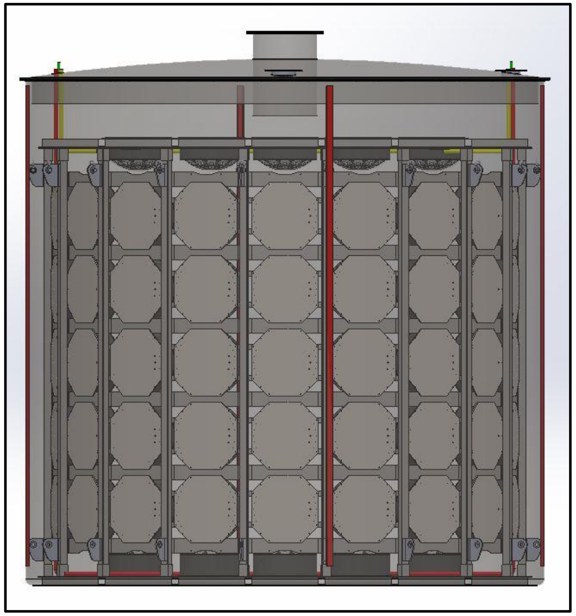
WCTE Mechanical Design- Structural Simulation

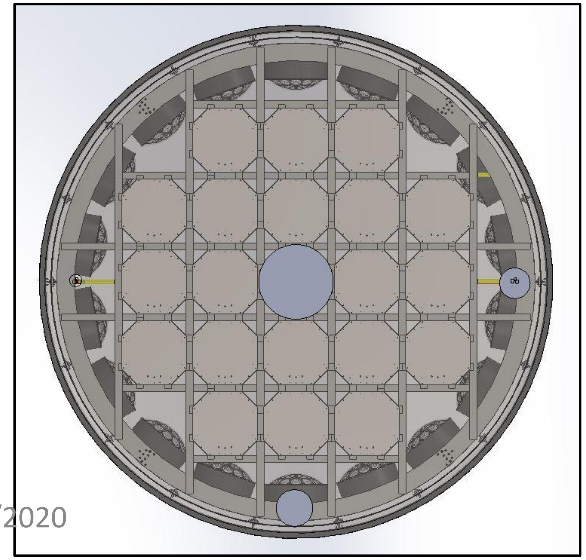
Vishwakarma Institute of Information Technology, (VIIT)
India

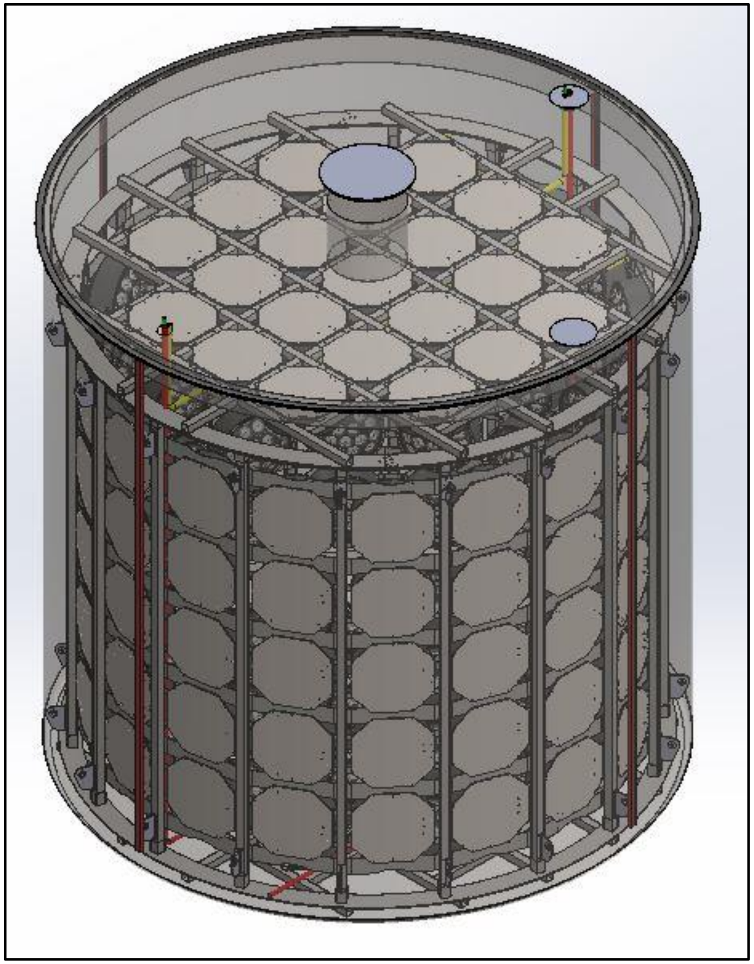
Contents of the Presentation

- Details of the Detector
- Assembly Procedure
- Structural actions induced in each operational phase
- Methods of Analysis of the support structure and tank
- Analysis Results- Support Structure
- Analysis Results- Tank with and without water
- Concluding Remarks

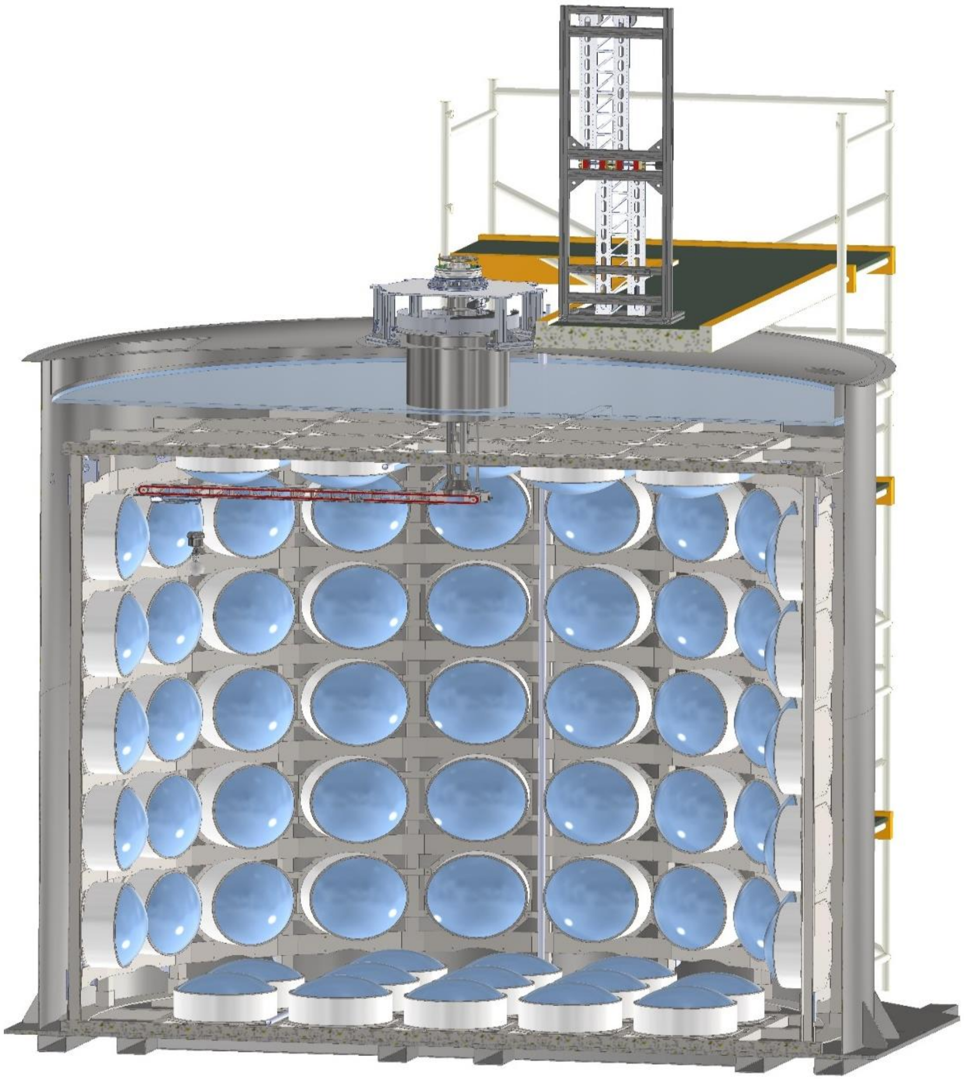
WCTE Detector





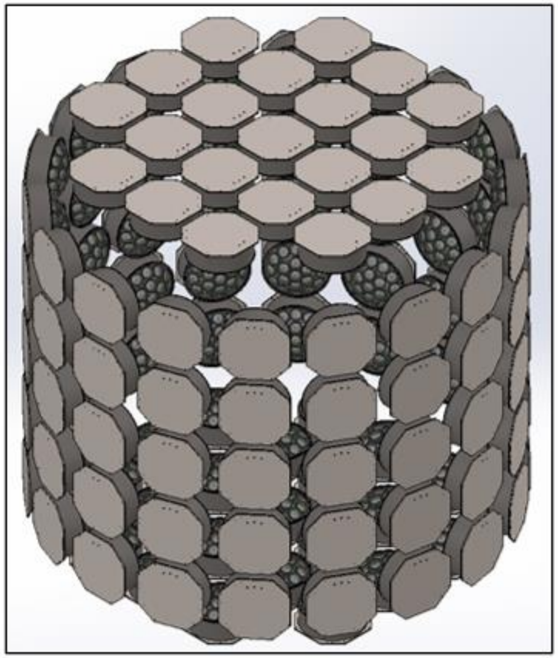


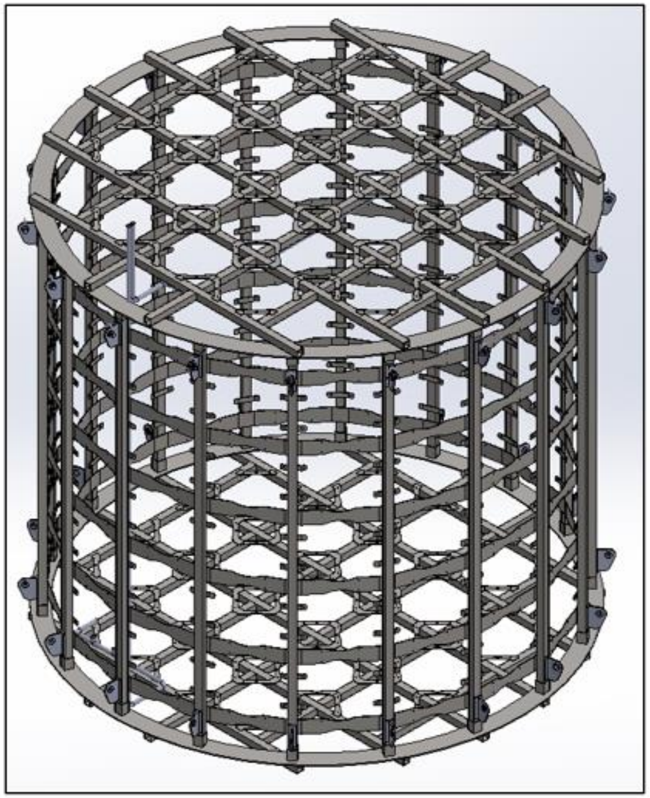
Tank Details



Tank internal diameter : 4.1 m
Tank wall thickness : 6 mm
Tank base thickness : 30 mm
Tank wall height : 4 m
Tank Lid : conical roof supported on wall and having mass 750 kg
Tank Material : SS 304

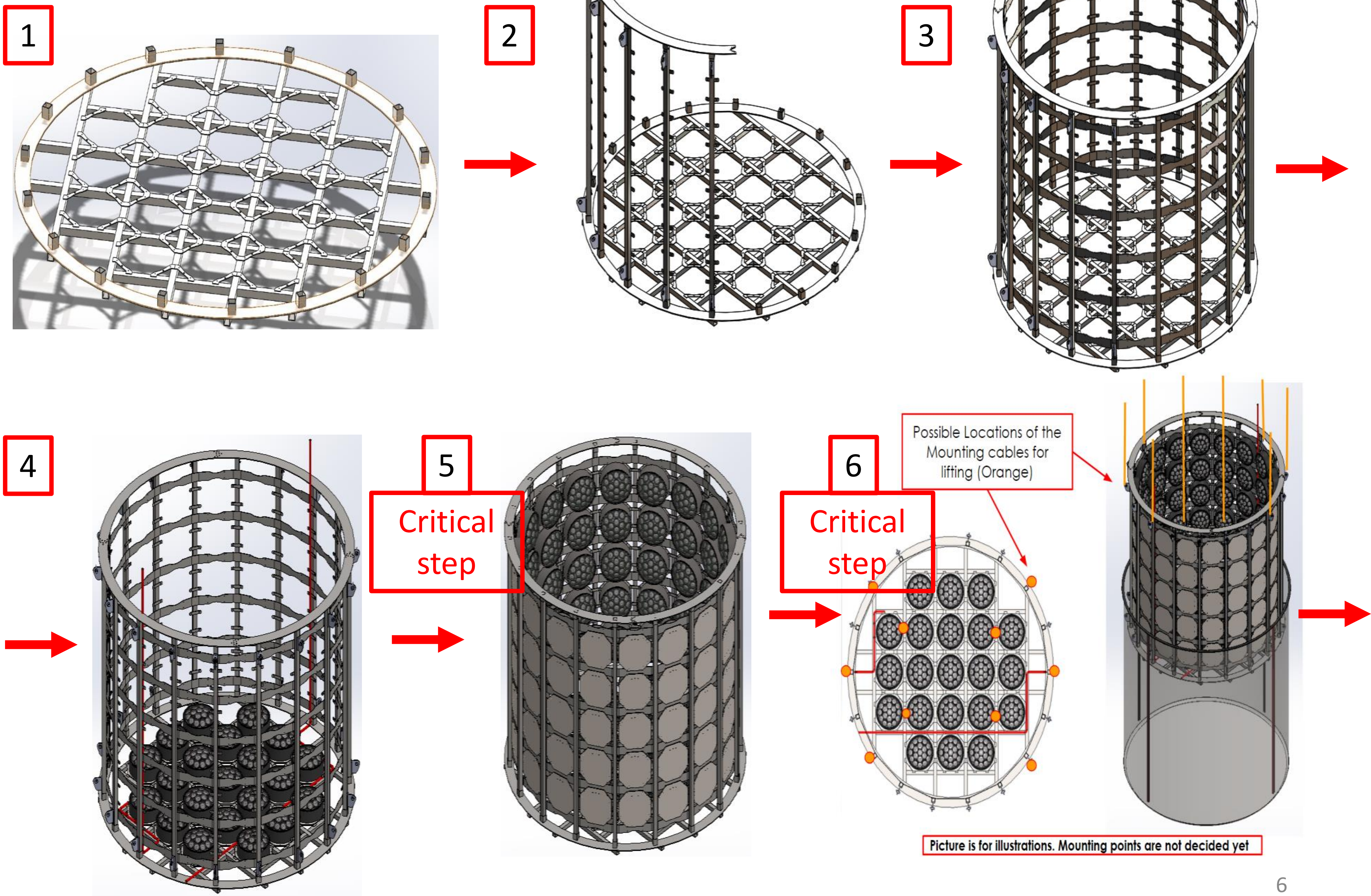
Details of the Support Structure



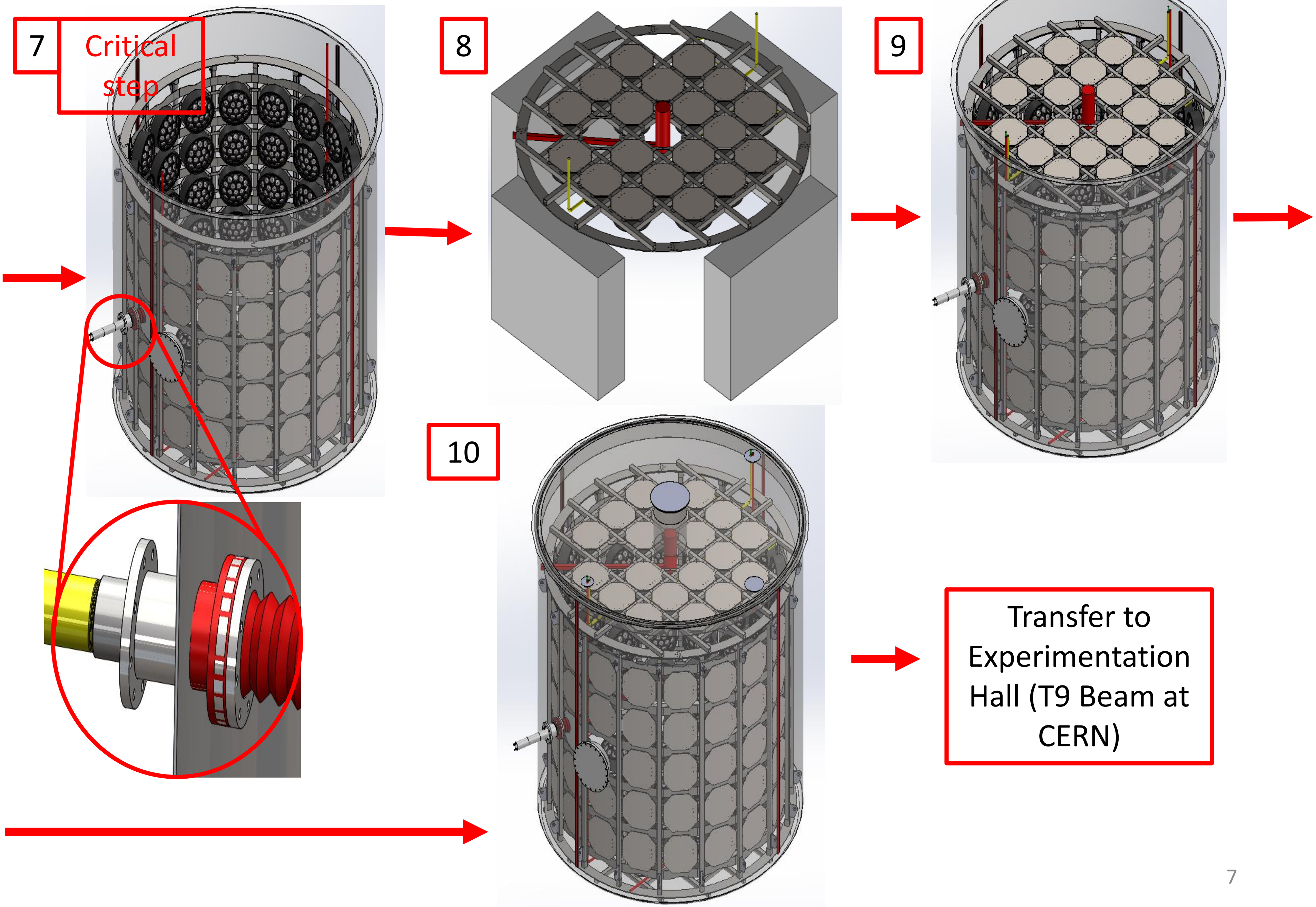


- **Dimensions:**
  - Diameter : ~ 4 m
  - Height : ~ 3.5 m
- Consist of 132 mPMT
- **Location:** CERN, Switzerland

Assembly Procedure



Assembly Procedure



Structural Actions during the operational phase

Operational Phase	Structural Actions	Remarks
Fabrication of the structure and mounting of mPMTs	Distortion of the structure due to mounting of mPMTs	Total weight of mPMTs ~ 5.2 Tonnes
Lifting of the structure +mPMTs and placing it in the tank	Localised stresses in the structure at the lifting points	Total weight of the structure around 7 Tonnes
Transport of the detector from assembly workshop to beam-line 1	Vibrations of the tank and structure- Natural frequencies of the tank and the structure	Total weight of the structure + mPMTs and the tank around 12 Tonnes
Filling up of water in the tank at beam-line 1	Self weight of the structure and tank+ Hydrostatic pressure on the walls + Weight of water	Total mass of water is around 50 Tonnes
Transport of the tank from beam-line 1 to beam-line 2	Water Vibrations induces dynamic pressure on the walls of the tank - Natural frequencies of the tank and the structure	Total weight ~62 Tonnes

Methods of Analysis of the Support Structure and Tank

A) Static Analysis

- Support Structure
  - Self weight of the structure + self weight of mPMTs
  - Lifting stresses in the support structure
  - Buckling Analysis of the supporting structure
- Tank
  - Self weight of the structure + self weight of mPMTs + Weight of water on the base of the tank + Hydrostatic pressure on the walls of the tank
  - Buckling Analysis of the tank

Methods Analysis of the Structure and Tank

B) Dynamic Analysis

- Tank

- Vibrations of the tank and support structure + mPMTs during transit from workshop assembly to beam-line 1
- Water Vibrations during the transit of the tank from beam-line 1 to beam-line 2
- Seismic Analysis of the Tank: (Time History Analysis)
  1) Without water
  2) With water

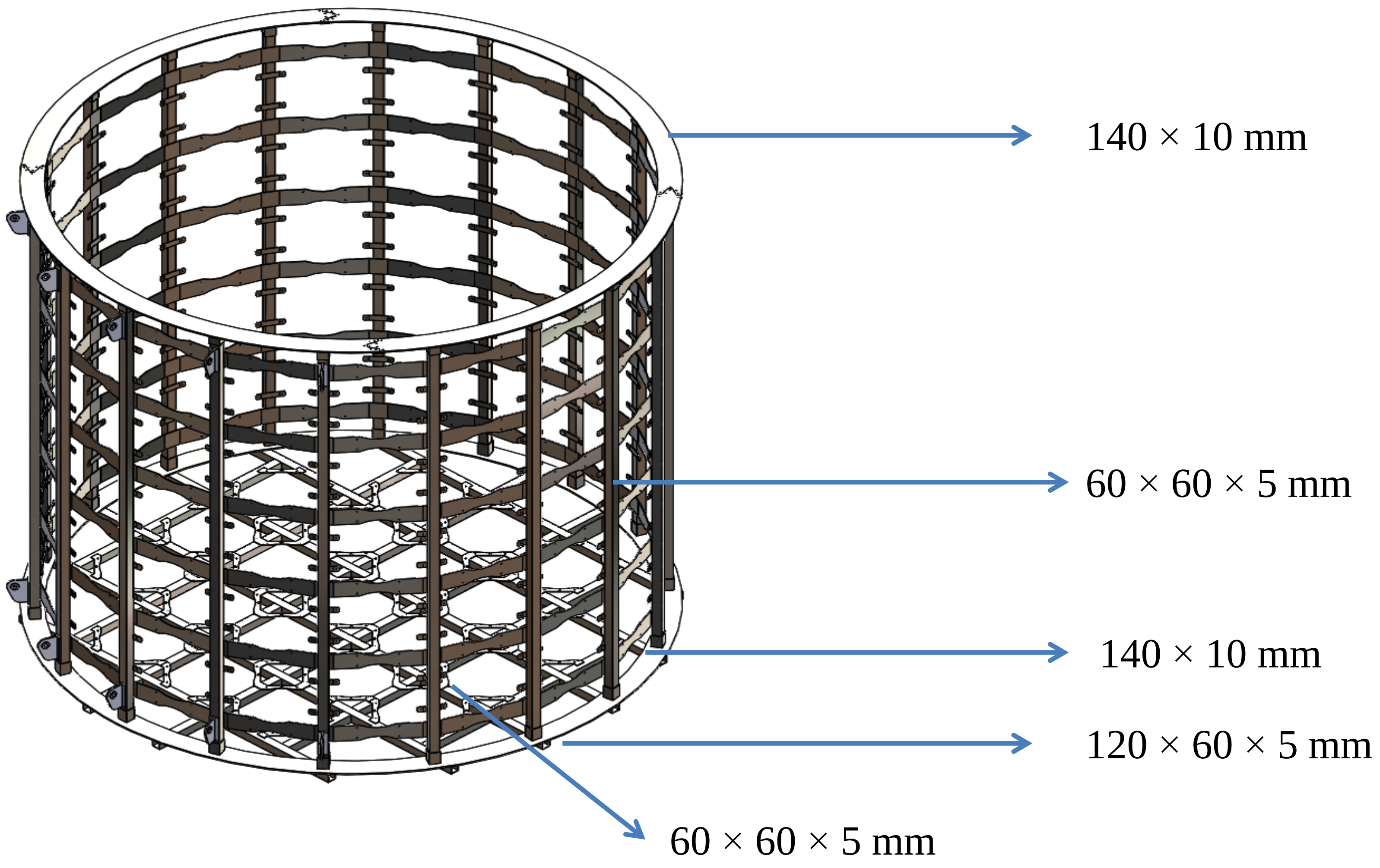
Software :

ANSYS
HYPERMESH-OPTISTRUCT
STAAD PRO
ETABS

Material Properties

1. Material Type: Stainless steel
2. Grade: SS 304
3. Poisson's ratio : 0.31
4. Density of Material : 7750 kg/m^3
5. Modules of Elasticity : 193 X 10^3 M Pa
6. Design Yield Strength : 207 M Pa
7. Ultimate Tensile Strength : 586 M Pa
8. Thermal Coefficient : 1.7 X 10^{-5} /°C

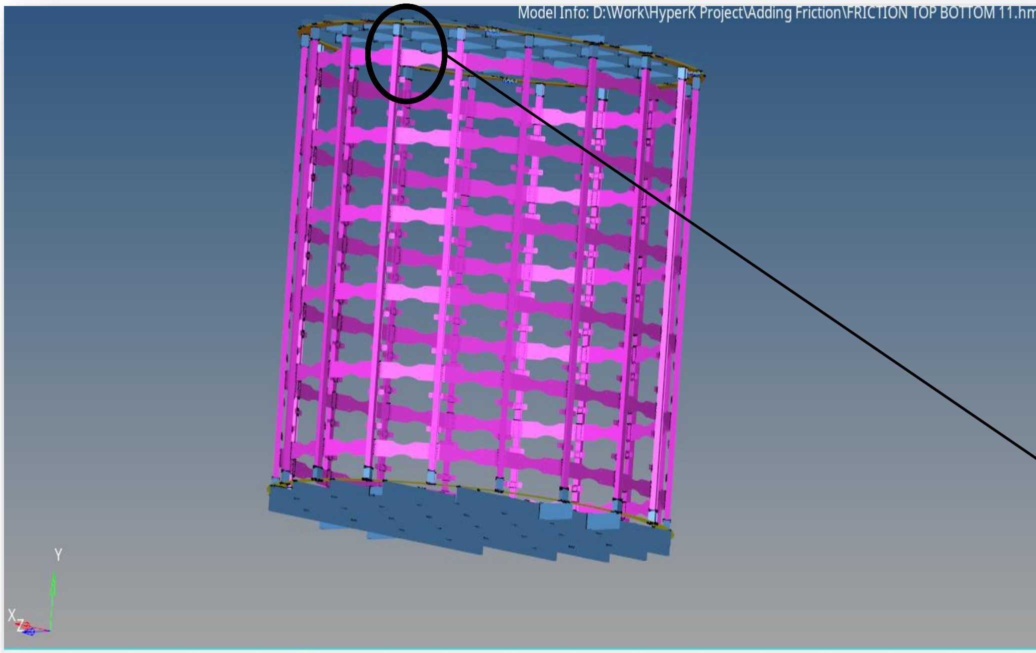
Sectional Dimensions

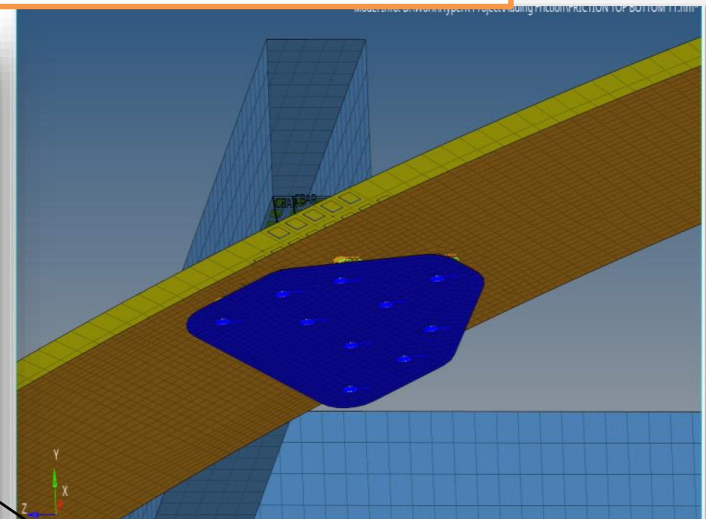


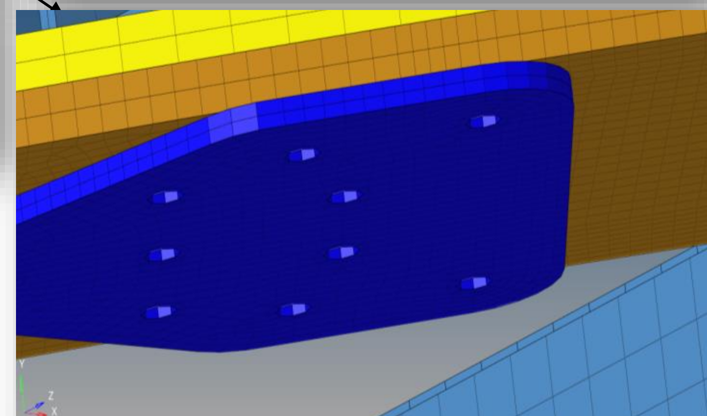
Analysis of Support Structure

Software: HYPERMESH-OPTISTRUCT

Finite Element Model of WCTE Structure





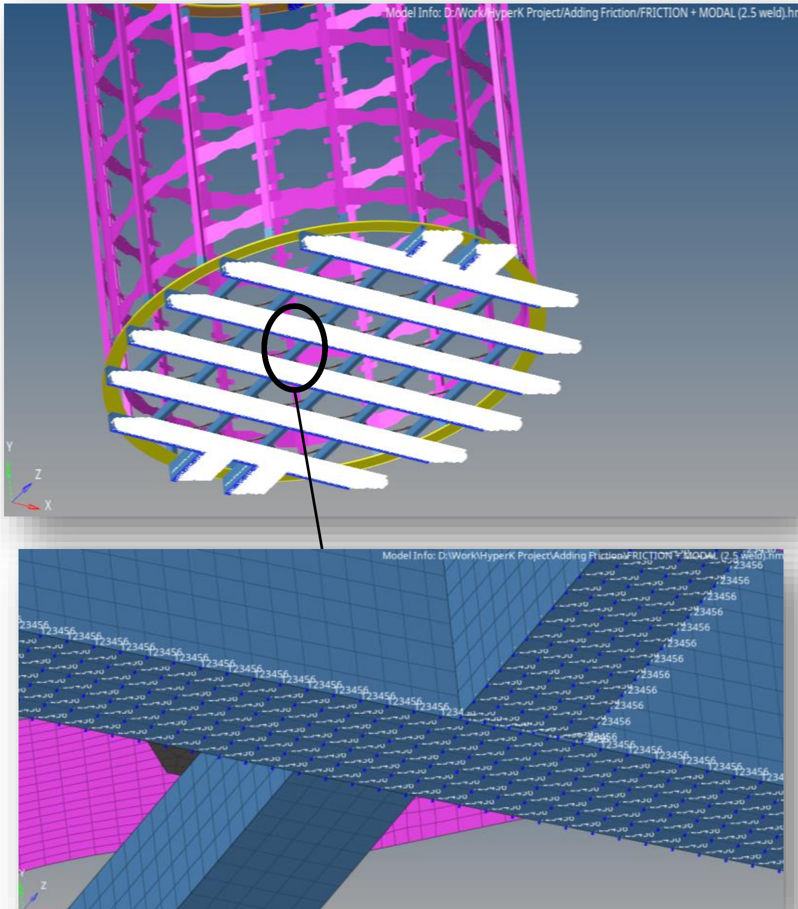


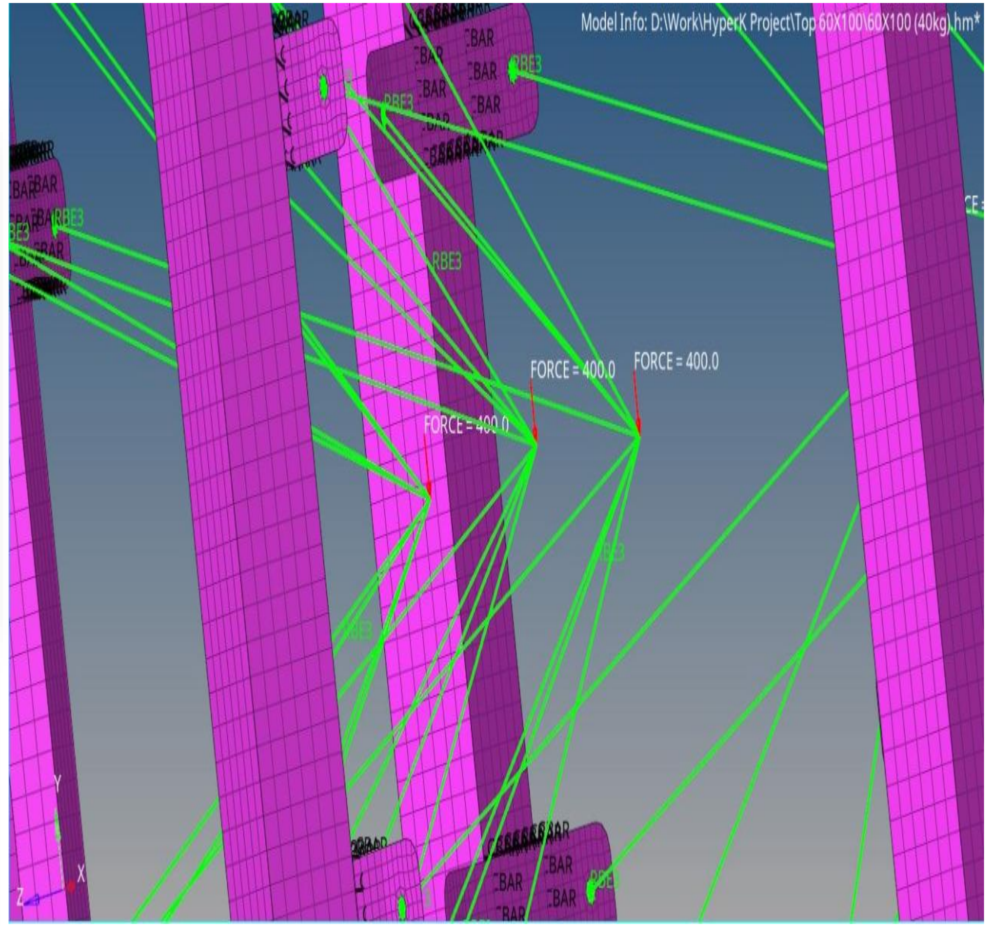
Thickness Assigned to shell element properties –
Ring : 10 mm
All other components : 5 mm

Elements –
Type : Shell (Quad and Tria)
Material Properties , **Young's Modulus E : 193GPa** , ν = 0.31, **Yield strength = 207 MPa**
Card Type : MAT1 Elastic Material Card
Element Formulation: Shell Element (Card Image- PSHELL , Size : 5mm Max length of elements
Regular order elements used

Boundary Conditions

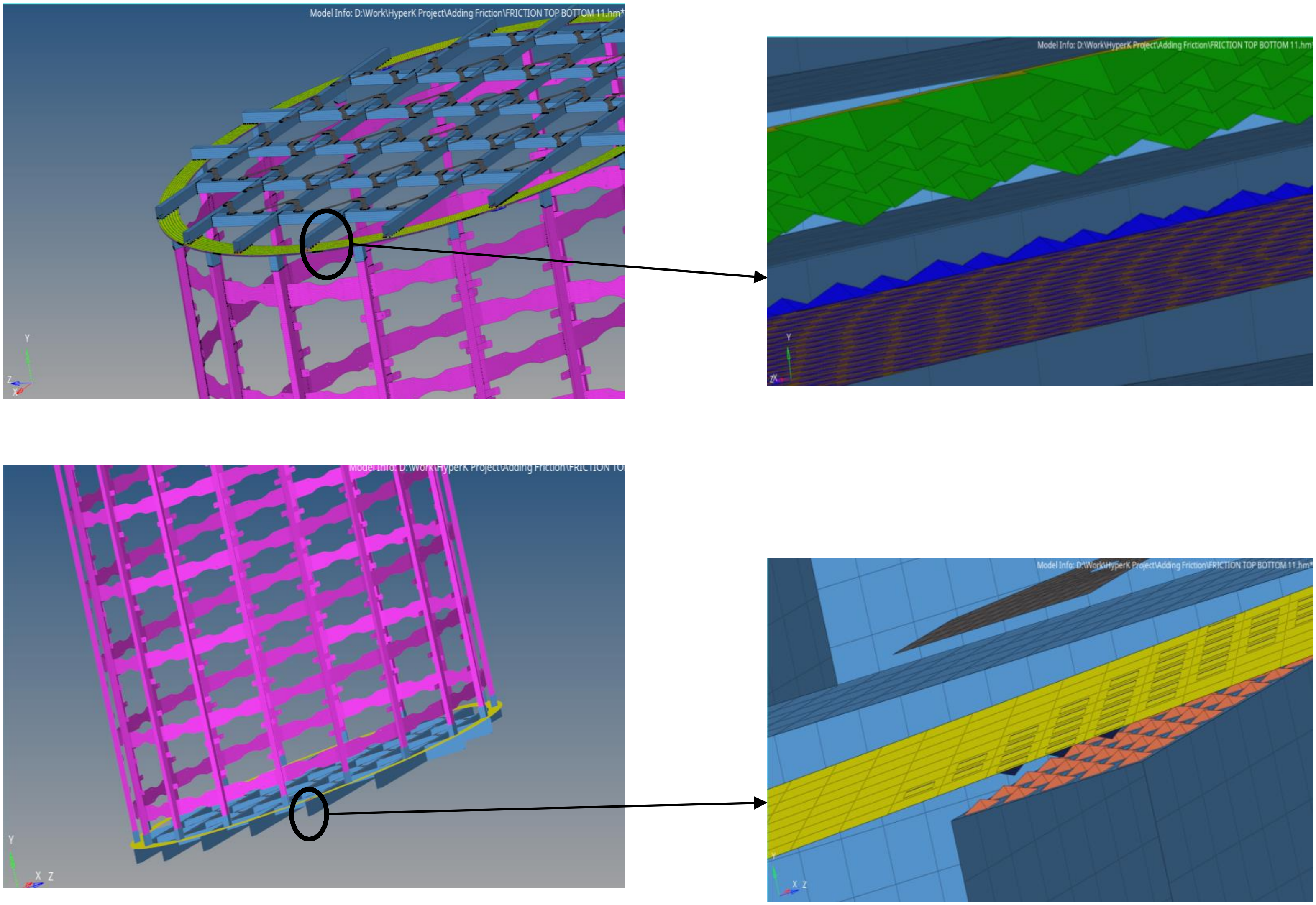
Single Point Constraints (SPC)
Nodes Constrained in all 6 DOF



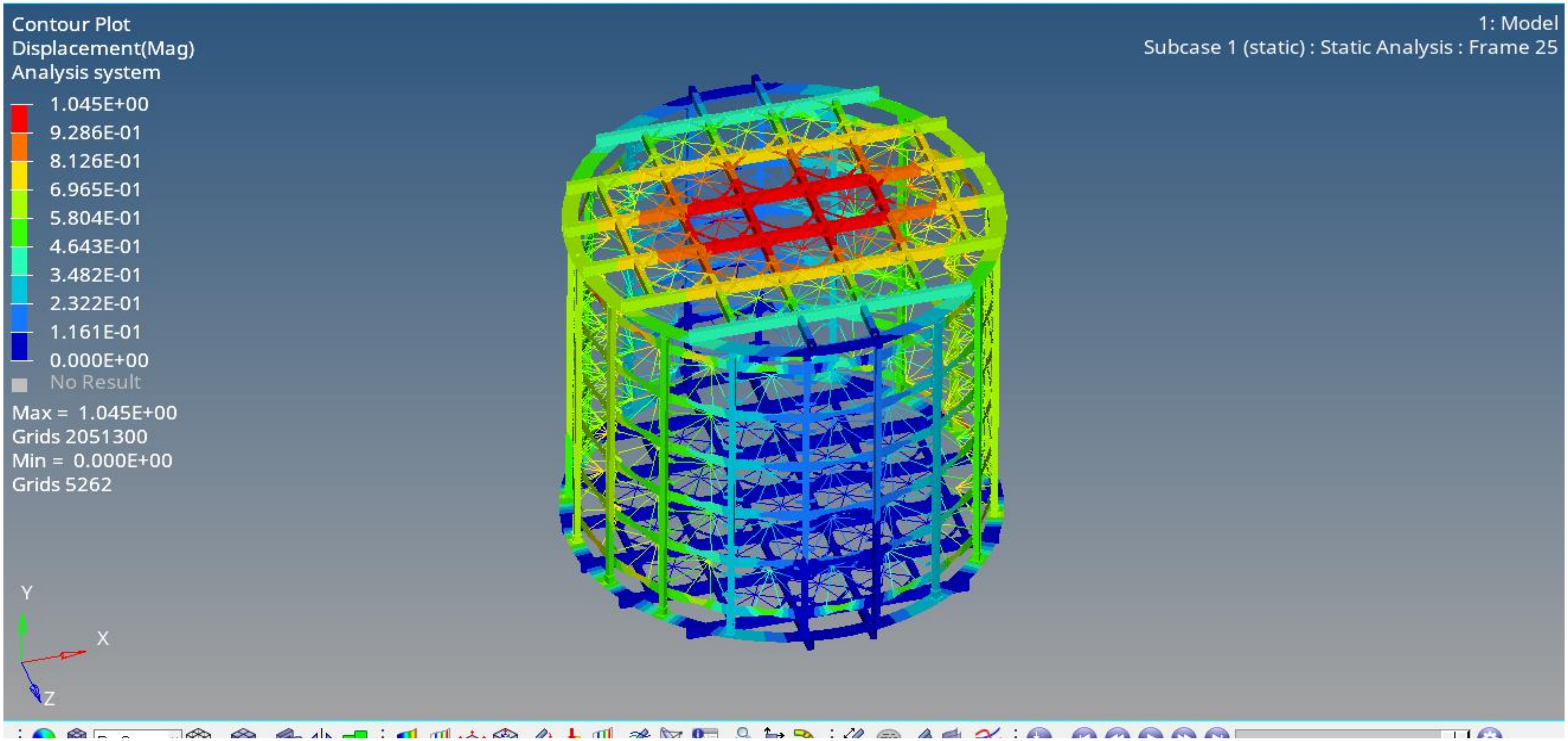


Forces : 400N, Due to self weight for each mPMT

Mounting of Top End Rings: Friction Surfaces



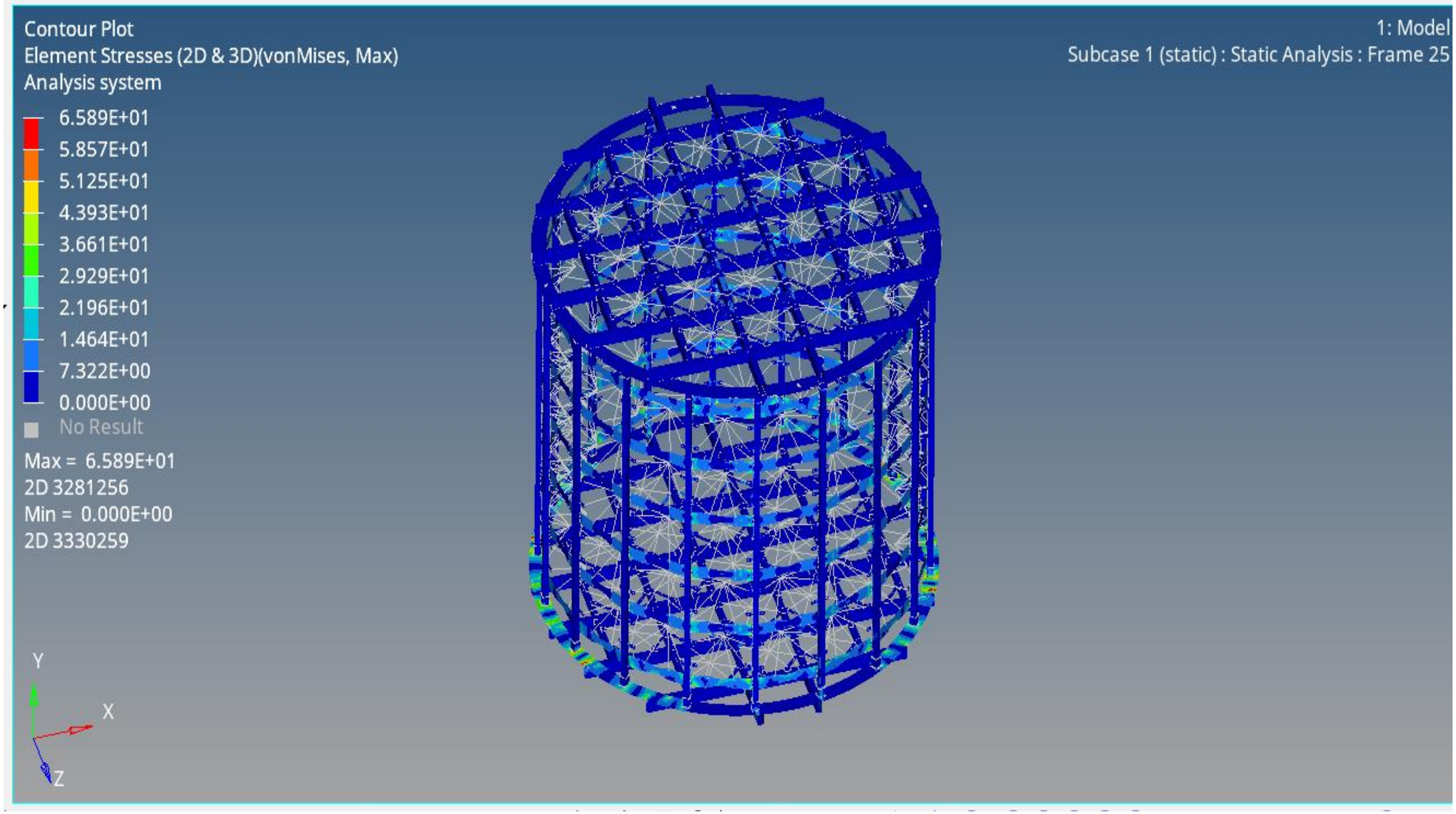
Maximum Deformation for rectangular cross-section of beam considering 40 kg mPMT



Max Deformation – 1.045 mm

Within safe limits. It's effect on mPMTs will be assessed

Elemental Stresses (Von-Mises) considering 40 kg MPMT



Max Stress – 65.89 M Pa

Permissible Stress: 165 .6 M Pa. So the stresses are within permissible limits.

Factor of safety: 3.14

Analysis of Tank

Software: STAAD PRO

Loading Details of the Tank

1. **Dead Load**
   - Self weight of support structure + mPMTs + tank + Tank lid
2. **Superimposed Load**
   - Mass of the mPMT : 40 Kg.
   - Equally distributed at the connecting points.
3. **Hydrostatic Load on tank**
   - Intensity at top of wall : 0 KN/m^2
   - Intensity at bottom of wall : 39.26 KN/m^2
   - Pressure on bottom plate : 39.26 KN/m^2

Loading Details

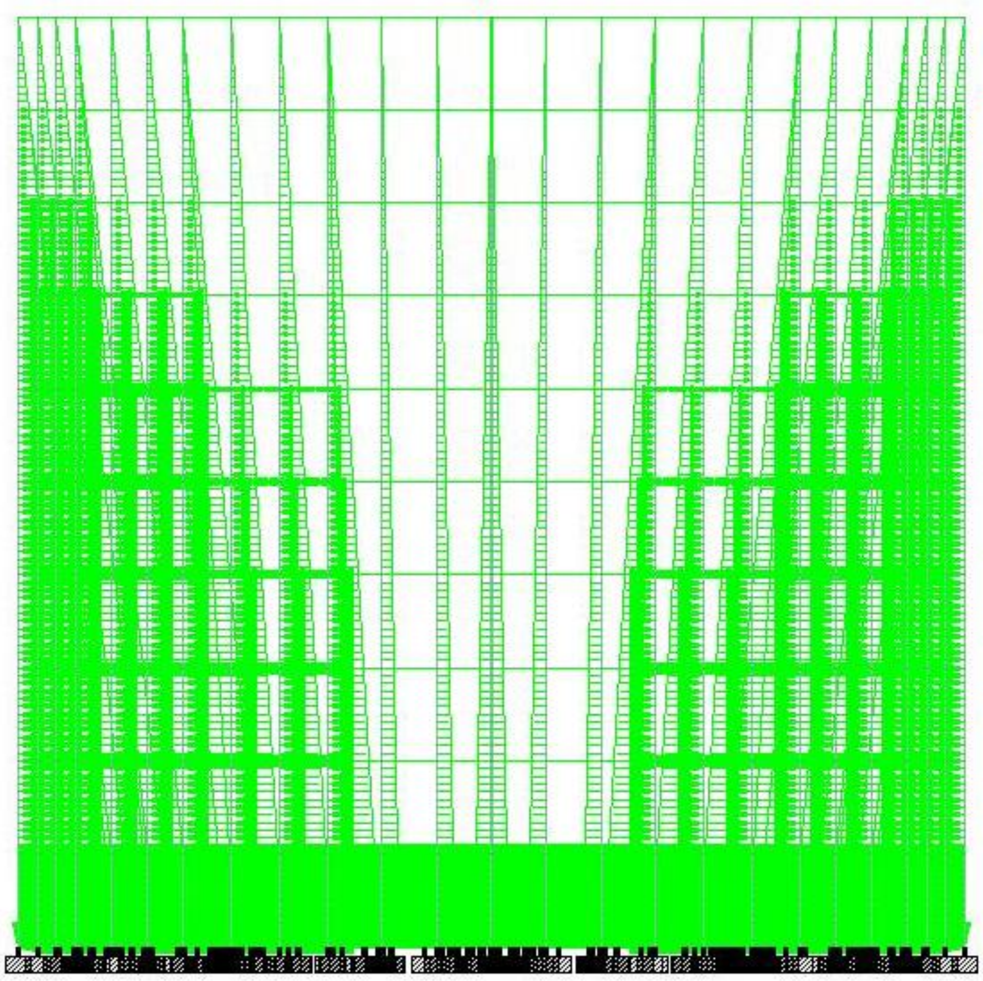
4. <u>Hydrodynamic Load</u>

- Hydrodynamic pressure is calculated as per EN 1998 Part: 4 (2007)

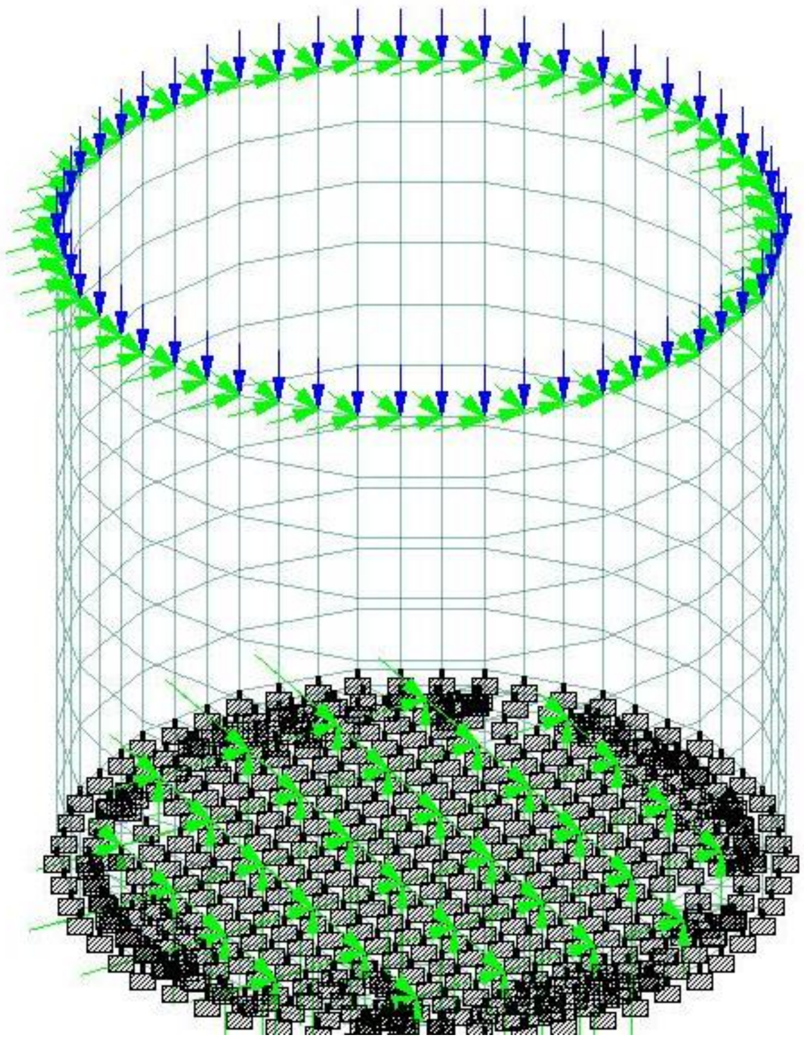
5. <u>Load combination</u>

- Self weight of the tank, support structure and mPMTs + Hydrostatic Load + Hydrodynamic Load

Loading Details (Hydrostatic Load)

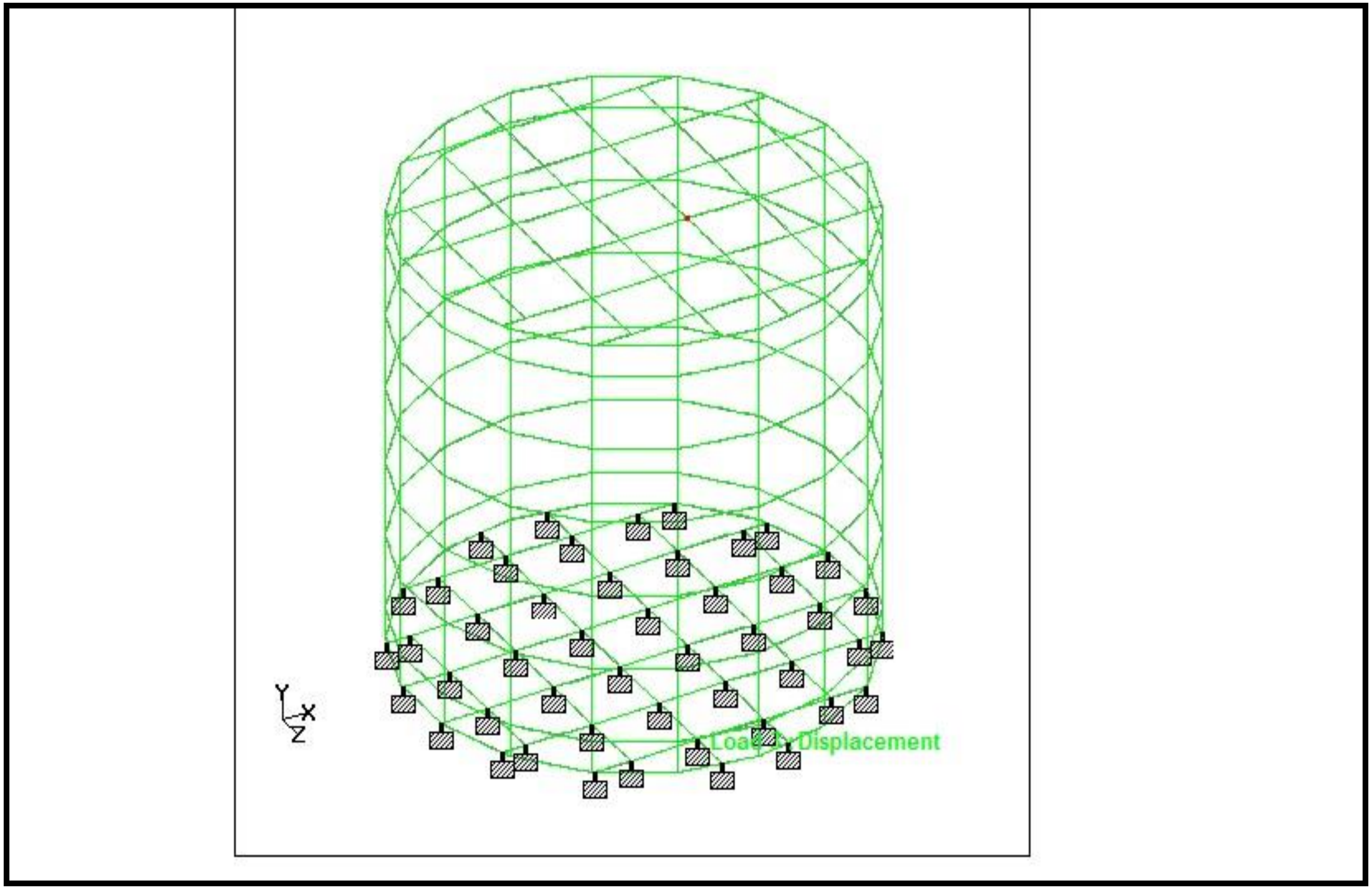


Loading Details (Tank Lid Load)

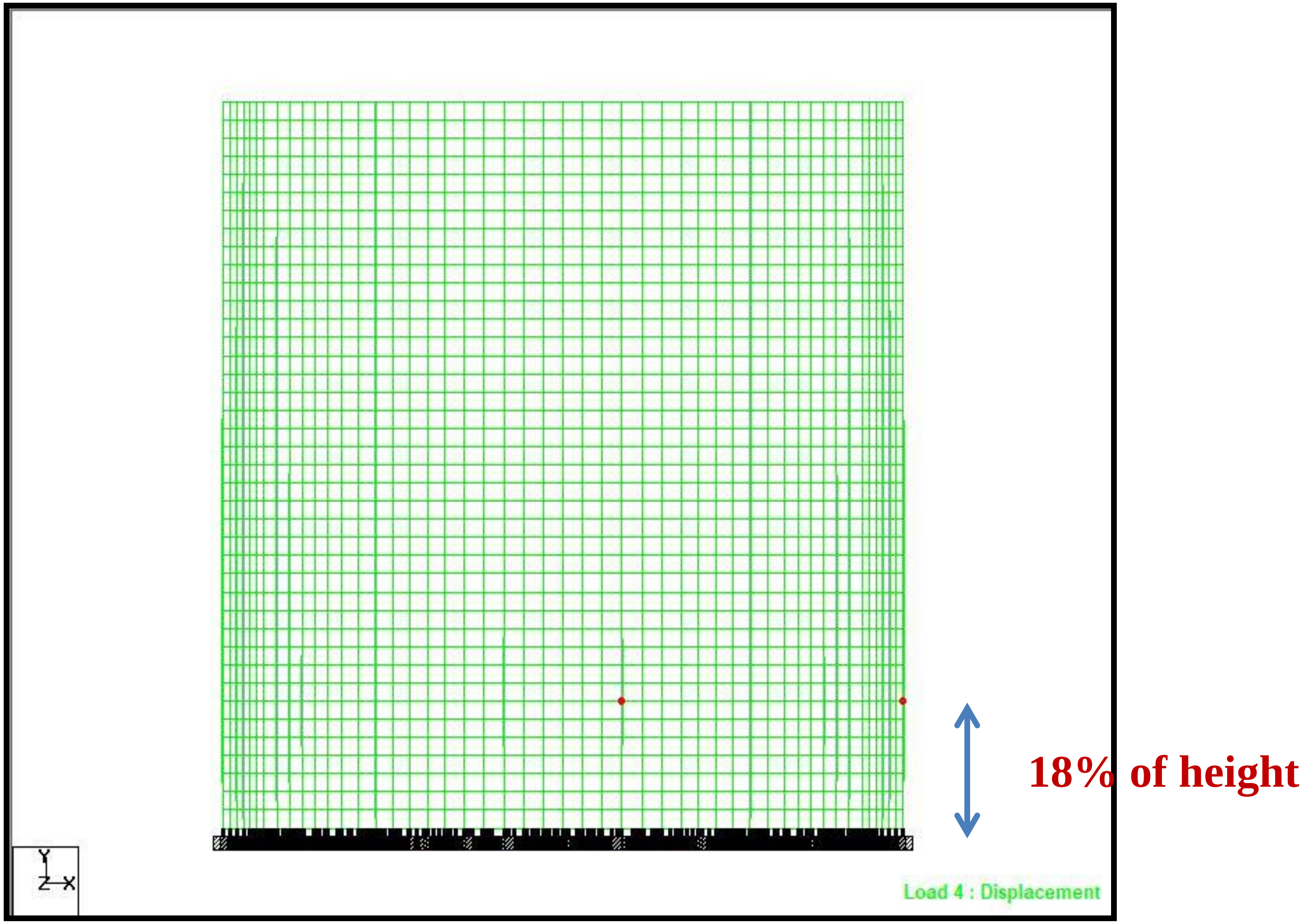


Note: Load of tank lid taken as gravity load acting at top nodes of tank. Figure shows Degrees of freedom assignment to tank lead load to generate dynamic mass matrix.

Analysis results (Self weight of tank and support structure + hydrostatic pressure on the tank+ weight of water)

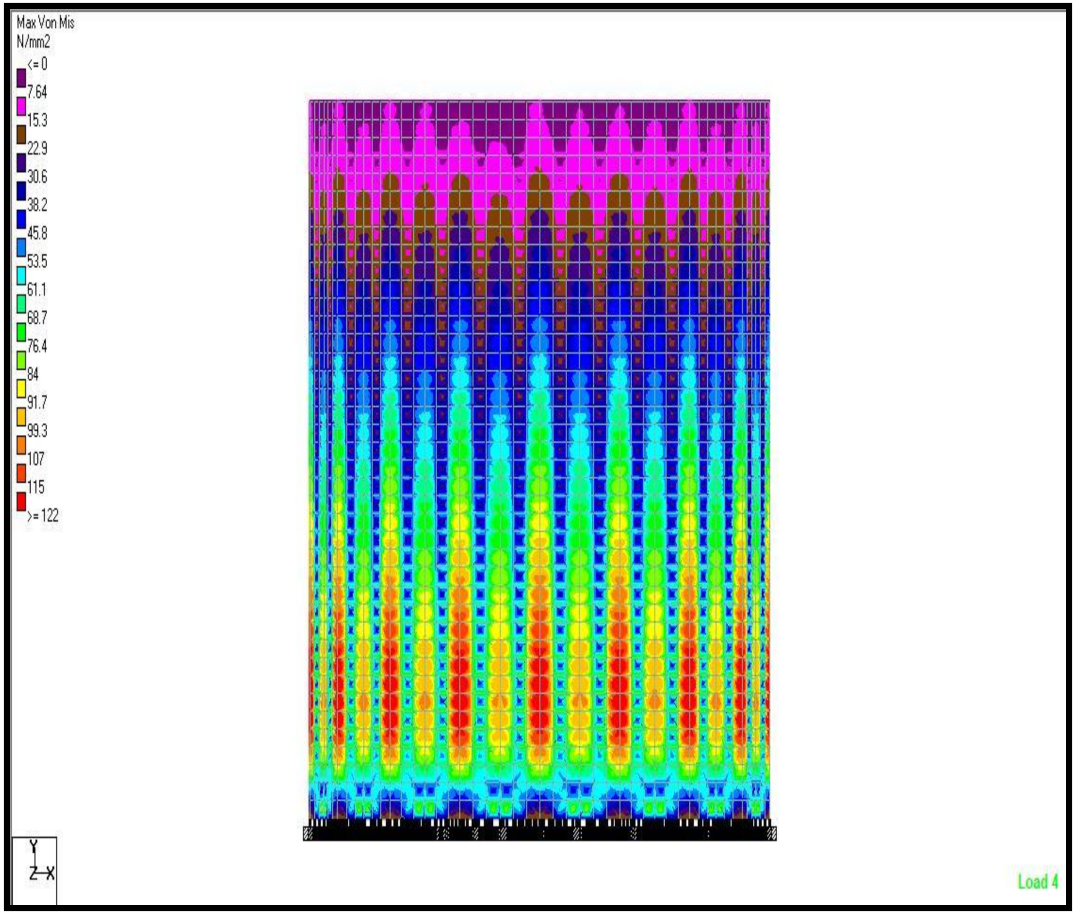


Maximum Displacement : **1.9 mm** (**At the top plate of the support structure**) due to hydrostatic Pressure along Y direction



Maximum Displacement: **4.2** mm (**0.75 m from the bottom**) due to hydrostatic Pressure in X-Z plane

Stress Distribution- Self Weight + Hydrostatic Load



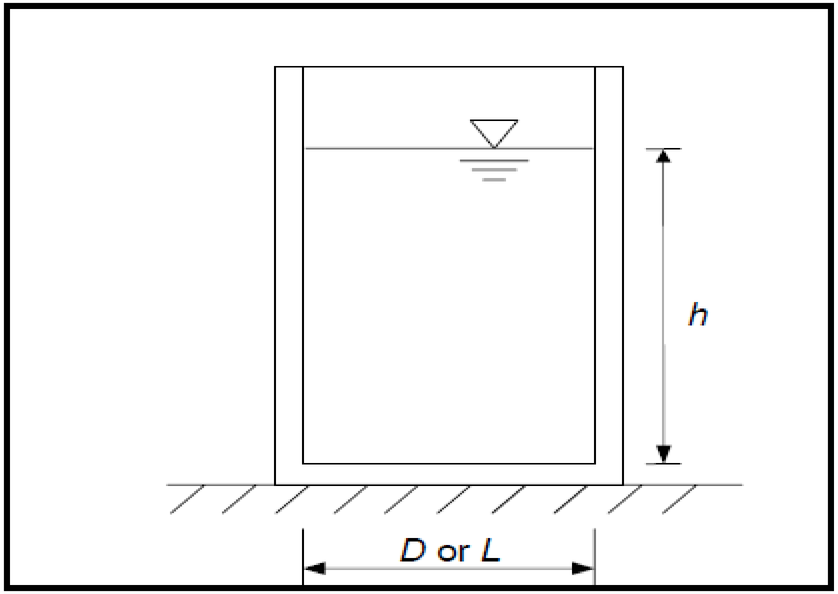
Maximum Stresses: 106.63 M Pa

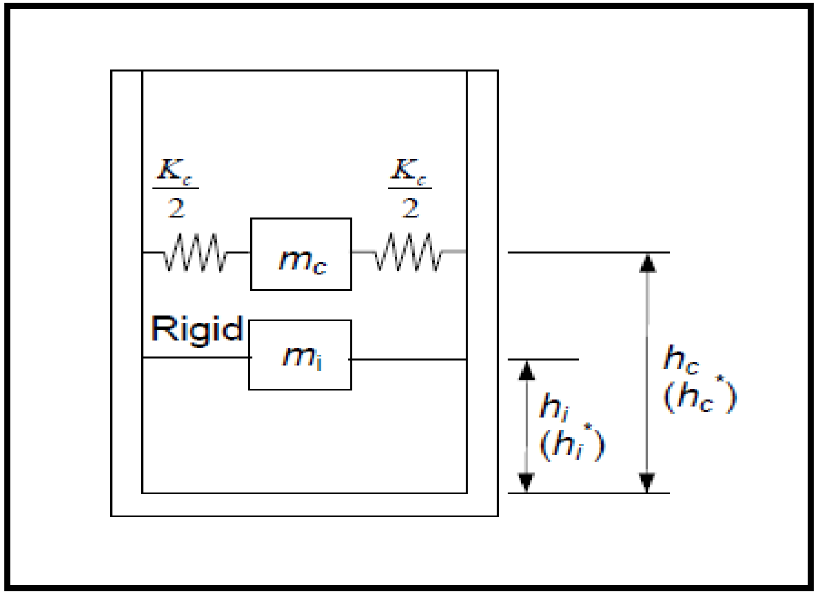
Permissible Stresses: 167.5 M Pa

Stresses within permissible limits

Factor of Safety
(w.r.t Yield Strength) : 1.95

Mathematical Model for Water Sloshing





$$\frac{m_i}{m} = \frac{\tanh\left(0.866\frac{D}{h}\right)}{0.866\frac{D}{h}}$$

$$\frac{m_c}{m} = 0.23\frac{\tanh\left(3.68\frac{h}{D}\right)}{\frac{h}{D}}$$

$$K_c = 0.836\frac{mg}{h}\tanh^2\left(3.68\frac{h}{D}\right)$$

$$\frac{h_c}{h} = 1 - \frac{\cosh\left(3.68\frac{h}{D}\right) - 1.0}{3.68\frac{h}{D}\sinh\left(3.68\frac{h}{D}\right)}$$

$$\frac{h_i}{h} = 0.375$$

h/D <0.75

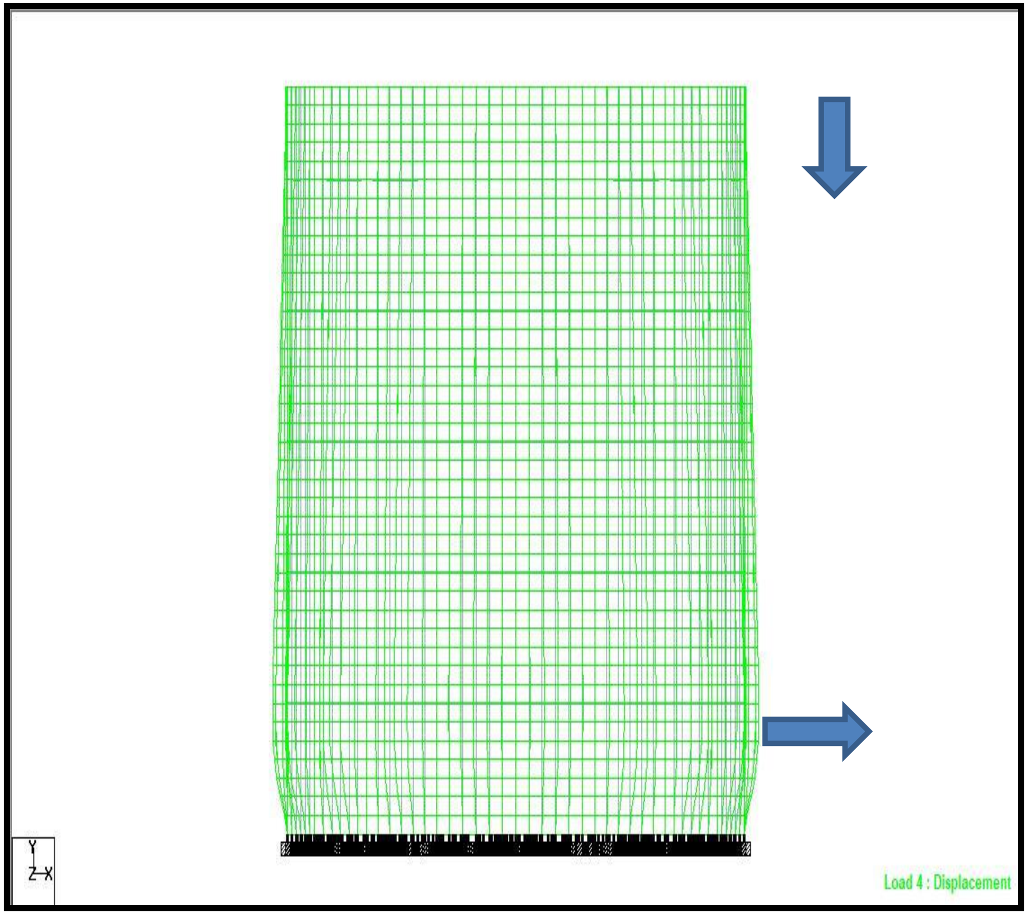
$$= 0.5 - \frac{0.09375}{h/D}$$

h/D >0.75

Mathematical Model for Water Sloshing

- M_i is the impulsive mass of water =42000 kg,
- h_i= 1.61 m,
- M_c is the convective mass of water =12000 Kg,
- h_c= 2.94 m,
- Total height = h =4 m

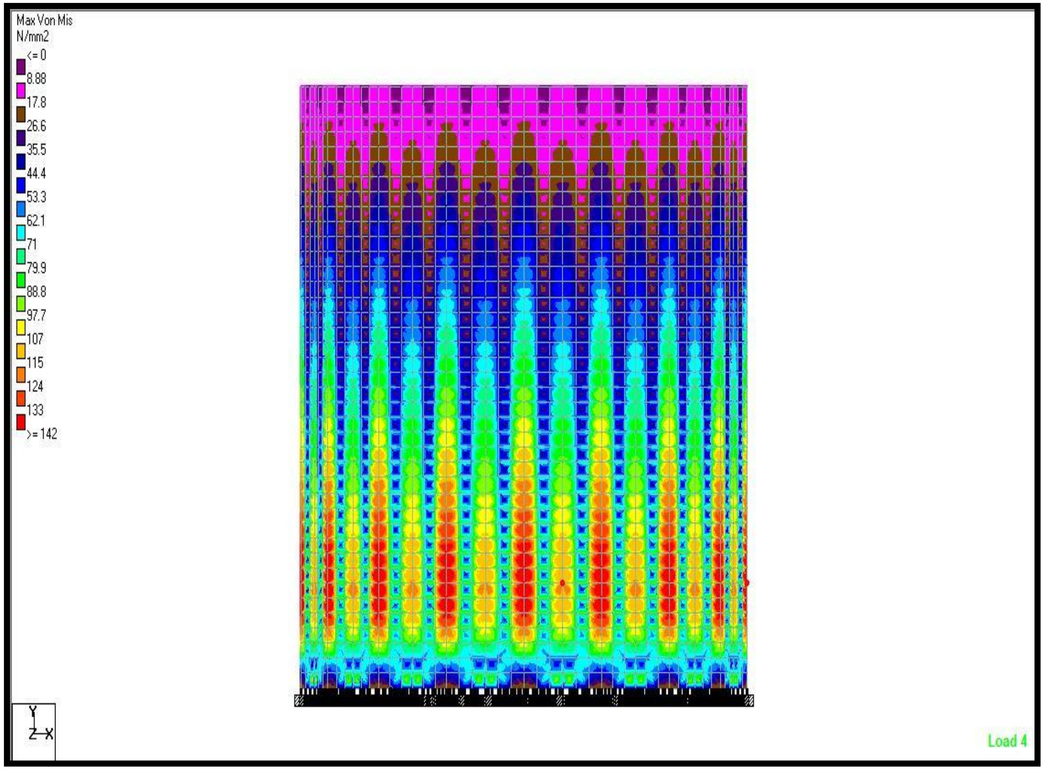
Deflection of the tank– Self Weight + Hydrostatic + Hydrodynamic Load



Along x: 6.3 mm
Along y: 1.9 mm
Along z: 6.3 mm

This may lead to relative displacement between the support structure and the tank. Hence the connection between the two have to be designed critically, like having a spring loaded connection.

Stress Distribution – Self Weight + Hydrostatic Load + Hydrodynamic Load

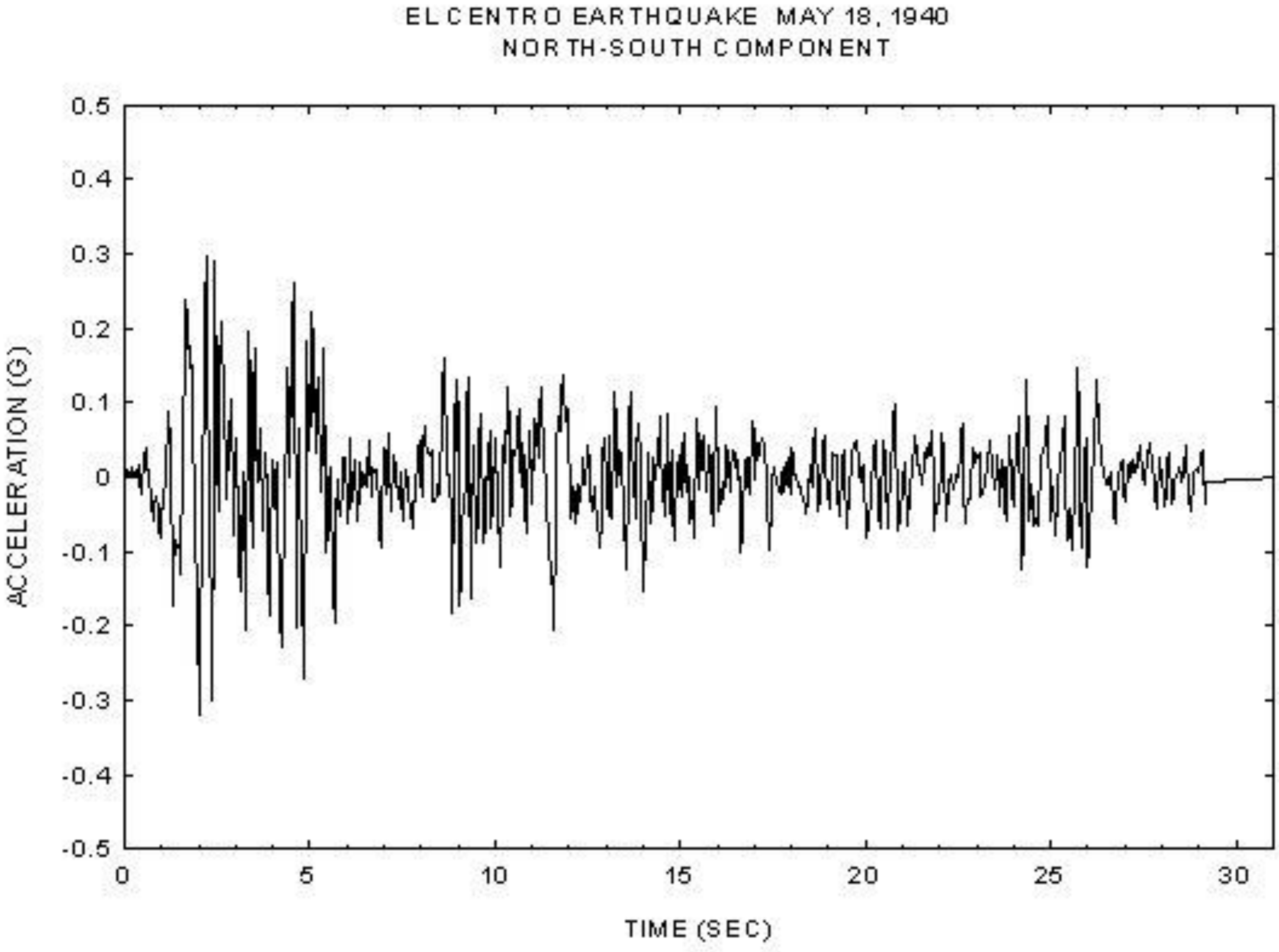


Maximum Stresses: 142.055 M Pa

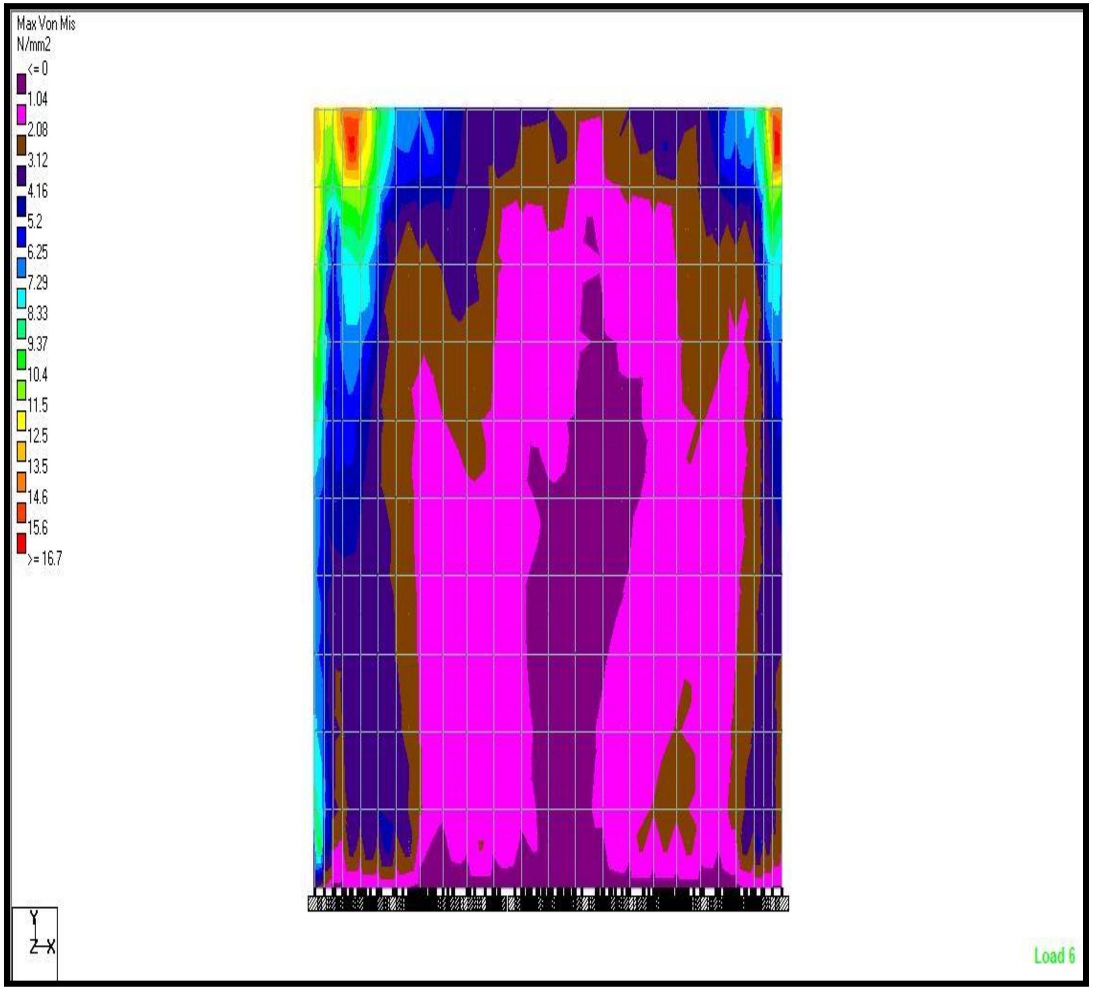
Permissible Stresses: 167.5 M Pa

Factor of Safety (w.r.t Yield Strength) : 1.45

El Centro Earthquake Data-Time History Analysis



Stress Distribution -Time History analysis (without water)



Von-Mises Stress:

16.57 M Pa

Permissible Stress:

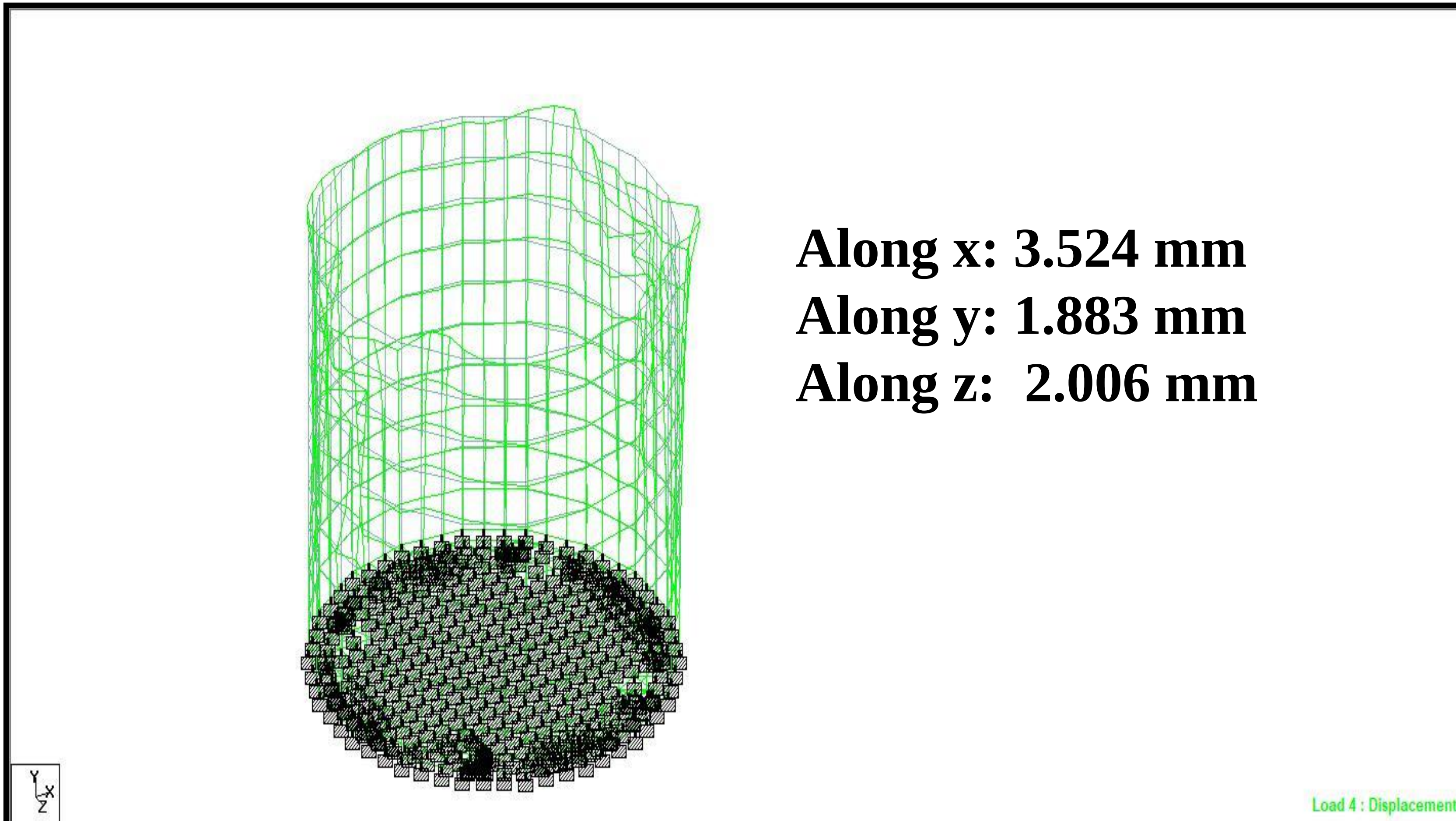
167.5 M Pa

Natural Frequencies:

1. **7.683 Hz**
2. **7.82 Hz**
3. **10.823 Hz**
4. **17.53 Hz**
5. **22.311 Hz**

This will determine the maximum acceleration and deceleration during transport

Deflected Shape of the tank -Time History analysis



Along x: 3.524 mm
Along y: 1.883 mm
Along z: 2.006 mm

Concluding Remarks

Operational Phase	**Structural Actions**	**Remarks**
Fabrication of the structure and mounting of mPMTs	Distortion of the structure due to mounting of mPMTs	Complete. **The effect of these displacements on the mPMTs and the plates/links on which the mPMTs are mounted will be studied.**
Lifting of the structure +mPMTs and placing it in the tank	Localised stresses in the structure at the lifting points	Future Work **(Lifting Mechanism to be defined in consultation with CERN)**
Transport of the detector from assembly workshop to beam-line 1	Vibrations of the tank and structure- Natural frequencies of the tank and the structure	Future Work **Setting upper limits on acceleration/ deceleration and vibrations**

Concluding Remarks

Operational Phase	Structural Actions	Remarks
Tank with static water at beam-line 1	Self weight of the structure and tank+ Hydrostatic pressure on the walls + Weight of water	Complete.
Transport of the detector from beam-line 1 to beam-line 2	Water Vibrations induces dynamic pressure on the walls of the tank - Natural frequencies of the tank and the structure	Future Work. **Setting upper limits on acceleration/ deceleration and vibrations. This will govern the design of the transport system**
Miscellaneous	Buckling Analysis of the support structure and tank	Future Work
	Modelling of the lid of the tank	Future Work
	Welding / bolting analysis	Future Work

THANK YOU