

Investigating Effect Of Fluid Density On Seismic Response Of Steel Storage Tank

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Abstract- *The shaking response in fluid-filled metal container stores is very important in areas that are prone to earthquakes since there is a possibility that liquid may flow out when the structure is being affected. Sloshing displacement is only marginally impacted by tank flexibility; nevertheless, impulsive pressures and base shear are both increased because of greater tank flexibility. Traditional modeling tools such as Staad Pro and ETABS have difficulty accurately representing complicated fluid-structure interactions (FSI). On the other hand, more modern modeling tools such as ANSYS make it possible to accurately describe nonlinear behaviors and seismic dynamics. The purpose of this research is to investigate the impact of fluid density on seismic reactions such as displacement, shear, moment, sloshing height, and hydrodynamic pressure. The investigation is carried out by using Time History Analysis (THA) in ANSYS to investigate cylindrical tanks that contain fuel oil, kerosene, and motor oil. The study is being conducted with the intention of enhancing the safety and ergonomics of storage containers that are exposed to seismic stresses.*

Keywords- ANSYS, Time history analysis, Bhuj, Storage tank, Modal analysis, Fluid, etc.

Abbreviation:FSI - Fluid-Structure Interaction, THA - Time History Analysis, ANSYS - Analysis System (software for simulation), FEM - Finite Element Modeling, MPa - Megapascals

I. INTRODUCTION

1.1 General

At seismically active zones, seismic activity of filled with liquid storage vessels is a serious issue to the design of structures (Bedon et al., 2023). These tanks are essential for storing liquids like water, oil, and industrial chemicals, but seismic forces can induce fluid sloshing, generating additional dynamic pressures on the tank walls (Hosseini & Beskhyroun, 2023) are particularly susceptible to seismic forces due to their shape and flexible material properties. Stress concentrations at the base, sloshing-induced hydrodynamic pressures, and wave resonance within the fluid exacerbate the challenges, making advanced seismic modelling vital for improving resilience and safety (Cheng et al., 2024).

Fluid-Structure Interaction (FSI) is important in seismic analysis as it captures the dynamic coupling between fluid motion and structural behaviour. During seismic events, the interaction between the tank walls and the moving liquid generates complex hydrodynamic forces, including impulsive and convective components (Amira Mohamed Hussin, 2024).

Factors such as fluid density, viscosity, tank geometry, and seismic wave frequency significantly influence these forces (Moslemi et al., 2011). High-density fluids, for instance, amplify hydrodynamic pressures, increasing deformation risks (Khayat et al., 2022). Without accounting for FSI, analyses may misrepresent stress distributions and sloshing dynamics, leading to insufficient designs. FSI analysis ensures a more accurate evaluation of seismic responses, enabling engineers to mitigate risks effectively (Chouhan & Gharad, 2024).

Advancements in computational tools like ANSYS have enhanced the ability to model FSI under seismic loading. These tools incorporate finite element analysis to simulate nonlinear behaviours, such as flexible wall deformations and complex fluid motion, with high precision (Kalita, 2023). They allow engineers to predict critical parameters like sloshing wave height, hydrodynamic pressures, and deformation patterns, informing the design of safer, more resilient storage tanks (Ganuga et al., 2014). By addressing the interplay of material properties, tank design, and seismic intensities, these simulations provide a comprehensive understanding of tank performance, reducing the risk of structural failure and environmental hazards in seismic zones (Lucey et al., 1997).

1.2 Aim and Objective

The aim of the current study was to investigate the hydraulic and geologic movements of container containers for storage, which include a diverse array during substances. The objectives for this investigation have been to analyze the mode analysis of a cylinder reservoir in order to ascertain its inherent sounds, conduct an Event Tradition Investigation for the bubbling reacting to different substances in order to comprehend fluid-structure interaction (FSI) according to tremors excitement, and analyze the impact of density of fluid on the earthquake and hydrodynamic replies of steel tanks used for storage.

II. FSI USING ANSYS FOR SEISMIC AND HYDRODYNAMIC RESPONSES

This study focuses on evaluating the seismic and hydrodynamic responses of cylindrical steel storage tanks containing fluids of varying densities under seismic excitation. Using ANSYS 16.0, advanced simulations are conducted to analyse fluid-structure interaction (FSI), assessing sloshing dynamics, hydrodynamic pressures, and structural deformations. A Time History Analysis (THA) approach is used, modelling the tank as a 3D finite element structure with a height of 9 meters and inner and outer radii of 7 and 6.95 meters, respectively. Material properties and geometric details are accurately defined to replicate real-world conditions. The study investigates the impact of three fluids, fuel oil (850 kg/m³), kerosene (810 kg/m³), and engine oil (920 kg/m³) on the dynamic behaviour of the tank, focusing on how fluid density influences displacement, shear forces, moments, and sloshing patterns under seismic loads.

The methodology involves simulating the coupled dynamics between the tank structure and its contents under seismic excitation, incorporating the physical and dynamic properties of each fluid. The analysis evaluates critical parameters such as sloshing wave heights, hydrodynamic pressures, and structural deformations to understand the effects of fluid density on tank performance. Comparative results are analysed to identify variations in seismic and hydrodynamic responses across the selected fluids, with findings validated against standard guidelines to ensure reliability. This comprehensive simulation-based approach provides valuable insights into designing safer and more resilient storage tanks for earthquake-prone regions, addressing crucial safety and structural considerations.

III. TANK DIMENSIONS AND FLUIDS TO BE STUDIED

3.1 General

This table outlines the critical parameters and design considerations for the study, providing a detailed overview of the parameters being analyzed.

Aspect	Details
Tank Geometry	Cylindrical Shape with a Height of 9 m and a Diameter of 7 m
Material of Tank	Steel (Grade: IS 2062)
Tank Wall Thickness	25 mm

Roof Material	Steel Plate (Grade: IS 2062)
Base Slab Material	Reinforced Concrete (Grade: M25)
Concrete Slab Thickness	300mm (Thickness of the foundation slab)
Load Conditions	Hydrostatic Pressure from Liquids, Seismic Loads
Liquid Types	Kerosene, Fuel Oil, Engine Oil
Liquid Density	Kerosene: 0.81 g/cm ³ , Fuel Oil: 0.85 g/cm ³ , Engine Oil: 0.92 g/cm ³
Seismic Load Considerations	Consideration of seismic load factors as per IS 1893-2016 (Seismic Zone III)
Design Approach	Finite Element Modeling (FEM) for stress, displacement, and stability analysis
Base Slab Reinforcement	Steel Reinforcement (Fe500) based on IS 456:2000 for seismic load resistance and concrete strength
Temperature Considerations	Temperature variations considered for both steel and concrete components
Software Used	ANSYS for structural analysis, including the impact of seismic, hydrostatic loads

Table 1: Critical parameters and design considerations

IV. MODELLING IN ANSYS

4.1 General

The model incorporates both structural and fluid domains to account for the interaction between the tank walls and the fluids stored inside. The structural domain represents the steel shell of the tank, which must withstand not only the hydrostatic pressure from the fluid, but also dynamic forces induced by seismic excitation. The fluid domain, on the other hand, captures the behavior of the contained fluid, including its density, viscosity, and potential for sloshing under external forces. This dual-domain modeling is essential for performing a coupled Fluid-Structure Interaction (FSI) analysis, which evaluates the mutual influence of the fluid's motion and the tank's structural deformation during seismic events.

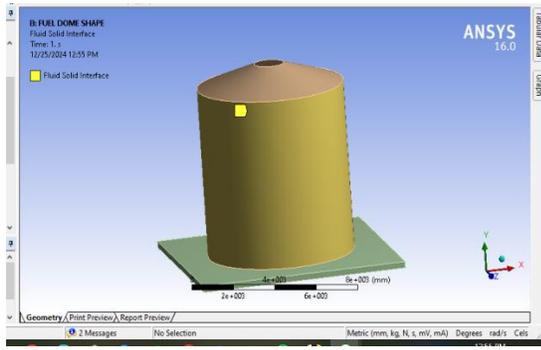


Fig 1: Geometry of model

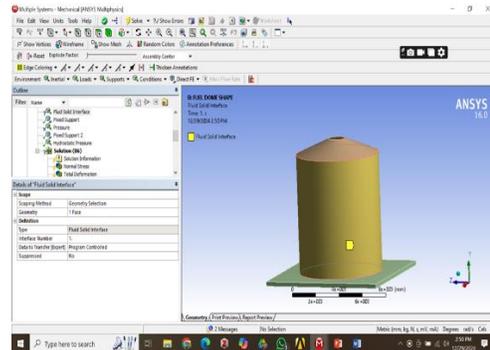


Fig 3: (FSI) Fuel Oil

4.2 Meshing of the model

The cylindrical tank, with a height of 9 meters and an outer radius of 7 meters, has been meshed in ANSYS 16.0 using the automatic meshing tool. The geometry of the tank was defined, and the automatic meshing generated a mesh for the entire structure, including the cylindrical walls and the base. Considering the shapes and dynamics of the framework, the modeling utility autonomously picked the right kinds of components while shapes. The mesh was generated with a balance between accuracy and computational efficiency, ensuring that the elements are fine enough to capture key structural behaviors while avoiding excessive computational cost.

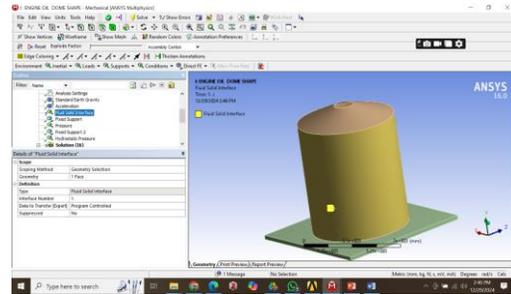


Fig 4: (FSI) Engine Oil

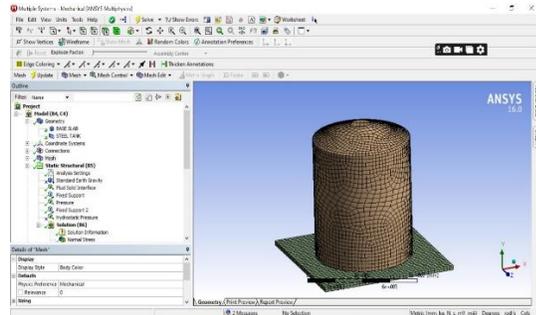


Fig 2: Meshing of model

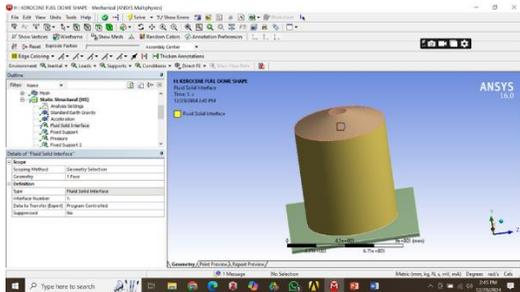


Fig 5: (FSI) Kerosene

4.3 Fluid Structure interaction (FSI) setup

The FSI setup in ANSYS is configured to capture the coupled dynamics between the tank structure and the contained fluid. This involves integrating the structural and fluid domains to evaluate their mutual influence under seismic excitation. The tank structure is modeled to account for stresses, displacements, and deformations, while the fluid domain simulates sloshing behavior and hydrodynamic forces. The FSI setup allows the analysis to capture complex interactions, such as how structural deformation affects fluid motion and how fluid dynamics affects the tank's structural integrity.

V. MODAL ANALYSIS

5.1 General

Important knowledge about the fluid dynamics inside the cylindrical tank according to seismic loads are provided by the outcomes during the mode evaluation. The typical frequencies and accompanying mode forms of the tank can be determined through dynamic examination, and are essential for comprehending its trembling properties. For the cylindrical tank, the lowest modes typically correspond to radial and longitudinal deformations of the structure, with higher modes representing more complex patterns of vibration.

5.2 Mode Shapes (Total Deformation)

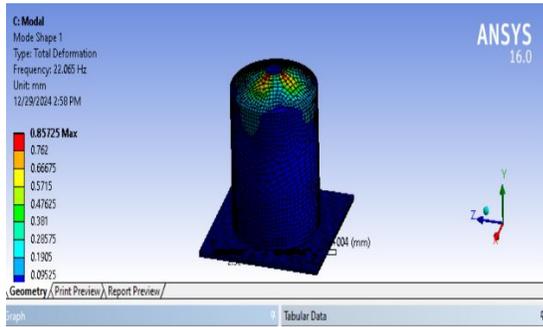


Fig 6: Mode shapes (Fuel tank)

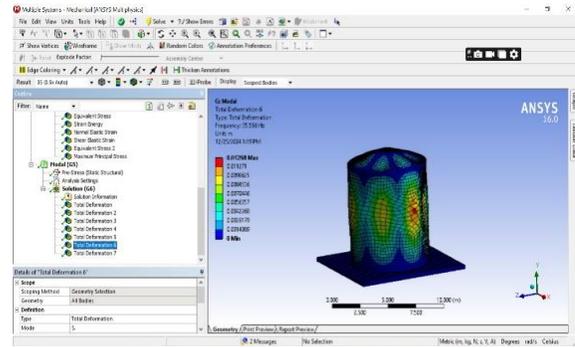


Fig 10: Total deformations (engine oil)

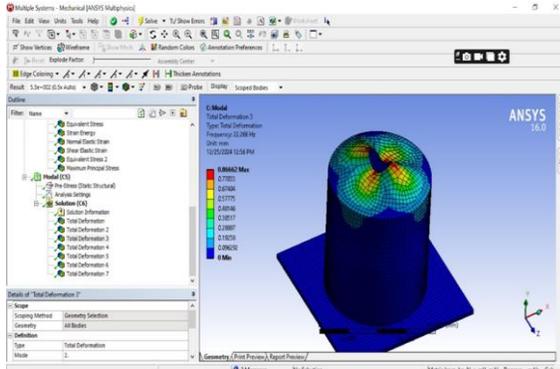


Fig 7: Mode shapes (Engine oil)

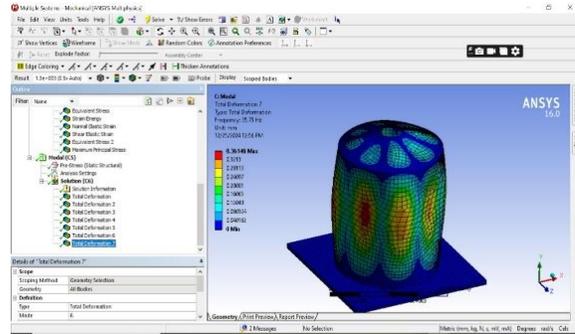


Fig 11: Total deformations (Kerosene)

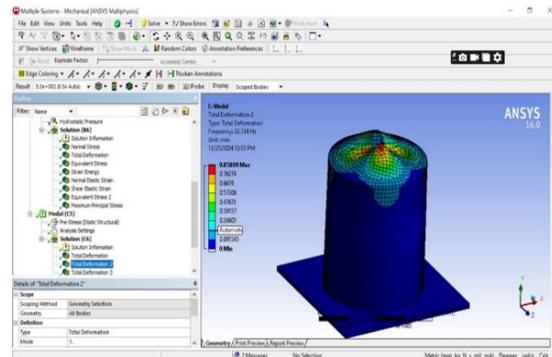


Fig 8: Mode shapes (Kerosene)

5.3 Frequency

Mode	Fuel (850)	Oil Engine (920)	Kerosene (810)
1	24.705	22.162	22.116
2	24.832	22.264	22.258
3	37.254	33.391	32.576
4	37.313	33.475	32.66
5	42.955	35.556	35.054
6	42.957	35.625	35.155

Table 2: Frequency (Hz) results

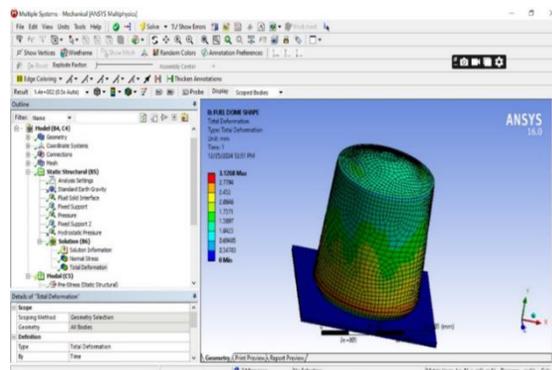
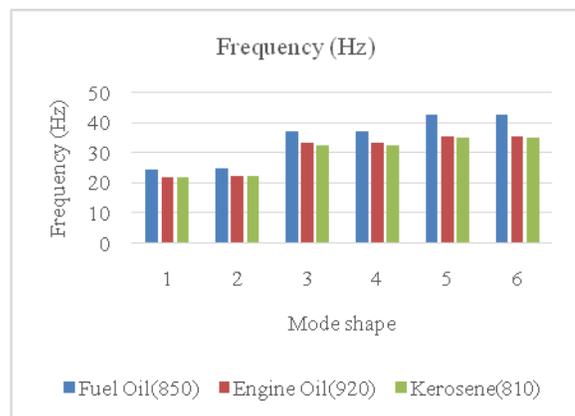


Fig9: Total deformation (Fuel Oil)



VI. TIME HISTORY ANALYSIS

6.1 General (Bhuj Earthquake)

That Bhuj seismic of 2001 proved a large seismic that occurred upon January 26, 2001, via the Indian state of Gujarat, opposite the Pakistani border. The seismic event happened close to the village of Bhuj on the very first weekday of India's annual Republic Day, and this marks the creation of the Republic of India in 1950. The impact felt throughout the majority of northwestern India as Pakistani regions were affected. The earthquake's initial magnitude was 7.7 (6.9 for the Richter scale). The earthquake resulted in the destruction or harm of over one million properties, the relocation of millions on individuals, and the death of over 20,000 individuals as well as the injury of over 150,000 others. Additionally, nearly all of nearby harvests were destroyed. A whole year afterward, numerous individuals continued to stay on temporary accommodations.

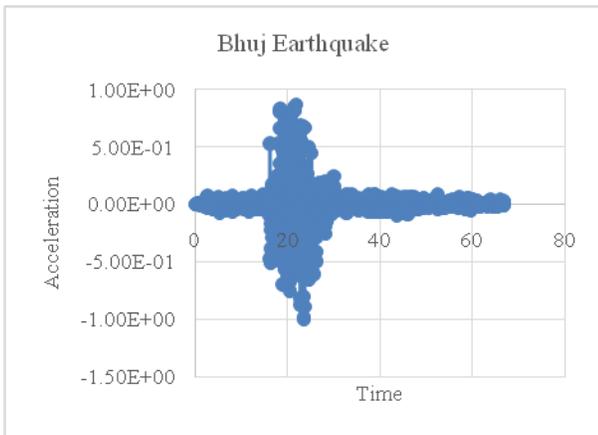


Fig 12: Bhuj earthquake data

6.2 Time History Results

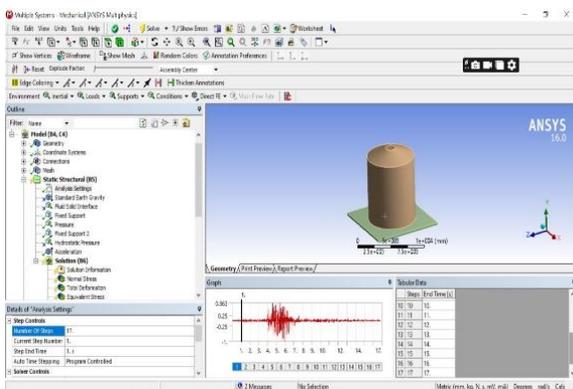


Fig 13: Applying Seismic Data (Fuel Oil)

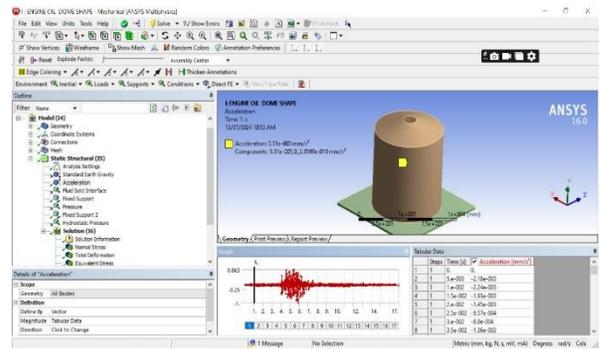


Fig 14: Applying Seismic Data (Engine Oil)

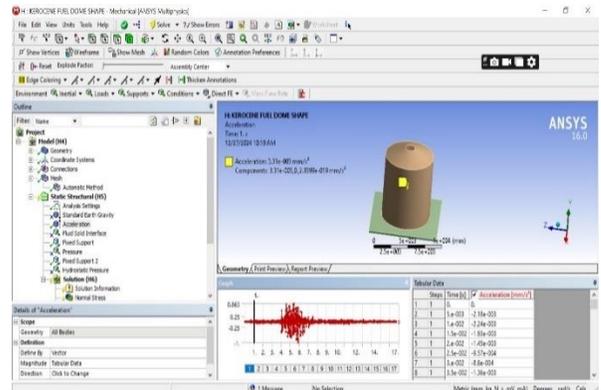


Fig 15: Applying Seismic Data (Kerosene)

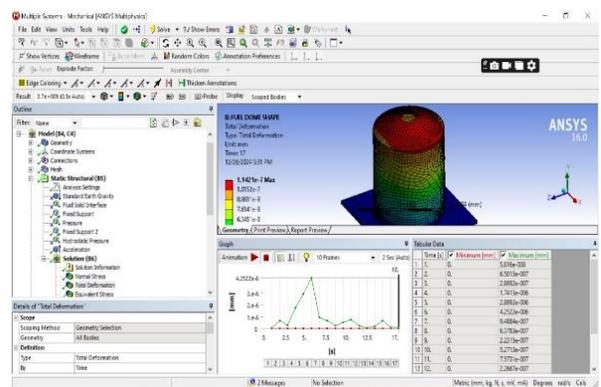


Fig 16: Total Deformation (Fuel Oil)

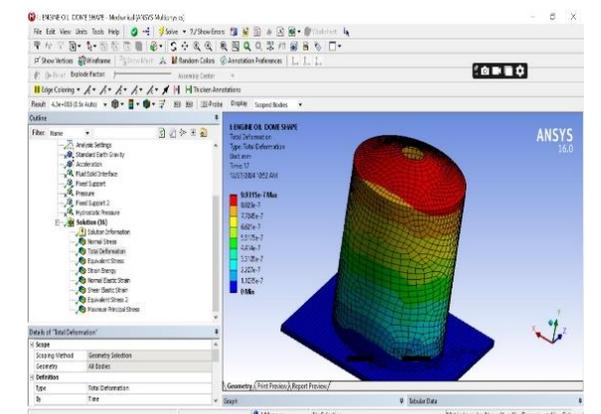


Fig 17: Total Deformation (Engine Oil)

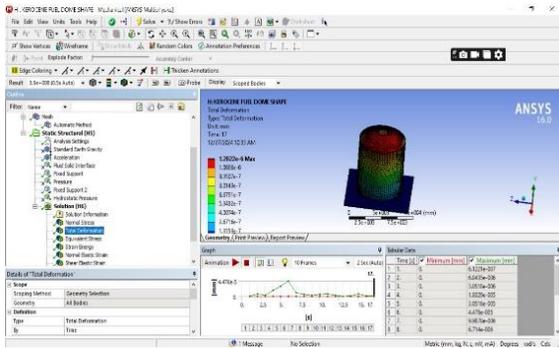


Fig 18: Total Deformation (Kerosene)

VII. RESULTS AND DISCUSSION

7.1 Max. Principal Stress

Maximum principal stress in MPA		
Fuel oil	Engine oil	Kerosene
184.5	178.85	165.78

Table 3: Maximum principal stress (MPa)

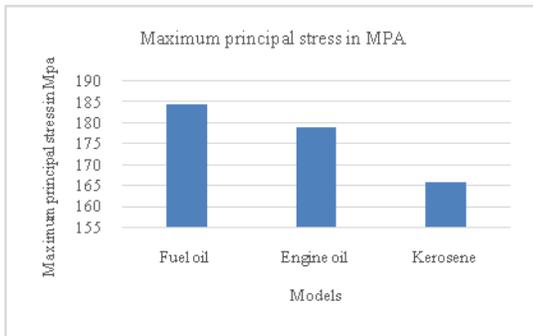


Fig 19: Maximum principal stress in (MPa)

The top tension as well compressive stresses that the fluids encounter under specified loads are represented for the highest principal stress readings.

7.2 Equivalent Stress

Equivalent stress in (MPa)		
Fuel Oil	Engine Oil	Kerosene
182.6	177.01	156.51

Table 4: Equivalent stress in (MPa)

The higher equivalent stress in Fuel Oil suggests it is more robust under complex loading scenarios compared to Engine Oil and Kerosene.

7.3 Strain Energy

Strain energy in mJ

Fuel oil	Engine oil	Kerosene
154490	145170	113490

Table 5: Strain energy in mJ

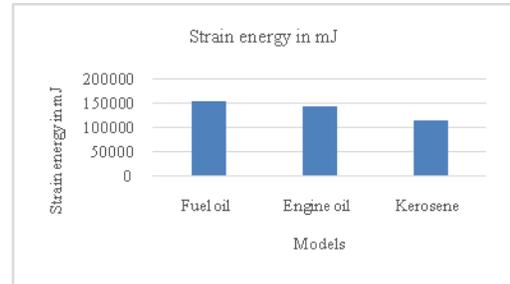


Fig 20: Strain energy in mJ

The higher strain energy in Fuel Oil suggests it is more resilient to deformation and can handle larger loads before failure.

7.4 Hydrostatic Pressure

Hydrostatic Pressure in Pa

Fuel oil	Engine oil	Kerosene
1259685	1085000	959685

Table 5: Hydrostatic Pressure

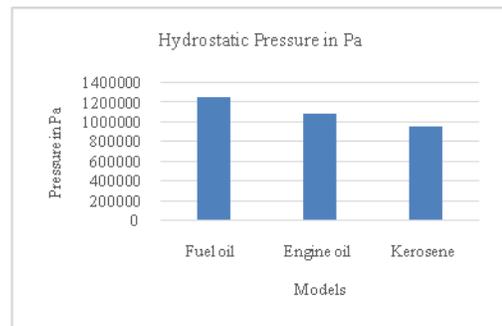


Fig 21: Hydrostatic Pressure

Fuel oil exerts the highest hydrostatic pressure (1.26 MPa), followed by engine oil (1.09 MPa) and kerosene (0.96 MPa), reflecting differences in their density and viscosity. These pressures are critical for ensuring stability and efficiency in hydraulic and fluid systems.

7.5 Normal Elastic Strain

Normal elastic strain

Fuel oil	Engine oil	Kerosene
0.00086	0.00083992	0.0007373

Table 6 Normal elastic strain

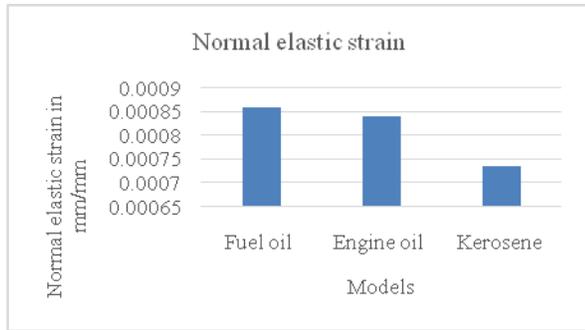


Fig 22: Normal elastic strain

The findings indicate that Fuel Oil, which exhibits the highest strain is more susceptible to deformation, whereas Kerosene, which has the lowest strain, exhibits a greater resistance to elongation or compression.

7.6 Shear Elastic Strain

Shear elastic strain		
Fuel oil	Engine oil	Kerosene
0.0000707	6.8589E-05	6.064E-05

Table 7: Shear elastic strain

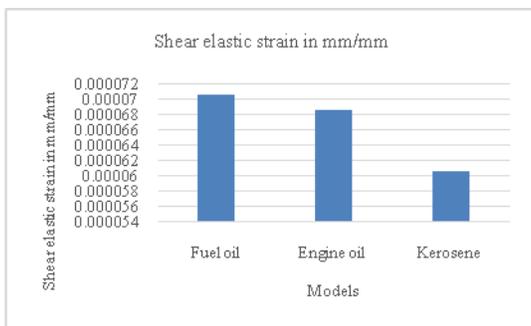


Fig 23: Shear elastic strain

Fuel oil exhibits the highest shear elastic strain (0.0000707 mm/mm), indicating greater deformation under shear stress compared to engine oil (6.8589E-05 mm/mm) and kerosene (6.064E-05 mm/mm). This reflects variations in the fluids' resistance to shear deformation.

7.7 Total Deformation

Total deformation in mm		
Fuel oil	Engine oil	Kerosene
3.1268	3.018	2.68

Table 8: Total deformation in mm

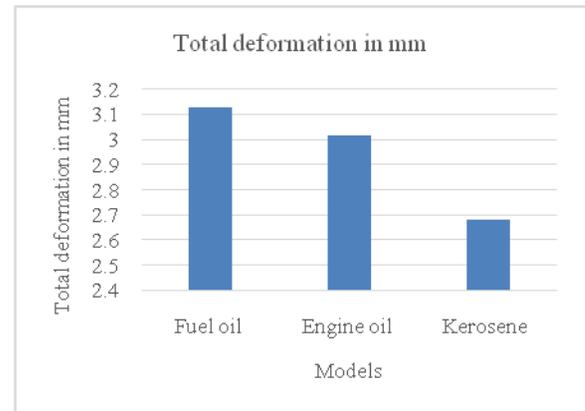


Fig 24: Total deformation in mm

Fuel oil shows the highest total deformation (3.1268 mm), followed by engine oil (3.018 mm) and kerosene (2.68 mm), indicating varying displacement due to differences in elastic modulus, density, and viscosity. Higher deformation reflects lower stiffness or greater compliance.

7.8 Time History Results

7.8.1 Fuel Oil

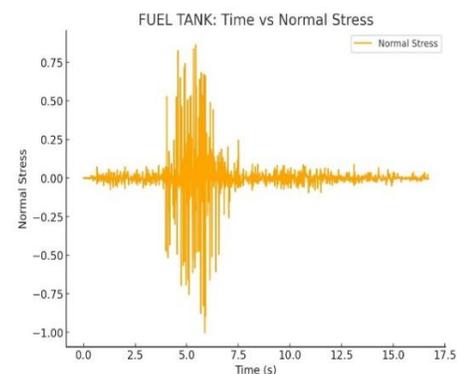


Fig 25: Time vs Normal Stress

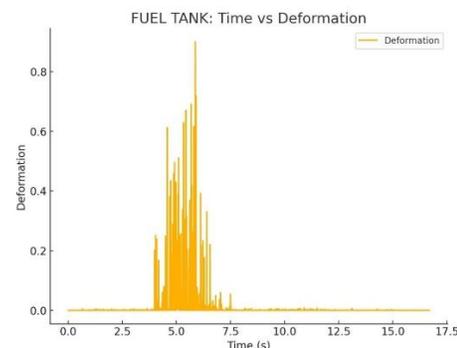


Fig 26: Time vs Deformation

7.8.2 Engine Oil

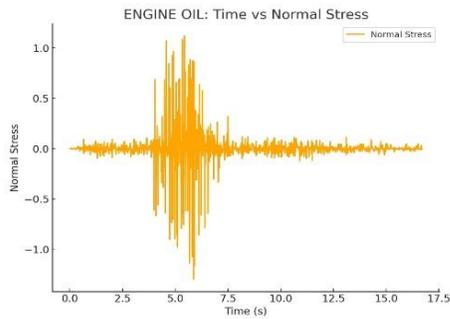


Fig 27: Time vs Normal Stress

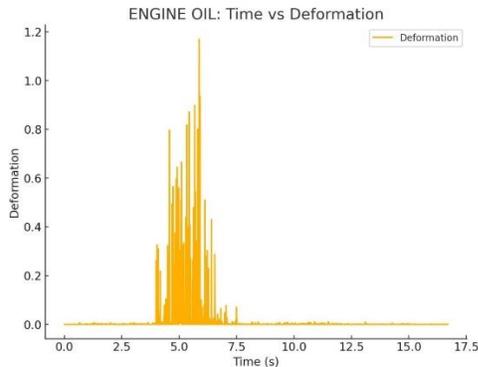


Fig 28: Time vs Deformation

7.8.3 Kerosene

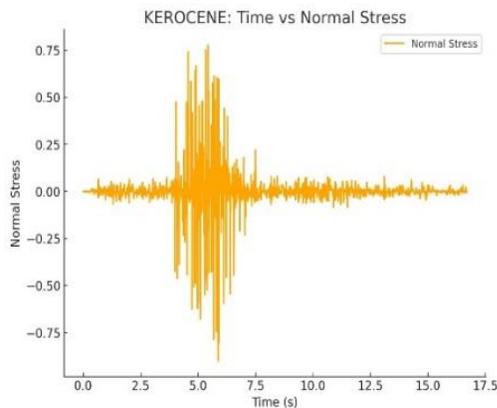


Fig 29: Time vs Normal Stress

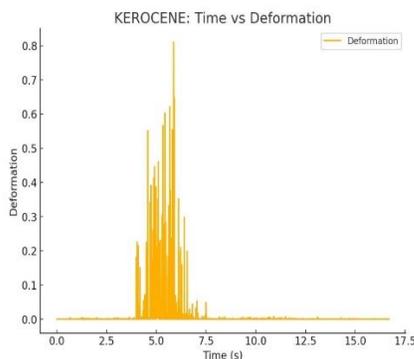


Fig 30: Time vs Deformation

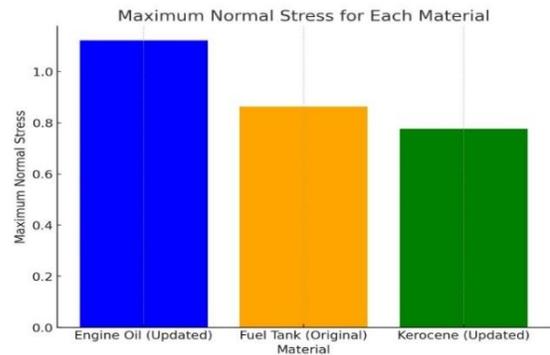


Fig 31: Maximum Deformation (Comparative)

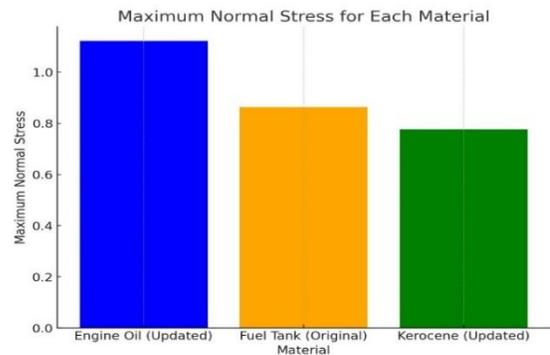


Fig 32: Maximum Normal Stress(Comparative)

Time history analysis reveals varying dynamic responses in steel storage tanks containing Engine Oil, Fuel Oil, and Kerosene, with Engine Oil demonstrating the highest maximum deformation (1.17), followed by Fuel Oil (0.9) and Kerosene (0.81). Similarly, maximum normal stress is highest for Engine Oil (1.1219), with lower values for Fuel Oil (0.863) and Kerosene (0.7767). These results indicate that the denser fluid, Engine Oil, induces greater deformation, stress, and strain in the tank under seismic loading, highlighting the significant impact of fluid density on the structural response.

VIII. CONCLUSIONS

The modes of motion analyses emphasize who the normal rhythms of steel boxes loaded in Engine Oil, Fuel Oil and Kerosene don't dependably correlate alongside fluid content on his own. Fuel Oil (850 kg/m³) exhibits higher frequencies than both Engine Oil (920 kg/m³) and Kerosene (810 kg/m³) in most modes, contradicting the simple expectation that denser fluids should lead to lower frequencies. This discrepancy arises from dynamic system principles, where natural frequency depends not only on mass but also on system stiffness and fluid-structure interaction. Factors like fluid viscosity, shear properties, and interaction with the tank walls significantly influence the dynamic behavior, resulting in unexpected variations across different modes.

The time history analysis under Bhuj earthquake conditions shows that deformation, normal stress, and strain are highest for the tank filled with Engine Oil, with values of 1.17 mm, 1.1219 MPa, and 1.2677, respectively. In contrast, the tank with Kerosene experiences the least deformation (0.81 mm), stress (0.7767 MPa), and strain (0.8776). Fuel Oil leads to intermediate values. These differences are attributed to fluid density and viscosity, where denser fluids like Engine Oil generate higher inertial forces during seismic events, increasing stress and deformation, while Kerosene's lower density results in a reduced structural response.

The analysis further underscores the tank's robust design, featuring a 25 mm steel wall thickness and reinforced concrete base slab, which effectively withstands hydrostatic and hydrodynamic forces. Despite higher pressures exerted by Fuel Oil, hoop stress, buckling stress, and localized stresses remain within safe limits. Interestingly, sloshing wave heights are consistent across all fluids at approximately 3.31 m, indicating the tank's shape and material properties effectively manage fluid motion. They underscore the vital function about liquid characteristics in the seismic while hydraulic behaviors about steel storage containers, thereby guaranteeing security and efficacy via hazardous environments.

Conflict of interest

The authors has no conflict of interest to disclose.

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