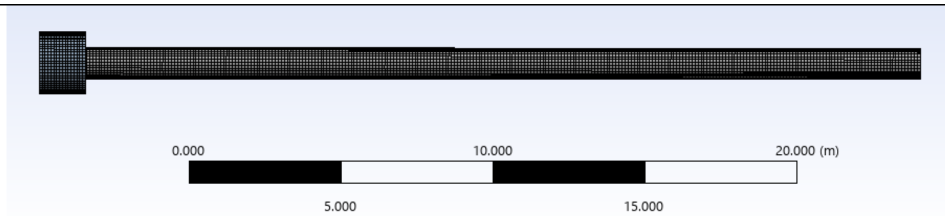
Given: Hammer mass of 7000 kg

- Properties:
  - Symmetrical Cylinder
  - 3D Geometry

- Geometry:
  - Pile: Flexible Body
    - Inner Diameter: 40”
    - Length: 90’
    - Wall Thickness: 1’
  - Hammer: Rigid Body
    - Diameter: 80”
    - Length: 60”
    - Weight: 7000 kg
  - Pile/Hammer Separation Distance: 0.2”

Mesh:

- Element Size: 0.1 m
- Element Order: Linear



Geometry with Mesh

Boundary Conditions:

- Fixed Support: Bottom face of Pile
- Initial Velocity: Hammer Body
  - Applied in -z direction

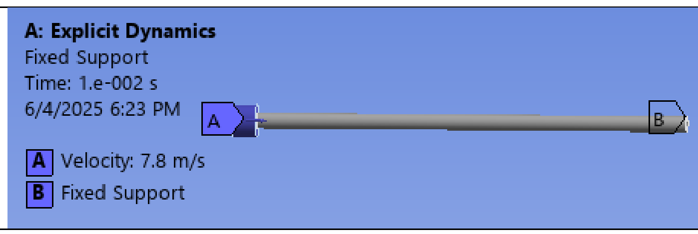
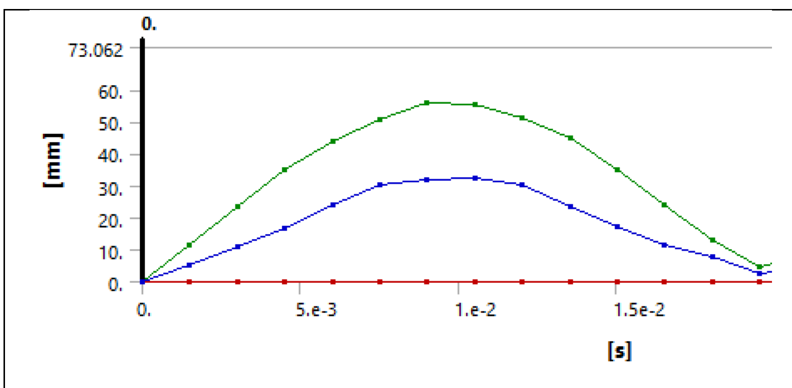
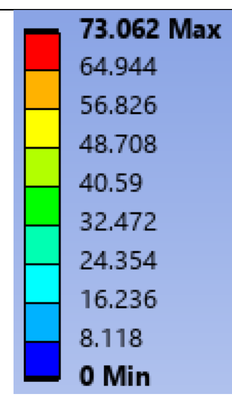


Diagram of Boundary Conditions

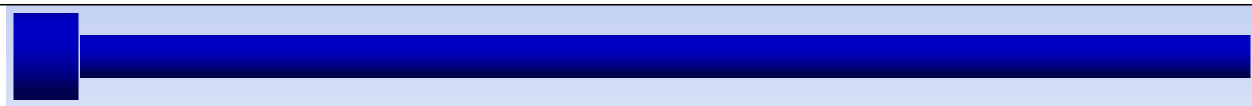
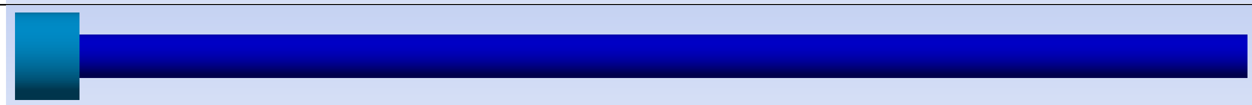
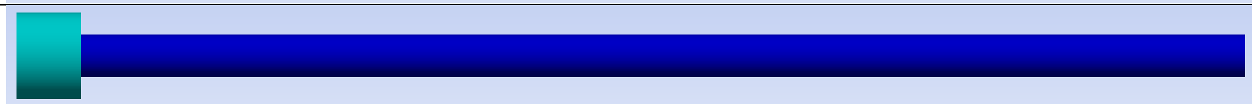
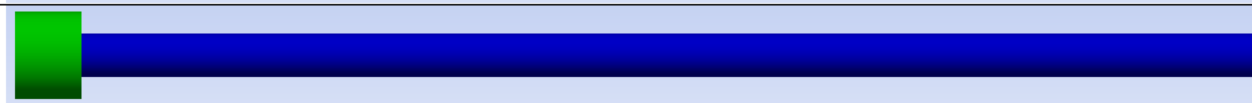
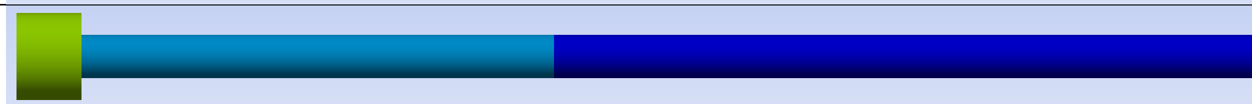
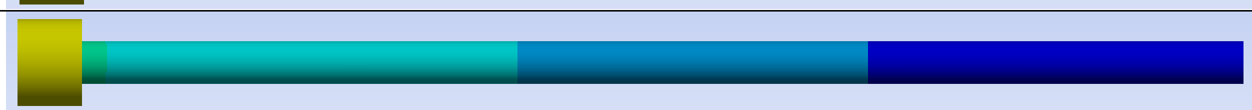
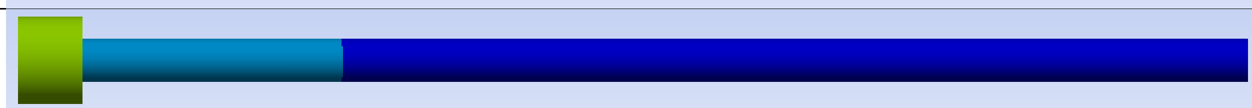
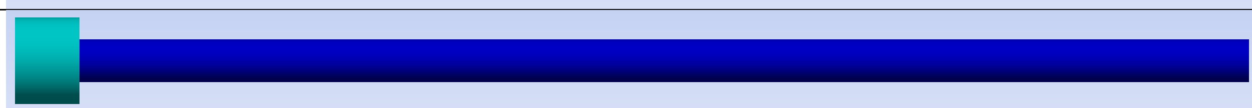
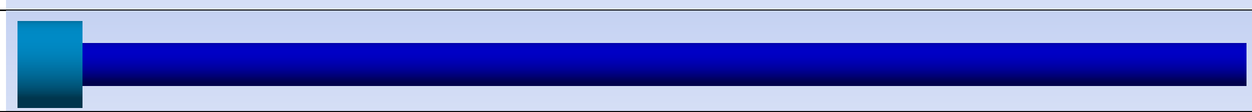
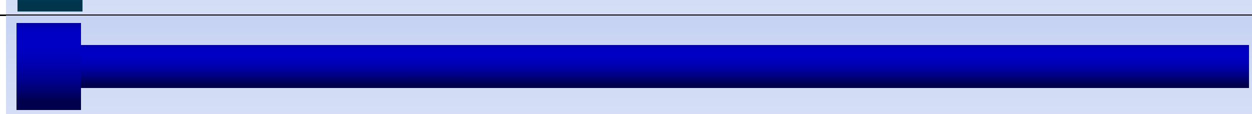
<u>**Ansys Solver: Wave Propagation of Total Deformation (0 to 0.03 sec):**</u>



Wave Propagation – Total Deformation of All Bodies



Color Scale [mm]

Total Deformation of All Bodies	
Time (s)	Wave Propagation Time Steps
0	
1.5E-3	
3E-3	
4.5E-3	
6E-3	
7.5E-3	
9E-3	
1.10E-2	
1.26E-2	
1.42E-2	
1.57E-2	
1.73E-2	
1.89E-2	

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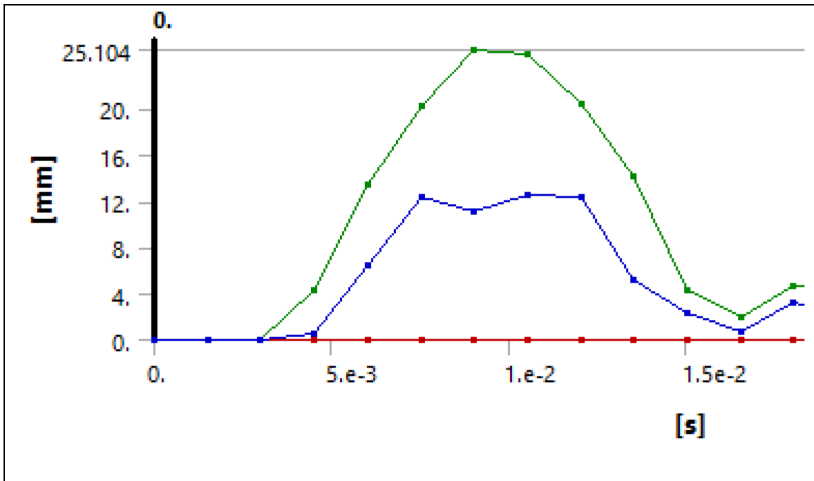
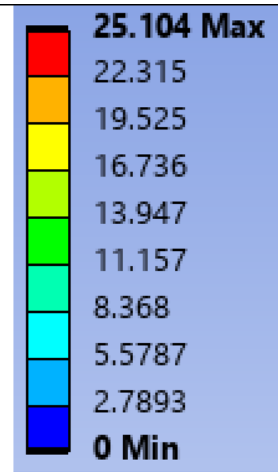
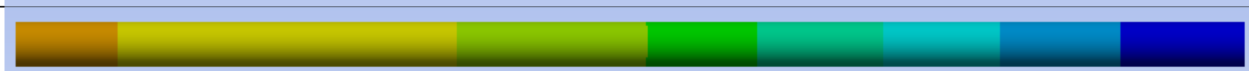
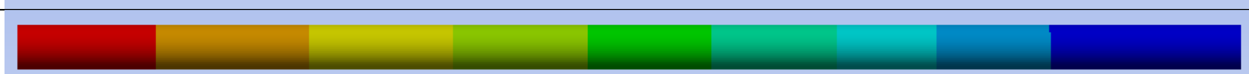
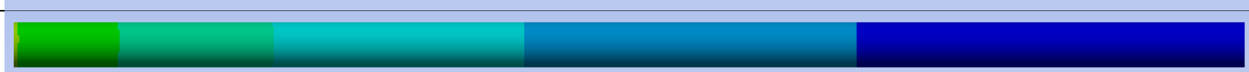
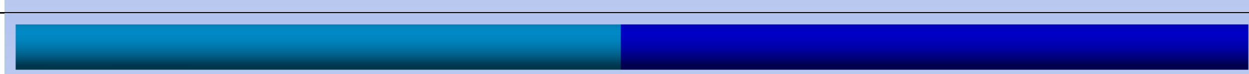
Ansys Solver: Wave Propagation of Pile Deformation (0 to 0.03 sec):

	
Wave Propagation – Total Deformation of Pile	Color Scale [mm]

Pile Deformation	
Time (s)	Wave Propagation Time Steps
0-0.003 s	
4.5E-3	
6E-3	
7.5E-3	
9E-3	
1.10E-2	
1.26E-2	
1.42E-2	
1.57E-2	
1.73E-2	
1.89E-2	
2.05E-2	

Conclusion:

The wave propagation of All the Bodies and of the Pile can be seen in the series of images. The goal of these images is to show how the elastic wave propagates through the steel pile as a steel hammer impacts it. Elastic wave propagation represents the movement of disturbances in the elastic material. The wave movement is caused by the force applied by the hammer causing the material to deform and then return to its original shape.

For example, during earthquakes, tectonic plates collide with each other causing seismic waves to travel through the earth's crust. The plate movement causes stored 'elastic strain' energy to be released which makes the ground shake. Elastic wave propagation from an earthquake is transferred from the rupture point (on the fault) to the surface. The transmission of this seismic energy is crucial for earthquake detection. Seismographs sense the seismic wave signals that are emitted.

discussion of results? Do these values make sense and wl

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Problem 3:

The goal is conduct a stress and buckling analysis of a vacuum vessel with an external load of 65 MPa applied to the surface. The ANSYS solver will output the critical load applied for the vessel to buckle. A factor of safety of 1.75 will be used to calculate the allowable load to avoid buckling. Additionally, an image of load versus deformation will be given.

Assumptions:

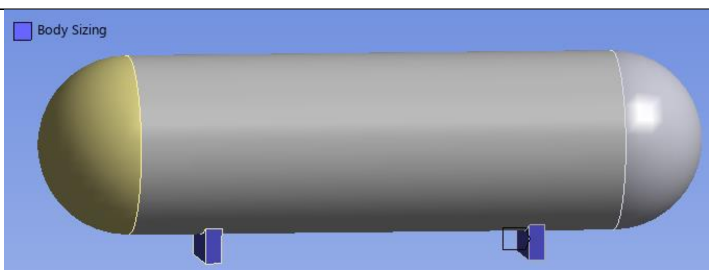
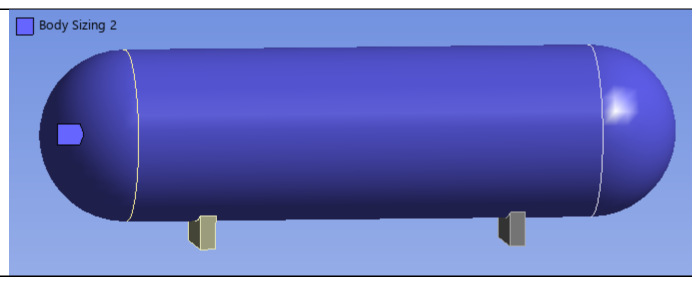
- Material Choice: Aluminum Alloy
  - Elastic Modulus: 71 GPa
  - Poisson Ratio: 0.33

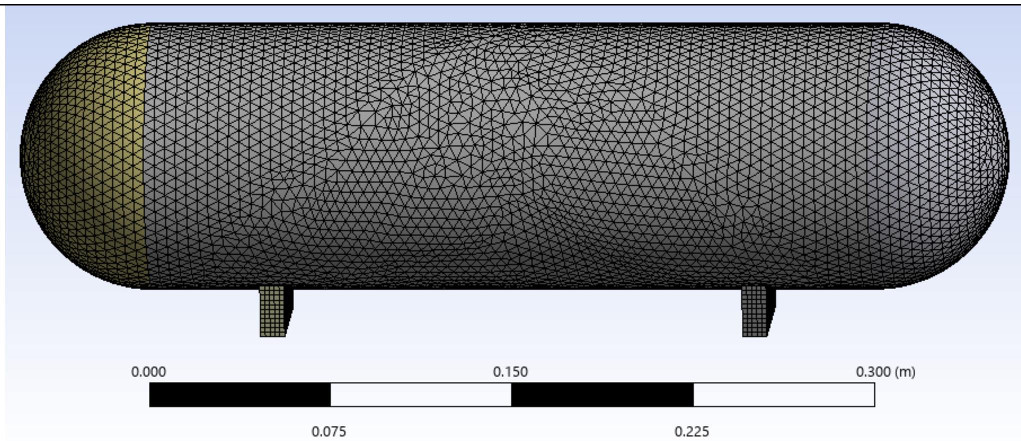
- Symmetry:
  - Symmetric Geometry

- Geometry:
  - Full Length: 400 mm
  - Full Height: 100 mm
  - Vessel Wall Thickness: 5 mm
  - End cap radius (Left & Right): 50 mm
  - Leg (L x W x thickness): 21.7 x 50 x 10 mm

Mesh:

- Element Size: 0.003 m
- Element Order: Quadratic
  - This provides a higher degree of accuracy per element and greater geometry capture
- Body Sizing:

	
Body Sizing (0.002 m) – Hard Behavior	Body Sizing 2 (0.005 m) – Hard Behavior



Geometry with Mesh

Boundary Conditions:

- Applied external load to entire vessel surface: 65 MPa
    - Defined Normal to surface
- Fixed Supports: Bottom face of Left & Right legs

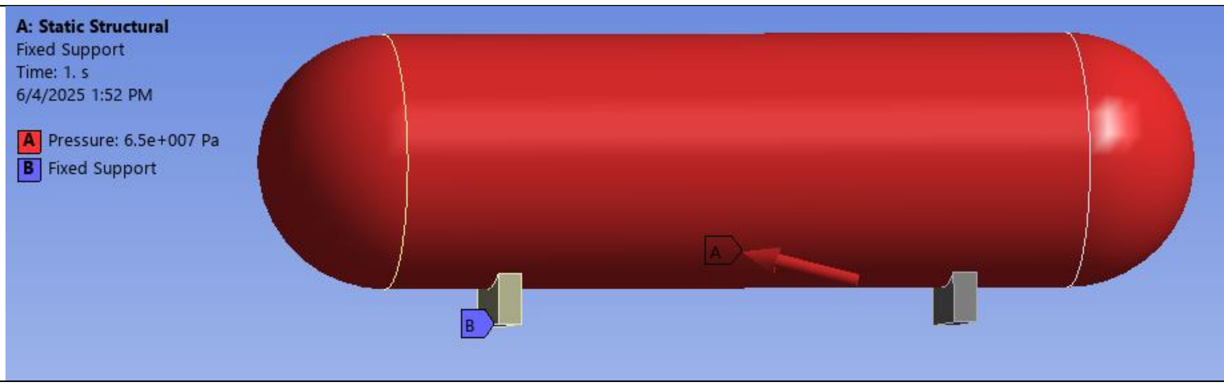
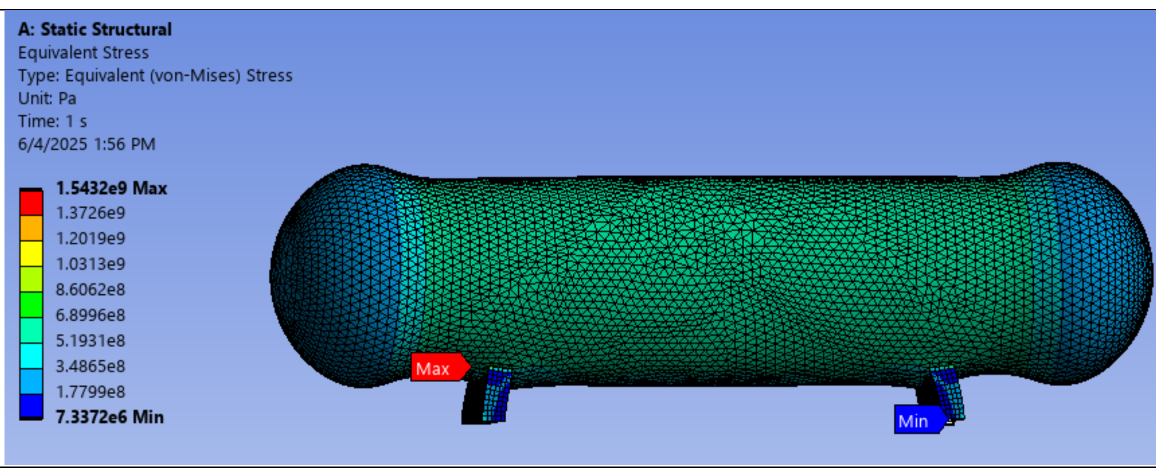
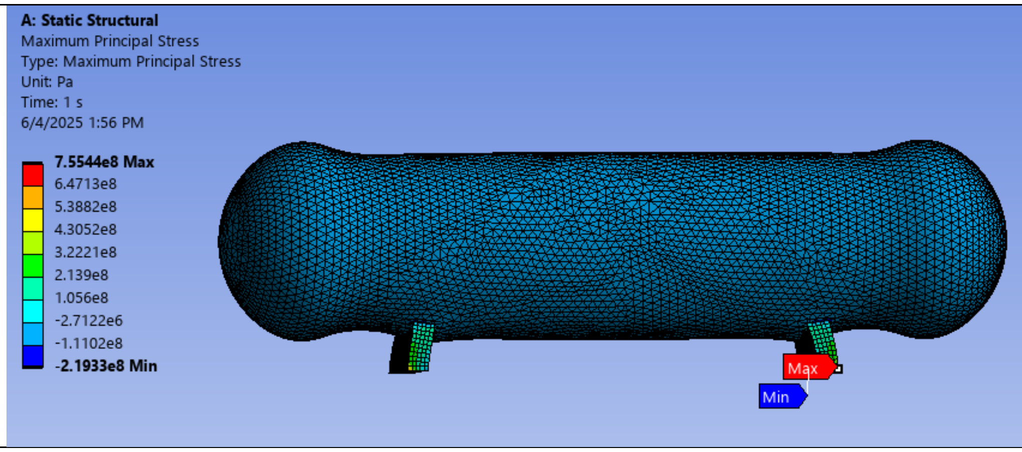


Diagram of Boundary Conditions

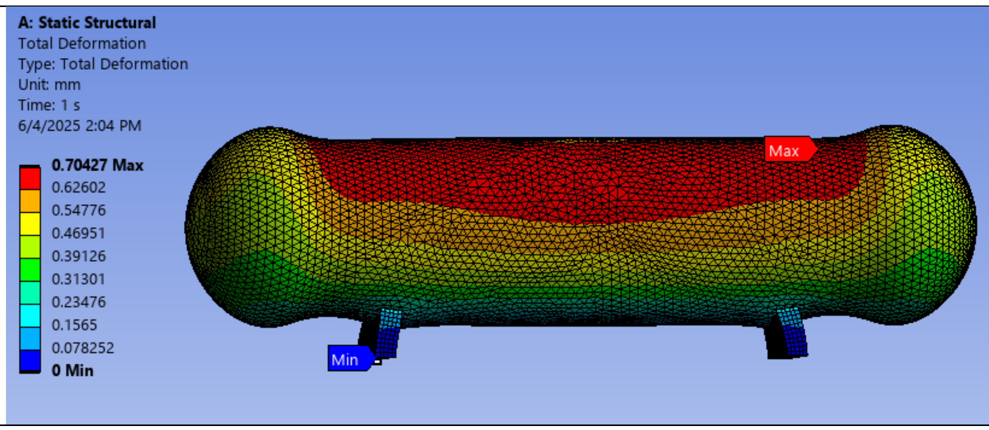
Ansys Stress Analysis:



Equivalent Stress (von-mises) at 65 MPa



Maximum Principal Stress at 65 MPa



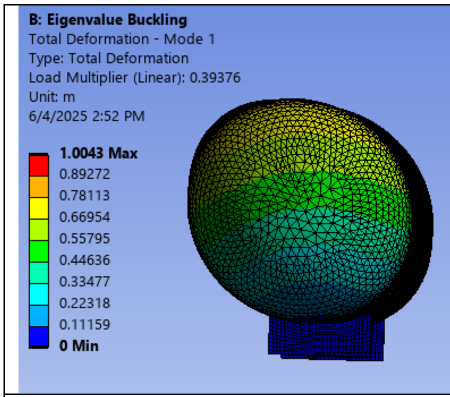
Total Deformation at 65 MPa

The equivalent von-mises is 1.5432 GPa and the maximum principal stress is 0.75544 GPa. The location of maximum equivalent stresses is on the left leg. The max total deformation is on the top surface of the vessel and is approximately 0.70427 mm.

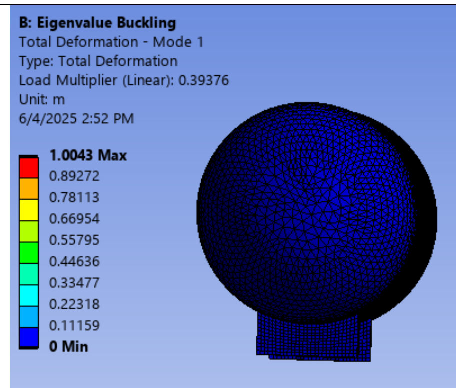
Ansys Buckling Analysis:

	Mode	Load Multiplier
1	1.	0.39376
2	2.	0.42702
3	3.	0.75041
4	4.	0.78603
5	5.	1.0212
6	6.	1.0723
7	7.	1.352
8	8.	1.3639
9	9.	1.4372
10	10.	1.461
11	11.	1.4655
12	12.	1.5169

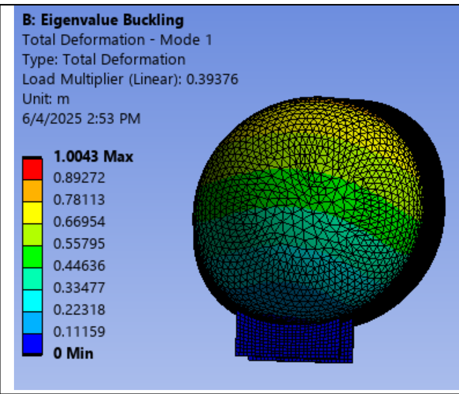
12 Load Multiplier Modes



t=0 s

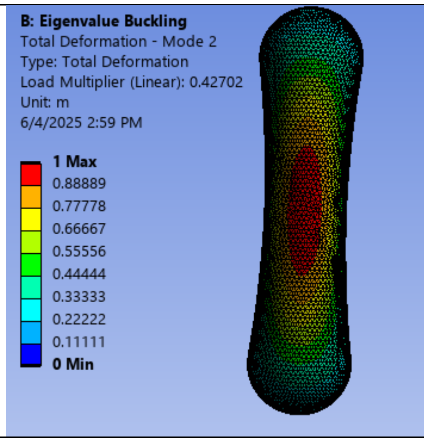


t=0.47 s

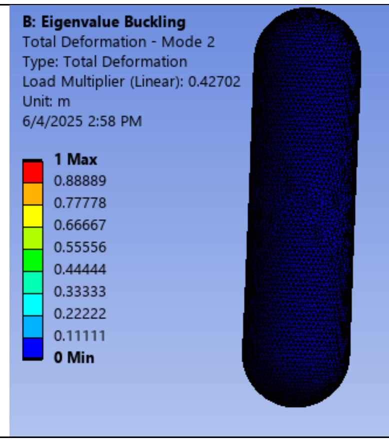


t = 1 s

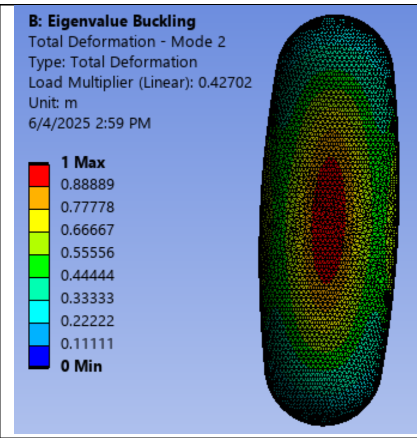
Total Deformation – Mode 1 *(front view)*



t=0 s

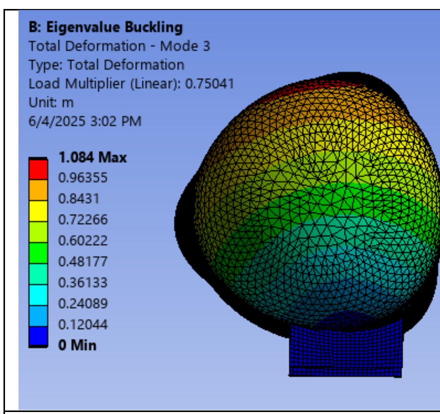


t=0.47 s

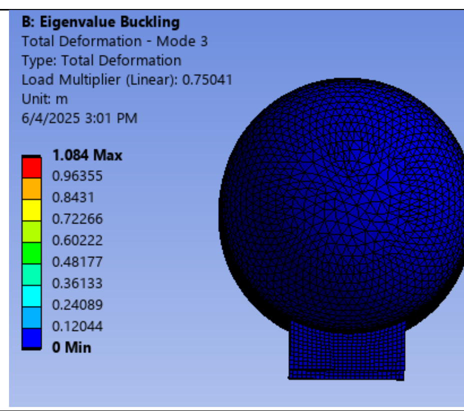


t = 1 s

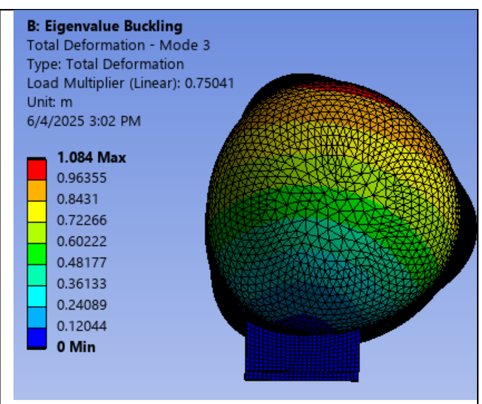
Total Deformation – Mode 2 *(top view)*



t=0 s

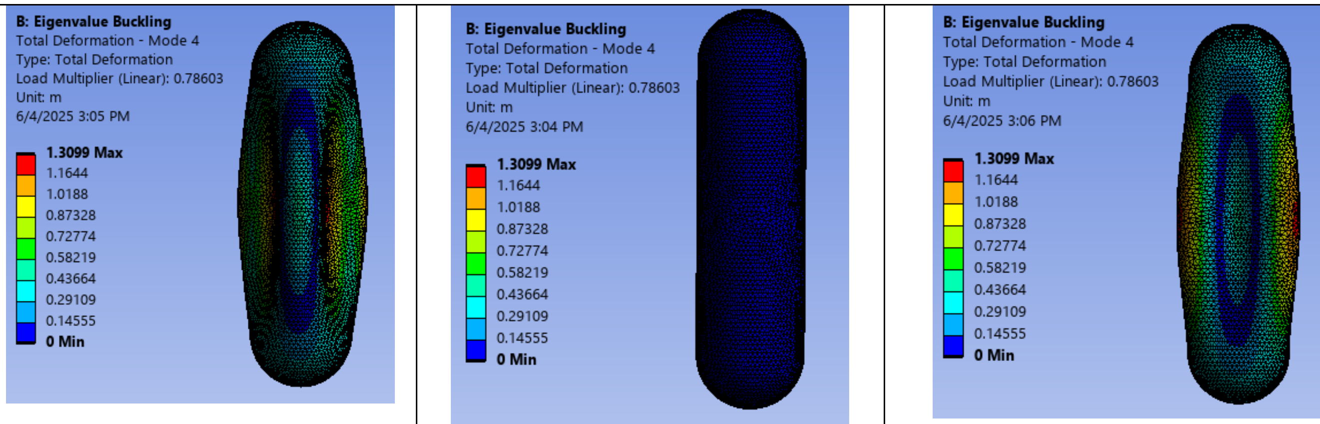


t=0.47 s

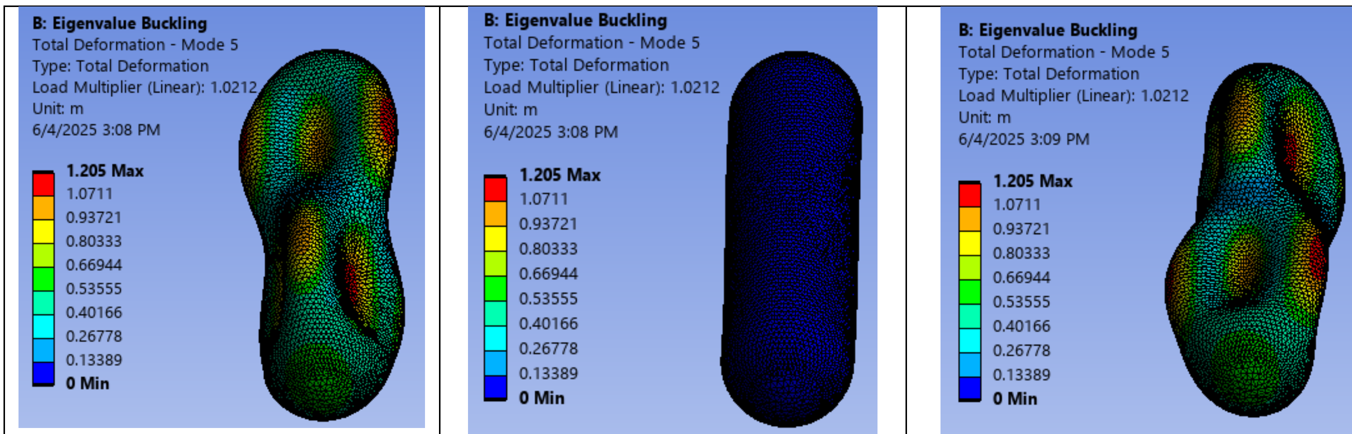


t = 1 s

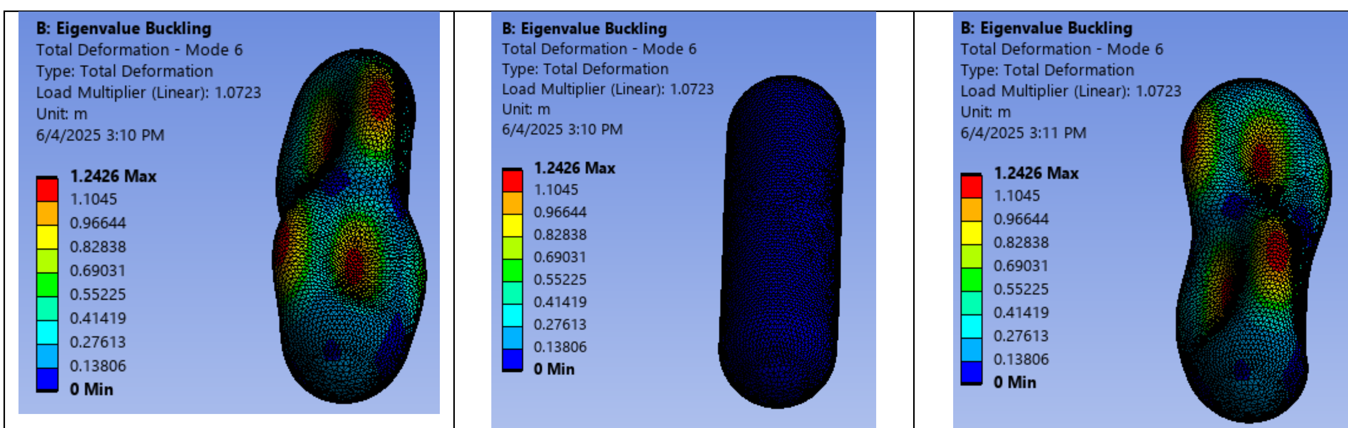
Total Deformation – Mode 3 *(front view)*



t=0 s	t=0.47 s	t = 1 s
Total Deformation – Mode 4 *(top view)*		



t=0 s	t=0.47 s	t = 1 s
Total Deformation – Mode 5 *(angled top view)*		



t=0 s	t=0.47 s	t = 1 s
Total Deformation – Mode 6 *(angled top view)*		

In the Eigenvalue Buckling analysis (at an applied pressure of 65 MPa), the linear load multiplier at Mode 1 is 0.39376. The max total deformation is 1.0043 m.

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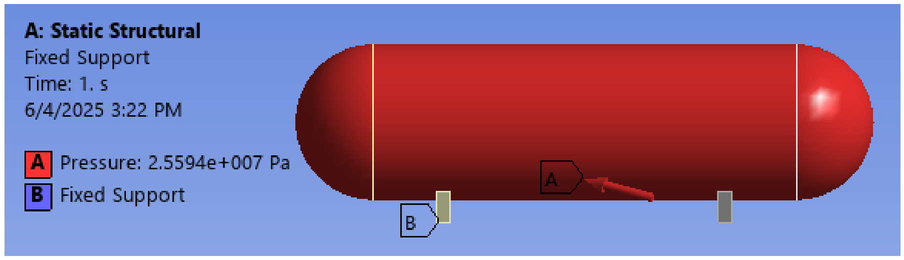
Critical Buckling Load

The critical load applied for when the vessel buckles occurs when the Load Multiplier value equals 1. This is calculated by 65 MPa / $\frac{1}{0.39376}$ = 25.594400 MPa (25,594,400 Pa).

The calculated pressure when the vessel begins to buckle is 25.5944 MPa.

	Mode	Load Multiplier
1	1.	0.99999
2	2.	1.0845
3	3.	1.9057
4	4.	1.9962
5	5.	2.5935
6	6.	2.7233



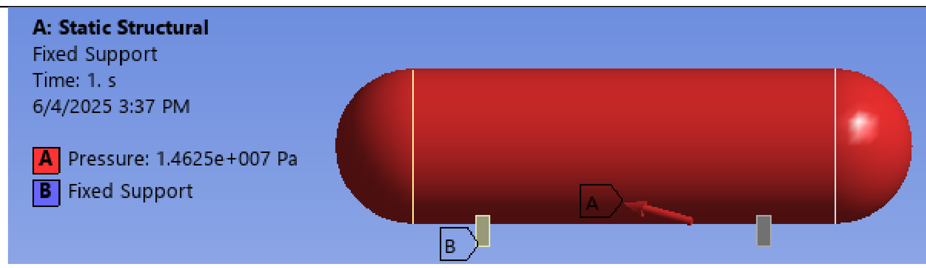
Critical Buckling Load: Applied Surface Pressure of 25.944 MPa

Allowable Load to Avoid Buckling:

Using a factor of safety of 1.75, the allowable load to avoid buckling can be solved. This can be done by calculating 65 MPa / $\frac{1.75}{0.39376}$ = 14.62537142857140005 MPa (14625371.4285714 Pa).

The calculated pressure to avoid buckling is 14.625 MPa

	Mode	Load Multiplier
1	1.	1.75
2	2.	1.8978
3	3.	3.3351
4	4.	3.4934
5	5.	4.5387
6	6.	4.7658



Allowable Load to Avoid Buckling: Applied Surface Pressure of 14.625 MPa

Conclusion/Discussion:

The critical load applied for when the vessel buckles occurs when the Load Multiplier value equals 1. The calculated pressure when the vessel begins to buckle is 25.5944 MPa. For this reason, at an applied surface pressure of 65 MPa, the vessel buckles significantly (as seen by deformation images).

On June 18th 2023, an OceanGate Pressure vessel voyaged to the Titanic wreckage. The vessel could not withstand the ocean pressure during its descent to the ocean floor. As a result, the pressure vessel imploded at approximately 3341 meters. At this ocean depth, the approximate hydrostatic pressure was 32.72 MPa. The titanic wreckage lies at a depth of approximately 3810 meters. At this ocean depth, the approximate hydrostatic pressure is 37.25 MPa.

The pressure vessel designed in problem 3 would not be able to withstand this voyage. At a safety of factor of 1.75, the allowable load is only 14.625 MPa. A few design considerations would be to use a material such as a Titanium pressure hull. Additionally, the geometry must be machined to be perfectly symmetrical without any welded contacts (locations for possible failure).

For example, the Limiting Factor submersible used a Weld-free Titanium Pressure Hull with a 90 mm thickness. The design was able to achieve a dive depth of 11,000 meters and pass a pressure test of up to 14,000 meters.