e-ISSN: 2582-5208
International Research Journal of Modernization in Engineering Technology and Science
( Peer-Reviewed, Open Access, Fully Refereed International Journal )
Volume:06/Issue:07/July-2024 Impact Factor- 7.868 www.irjmets.com

# DYNAMIC BEHAVIOUR OF AN ELEVATED WATER TANK CONSIDERING THE EFFECT OF SLOSHING

**Majidhussain M Sayyad*1, Prof. Vikhyat Katti*2**

*1Student, Master Of Technology, Structural Engineering, India.

*2Guide, Master Of Technology, Structural Engineering, India.

## ABSTRACT

This thesis investigates the dynamic behaviour of elevated water tanks, with a particular focus on the effects of sloshing and their application as tuned liquid dampers (TLDs) using ABAQUS software. Elevated water tanks play a critical role in urban infrastructure, but their dynamic responses to seismic and wind loads present significant challenges, especially due to the complex fluid-structure interactions induced by sloshing. To address these challenges, this study employs the Coupled Eulerian-Lagrangian (CEL) method within ABAQUS, a powerful approach that accurately captures the interaction between the fluid and the tank structure without the need for frequent remeshing. The CEL method allows for a detailed simulation of the sloshing behaviour of the liquid inside the tank, providing a comprehensive understanding of how these movements affect the overall dynamic response of the structure. The research begins with a thorough literature review, establishing the importance of understanding fluid-structure interactions and the efficacy of TLDs in mitigating structural vibrations. A detailed computational model of the elevated water tank is created in ABAQUS, incorporating geometric and material properties. The model is subjected to dynamic loading scenario of seismic loads, to evaluate the tank's performance. Simulations are conducted both with and without the implementation of TLDs, allowing for a comparative analysis of their effectiveness. The results demonstrate that the inclusion of TLDs significantly reduces the vibrational amplitudes of the tank, enhancing its seismic resilience and overall stability. The study also highlights the critical role of sloshing effects in influencing the dynamic behaviour of the tank, with the CEL method proving instrumental in accurately capturing these interactions. The findings contribute to the broader field of structural engineering by demonstrating the effectiveness of advanced simulation techniques in addressing complex fluid-structure interaction problems.

## I. INTRODUCTION

Elevated water tanks serve as vital components of urban infrastructure, primarily facilitating water storage and firefighting capabilities. However, their resilience to seismic events is critical due to the potential for significant structural stress and damage. The dynamic behaviour of these tanks under seismic loading, exacerbated by the phenomenon of sloshing—where water inside the tank moves due to external forces—adds complexity to their performance analysis. Their resilience against seismic events is paramount due to the potential for significant structural stress and damage during earthquakes.

### 1.1Seismic Behaviour of Elevated Water Tanks

Engineers are highly interested in the performance of elevated water tanks under dynamic loads like earthquakes and tsunamis. This interest stems not only from the tanks' crucial role in fire suppression but also because their simple structure facilitates relatively straightforward analysis which can be generalised for other structures. Therefore, studying these tanks can provide valuable insights into structural behaviour during seismic events. During the Chilean earthquakes of May, 1950, a number of large elevated water tanks were severely damaged whereas others survived, without damage. An analysis of the dynamic behaviour of such tanks should consider the motion of the water relative to the tank and the motion of the tank relative to the ground also. If a closed tank is completely filled with water or completely empty, it behaves essentially as a single mass structure. However, if the tank has a free water surface, water sloshing occurs during an earthquake, transforming the tank into a two-mass system. This dynamic behaviour can vary significantly: for some tank configurations, water sloshing dominates, while for others, its influence is minimal. Therefore, comprehending the earthquake resilience or vulnerability of elevated water tanks necessitates a thorough understanding of the dynamic forces induced by sloshing water. These tanks exhibit complex dynamic behaviours, particularly influenced by sloshing, where the movement of water inside the tank responds to

e-ISSN: 2582-5208
International Research Journal of Modernization in Engineering Technology and Science
( Peer-Reviewed, Open Access, Fully Refereed International Journal )
Volume:06/Issue:07/July-2024 Impact Factor- 7.868 www.irjmets.com

external seismic forces. Understanding these dynamics is pivotal for predicting their performance and ensuring their reliability under seismic loads.

### 1.2 Tuned Liquid Dampers (TLD)

In recent years, research has explored innovative approaches to enhance the seismic resilience of elevated water tanks. One promising strategy involves utilizing these tanks as Tuned Liquid Dampers (TLDs). TLDs exploit the sloshing motion of water to dissipate seismic energy, thereby reducing the structural response of the tank and adjacent buildings. This approach leverages the principles of fluid dynamics and structural mechanics to enhance the damping properties of the system. The principle behind TLDs lies in exploiting the natural frequency of sloshing water to counteract the resonant frequencies of the structure they are protecting. When subjected to external forces such as seismic waves, the liquid inside the damper oscillates, absorbing and dissipating energy through viscous damping and wave breaking mechanisms. This dynamic behaviour effectively reduces the amplitude of structural vibrations, thereby enhancing the structure's resilience against dynamic loads. TLDs are particularly advantageous in scenarios where traditional damping systems may not be feasible or effective. They can be designed to operate over a broad range of frequencies, making them versatile for different structural configurations and environmental conditions. Moreover, TLDs are relatively simple in concept and construction, often consisting of a tank or vessel partially filled with liquid, equipped with inlet and outlet ports to control the damping effect.

TLDs represent a sophisticated yet practical solution to enhance the seismic resilience of buildings and infrastructure. By harnessing the dynamics of sloshing liquid, these dampers contribute significantly to reducing structural vibrations, minimizing damage, and improving the longevity of critical infrastructure in earthquake-prone regions. Tuned Liquid Column Dampers (TLCDs) are a unique type of TLDs relying on the movement of a column of liquid in a U-tube like container to counter the forces acting on the structure. An orifice in the liquid passage ensures that damping is introduced in the oscillating liquid column. The damping in TLCDs, unlike in TMDs, changes with amplitude, resulting in non-linear dynamics. TLCD systems offer benefits such as low cost and minimal maintenance. Moreover, the containers can serve dual purposes, such as providing building water supply when contrasted to TMDs which only add dead weight of the mass which has no other functional use.

#### 1.2.1 Implementations of TLDs in Structural Engineering

Some of the early modern applications for liquid dampers studied in the past were in ship stabilization, satellite stabilization and now in building applications. The structural implementation of Tuned Liquid Dampers (TLDs) was first pioneered in Japan. Notable examples of TLD-controlled structures include the The Comcast Building in Philadelphia, Nagasaki Airport tower, Yokohama Marine Tower, Shin-Yokohama Prince Hotel, and the Tokyo International Airport tower. Tuned Liquid Column Dampers (TLCDs) have been used to attenuate wind-induced vibrations in the towers of the Higashi-Kobe cable-stayed bridge. The Hyatt Hotel in Osaka has installed a Liquid Column Damper with Pressure Adjustment (LCD-PA) to enhance its structural resilience. Previously, both passive and active forms of TLDs were proposed for the Millennium Tower in Tokyo Bay, Japan which was planned in 2022. Furthermore, liquid vibration absorbers are employed in tall chimneys to reduce oscillations.

#### 1.2.2 Tuned Mass Dampers (TMD)

Tuned Mass Dampers (TMDs), a well-established technique in structural engineering, share similarities with TLDs but operate with a different mechanism. TMDs typically have a mass-spring-damper system tuned to a specific vibration frequency in structures to reduce resonance effects. In contrast, TLDs modify this concept by using the liquid mass and its sloshing dynamics to achieve effective energy dissipation under seismic excitations. Engineers select between these systems based on the specific characteristics of the structure, the nature of the vibrations, and the desired damping efficiency.

### 1.3 Abaqus Software

The advancement in computational tools such as Abaqus software has revolutionized the simulation and analysis of complex structural dynamics, including the behaviour of elevated water tanks under seismic loads.

Abaqus facilitates detailed Finite Element Method (FEM) simulations, allowing engineers to model the intricate interaction between structural components and dynamic forces accurately.

Abaqus provides advanced simulation capabilities that are particularly beneficial for structural engineering applications:

1. Finite Element Analysis (FEA): Abaqus is exceptional in conducting FEA, essential for evaluating the structural integrity and performance of buildings, bridges, and other infrastructure. Engineers can model the geometry of structures, apply loads, and simulate responses to various conditions such as seismic events, wind loads, and thermal effects.
2. Nonlinear Analysis: Structural engineering often involves dealing with the nonlinear behaviour of materials and structures. Abaqus supports nonlinear analysis, allowing for the simulation of complex phenomena such as plastic deformation, cracking, and buckling. This capability is crucial for understanding the true behaviour of structures under extreme loads.
3. Dynamic Analysis: Abaqus provides robust tools for dynamic analysis, enabling engineers to simulate the response of structures to time-varying loads, including earthquakes and vibrations. This is particularly important for designing earthquake-resistant buildings and infrastructure.
4. Fluid-Structure Interaction (FSI): Abaqus can model the interaction between fluids and structures, making it ideal for analyzing scenarios where fluid dynamics significantly impact structural behaviour. This is essential for applications such as Tuned Liquid Dampers (TLDs) and Tuned Liquid Column Dampers (TLCDs), where the movement of liquid influences the structural response.

### 1.3.1 Eulerian and Lagrangian Methods

Abaqus supports both Eulerian and Lagrangian methods, providing flexibility in how engineers model and analyze structures:

1. Lagrangian Approach: In this method, the mesh moves with the material, making it suitable for analyzing solid structures and materials that undergo large deformations. It is commonly used in structural engineering for traditional FEA of buildings, bridges, and other static structures.

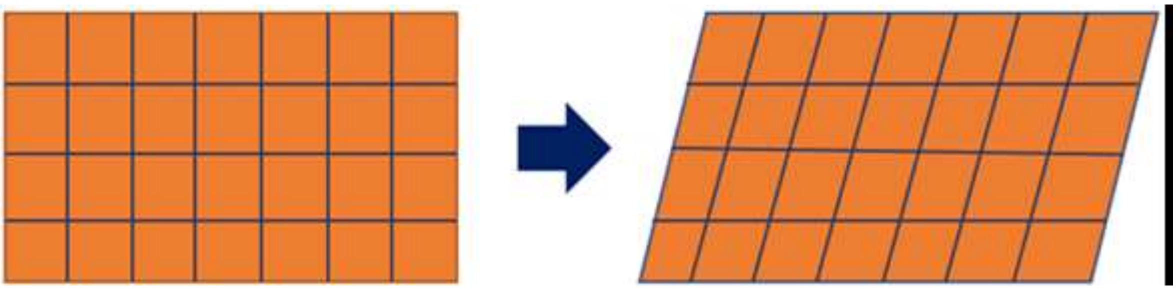


**Fig 1.1:** Behaviour of Lagrangian element

2. Eulerian Approach: The Eulerian method is used for modeling fluids and their interactions with structures. In the Eulerian approach, the mesh is fixed in space while the material flows through it. This method is particularly useful for simulating scenarios where there is a significant interaction between fluids and structural components, such as the impact of waves on offshore structures or the behaviour of liquid-filled components under dynamic loading. This approach allows for accurate representation of fluid motion and its interaction with solid boundaries, enhancing the accuracy of dynamic simulations involving fluids.

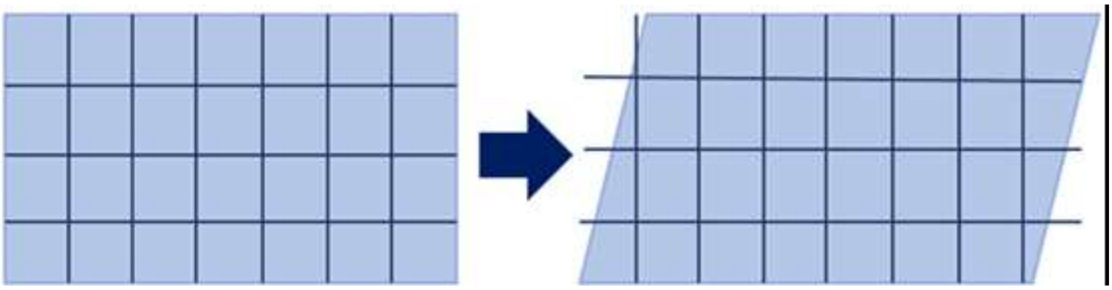


**Fig 1.2:** Behaviour of Eulerian element

e-ISSN: 2582-5208
International Research Journal of Modernization in Engineering Technology and Science
( Peer-Reviewed, Open Access, Fully Refereed International Journal )
Volume:06/Issue:07/July-2024 Impact Factor- 7.868 www.irjmets.com

### 1.3.2 Coupled Eulerian-Lagrangian (CEL) Analysis

In conventional Lagrangian analysis, nodes are attached to the material, causing elements to deform with the material. Thus, Lagrangian elements are consistently filled with one material, aligning the material boundary with the element boundary. On the other hand, Eulerian analysis keeps nodes stationary in space, allowing the material to move through fixed, non-deforming elements. Eulerian elements may not always be completely filled with material, often containing partial or complete voids. Thus, the material boundary must be calculated at each time increment, usually not aligning with the element boundary. The Eulerian mesh is commonly a basic rectangular grid that extends beyond the material boundaries to accommodate material movement and deformation. If material moves outside this mesh, it is lost from the simulation.

Eulerian and Lagrangian elements can interact through Eulerian-Lagrangian contact, enabling coupled Eulerian-Lagrangian (CEL) analyses. This feature in Abaqus/Explicit allows for multi-physics simulations such as fluid-structure interaction. The Coupled Eulerian-Lagrangian (CEL) approach in Abaqus allows engineers and scientists to effectively simulate problems involving significant interaction between structures and fluids. This method does not require the integration of multiple software products but instead handles fluid-structure interaction (FSI) directly within Abaqus, solving both aspects simultaneously.

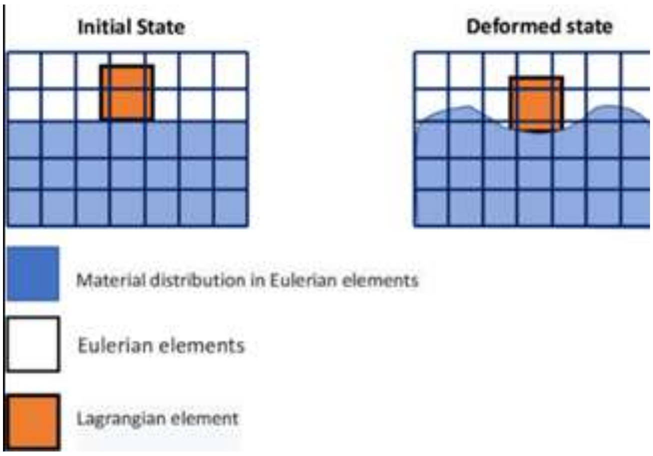



**Fig 1.3:** Behaviour of Coupled Eulerian-Lagrangian(CEL) element

### 1.3.3 Real-World Applications using Abaqus

Abaqus has been instrumental in several high-profile structural engineering projects:

1. Seismic Analysis
2. Wind Load Analysis
3. Damper Design
4. Bridge Engineering

Moreover, the Eulerian part type in Abaqus enables the simulation of fluids and their interaction with solids—a crucial feature for modeling sloshing effects in elevated water tanks. This capability enhances the accuracy of dynamic simulations by accounting for the fluid-structure interaction essential in TLD studies.

In this report, the dynamic behaviour of elevated water tanks considering the effect of sloshing, emphasizing their role as Tuned Liquid Dampers (TMDs) are explored. By integrating theoretical insights with computational simulations using Abaqus, this study aims to contribute to the understanding and development of resilient design strategies for urban infrastructure subjected to seismic hazards.

### 1.4 OBJECTIVES

- To investigate the dynamic response of elevated water tanks under seismic loading conditions and thereby study and quantify the effects of fluid-structure interactions caused by sloshing within the water tank.
- To explore the application and effectiveness of TLDs in reducing vibration amplitudes and enhancing seismic resilience.

## II. LITERATURE REVIEW

Housner G.W.'s (1963) [1] groundbreaking work emphasizes the necessity of considering both the movement of the water inside the tank and the tank's motion relative to the ground in such analyses. During the devastating Chilean earthquakes of May 1960, the differential damage experienced by various elevated water tanks highlighted the critical importance of understanding their dynamic behaviour under seismic conditions. His paper provides straightforward mathematical expressions for key dynamic properties relevant to tanks with free water surfaces. Housner proposes a simplified method for dynamically analyzing how elevated water tanks respond to earthquake-induced ground motions. This foundational research remains pivotal in earthquake engineering, influencing practices aimed at enhancing the seismic resilience of elevated water tanks worldwide.

Damatty A.A. (2002) [2] has explored the application of TLDs in mitigating structural vibrations caused by external forces like wind or earthquakes. TLDs utilize the movement of liquid within a tank to absorb and dissipate energy, thereby reducing the amplitude of structural oscillations. He highlights the advantages of TLDs, such as their cost-effectiveness, ease of implementation, and adaptability to various structural types. He also discusses different design parameters and optimization strategies to enhance the performance of TLDs. By addressing both theoretical and practical aspects, the paper underscores the effectiveness of TLDs in improving structural resilience and stability.

Wakchaure et al. (2014) [3] have investigated the dynamic behaviour of elevated water tanks subjected to sloshing effects during seismic events. It highlights the advancements in structural design, analysis methods, and materials used in elevated service reservoirs (ESRs). The study employs FEM simulations using ANSYS software to compare static and dynamic analyses of circular and rectangular ESRs, both with and without compartments. The research emphasizes the impact of sloshing on tank walls and roofs under various water fill levels (15%, 30%, 50%, 75%, and full), using response spectrum analysis to evaluate seismic loads. Key findings include variations in stress, deformation, and sloshing frequencies, demonstrating the effectiveness of compartmentalized tanks in mitigating sloshing effects. The study contributes to understanding the complex dynamics of ESRs under seismic conditions, essential for enhancing their structural resilience and safety.

Dhamak, et al. (2014), [4] in their study on the dynamic response of elevated water tanks, explored the seismic behaviour of these structures, which are critical for water supply in various regions. The analysis utilized both experimental and numerical methods to assess the tanks' responses to seismic activity. Key findings highlighted the significant impact of fluid-structure interaction on the tank's performance during earthquakes. The study also examined various influencing factors such as water levels, tank height, and seismic intensity, revealing that higher water levels and greater tank heights increase seismic demands. Validated through scaled model tests, the research provides essential design recommendations to enhance the seismic resilience of elevated water tanks, ensuring their operational functionality post-earthquake. This study contributes valuable insights for safer infrastructure in seismic-prone areas.

Bachhav, et al. (2016) [5]**:** This study focuses on the sloshing phenomenon in elevated rectangular water tanks, a critical consideration in seismic design due to its potential impact on structural integrity during earthquakes. Sloshing occurs when liquid inside a tank undergoes oscillatory motion due to seismic excitations, leading to significant hydrodynamic pressures on tank walls. The paper presents experimental findings conducted on mini shake tables to simulate seismic conditions. Parameters such as tank capacity, bracing spacing, water level, and vibration amplitude were varied, with and without internal obstructions. Sloshing heights and patterns were measured and compared with theoretical predictions from seismic codes and SaE Ca Net software. The study concludes that experimental results closely align with theoretical expectations, underscoring the importance of accurate sloshing analysis in seismic design to enhance the resilience of rectangular water tanks against earthquake-induced damage.

Vyanktesh, et al. (2016) [6] have investigated the seismic behaviour of elevated water tanks, which are crucial for water supply and firefighting during earthquakes. The study employs SAP2000 software to analyze lateral forces and compares results with ACI 350.3-06 standards. Various water fill conditions are modeled, and linear modal time history analysis is performed using scaled ground motions from multiple earthquakes. The research highlights that vertical ground motions can significantly increase axial forces in columns, suggesting that current design methods may not always be conservative, necessitating further research to enhance seismic response modeling of these structures.

Tippmann, et al. (2017) [7] have provided an in-depth exploration of the CEL method used in ABAQUS for simulating fluid-structure interactions. The study highlights the CEL method's ability to handle large deformations and complex interactions without needing frequent remeshing. It is particularly effective for applications like blast analysis, airbag deployment, and high-velocity impacts. The research underscores the importance of accurate meshing and boundary conditions to achieve realistic simulation results, demonstrating the method's versatility and precision in various engineering applications. This study enhances understanding and application of CEL in practical scenarios.

Dhondge et al. (2019) [8] have investigated the seismic behaviour of elevated water tanks, crucial for municipal and industrial water storage. Emphasizing their vulnerability to earthquakes due to fluid-structure interactions, the study uses both manual methods and STAAD-PRO software for analysis. It highlights that circular tanks generally outperform rectangular ones under seismic conditions. Key findings include the influence of tank height and seismic zone on parameters like base shear and displacement. The research underscores the importance of robust seismic design to ensure these tanks remain operational post-earthquake.

Li, et al. (2019) [9] have delved into the seismic behaviour of elevated water tanks, particularly focusing on the interaction between the fluid and the tank structure. The study emphasizes the importance of ensuring the functionality of these tanks during and after seismic events due to their critical role in maintaining water supply for drinking, sanitation, and firefighting. The research identifies key factors affecting the dynamic response of these tanks, such as tank shape, fluid properties, structural flexibility, and soil characteristics. Simplified modeling techniques, such as single-mass and two-mass models, are discussed for their effectiveness in reducing computational complexity while maintaining accurate results. These models, which incorporate fluid-structure interaction (FSI) effects, help in understanding the impulsive and convective masses' contributions to the overall seismic response. The study concludes that the dynamic behaviour of elevated water tanks is significantly influenced by the tank's filling level and the soil's flexibility, with fully filled tanks being most vulnerable during high-intensity ground motions.

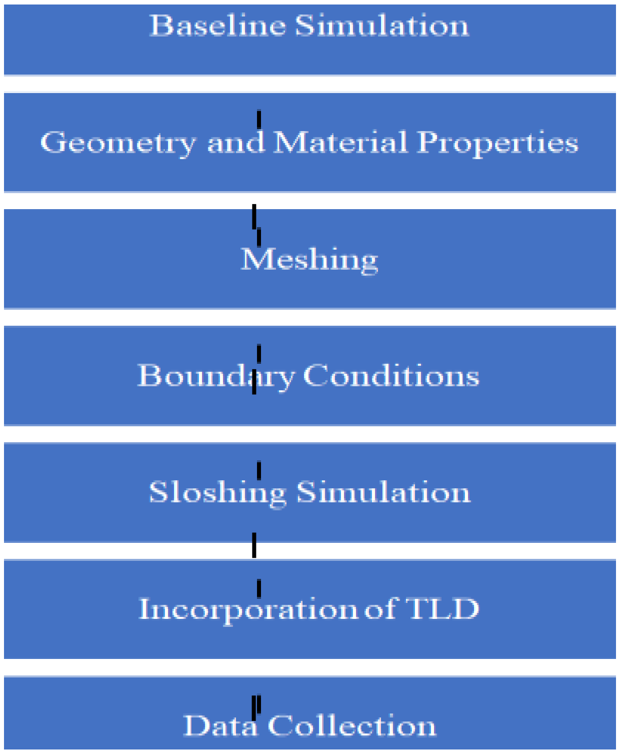
Gupta, et al. (2019) [10]: Elevated water tanks, critical for ensuring water supply in seismic-prone regions, have historically faced collapses during earthquakes, emphasizing the importance of robust structural support systems. This study investigates the seismic behaviour of reinforced concrete (RC) elevated water tanks using analytical and finite element methods. It employs IS 1893 standards to analyze tanks supported on shaft staging, comparing results from lumped mass and two-mass models with SAP2000 V14 simulations. Findings suggest that the two-mass model provides more accurate seismic predictions, highlighting its suitability for enhancing structural resilience. The study underscores the need for precise seismic design considerations in safeguarding these essential infrastructure elements.

Thomas, et al. (2022) [14]] have investigated the efficiency of tuned mass dampers (TMDs) in mitigating seismic responses in multi-storey buildings. The study utilizes numerical simulations to evaluate how TMDs, which consist of a mass, spring, and damper system, can reduce structural vibrations during earthquakes. Different configurations and placements of TMDs are analyzed to optimize their effectiveness. The results demonstrate that properly tuned and strategically placed TMDs significantly enhance the seismic resilience of building`s, thereby improving safety and reducing potential damage during seismic events.

Mondal et al. (2024) [15] have investigated the effectiveness of Tuned Liquid Dampers (TLDs) in reducing structural vibrations, particularly in buildings subjected to seismic and wind excitations. TLDs utilize the sloshing energy of water within a container, typically placed on top of structures, to mitigate dynamic responses. The experimental setup employed PASCO beams and trusses to model a building, with a motor-driven moveable base simulating earthquake conditions. Measurements were taken using a Vernier accelerometer, with data acquired through Vernier DAQ and LabVIEW software. Results demonstrated that TLDs could significantly dampen vibrations, particularly around the structure's resonant frequency, achieving up to an 80% reduction. The study also highlights the advantages of TLDs over traditional Tuned Mass Dampers (TMDs), including better performance at low frequencies, cost-effectiveness, and ease of maintenance.

Numerical simulations using Matlab confirmed the experimental findings, underscoring the potential of TLDs as an efficient and practical solution for vibration control in modern engineering applications.

## III. METHODOLOGY




## IV. FINITE ELEMENT ANALYSIS USING ABAQUS

Finite Element Analysis (FEA) is a powerful computational tool used for simulating and analyzing complex structures under various loading conditions. Abaqus is a comprehensive suite of powerful engineering simulation programs based on the finite element method. Abaqus provides advanced capabilities for modeling complex interactions between different materials and components, making it an ideal choice for studying the dynamic behaviour of elevated water tanks.

### 4.1 Simulation Procedure

The simulation of the dynamic behaviour of an elevated water tank using Abaqus is a comprehensive process that requires careful planning and execution to ensure accurate results. The procedure is divided into several key steps, each crucial for capturing the complex interactions between the fluid and the structure. The detailed steps are as follows:

1. Initial Setup
2. Dynamic Loading
3. Analysis Execution
4. Simulation Run
5. Results Post-Processing
6. Visualization
7. Validation and Verification

### 4.2 Baseline Simulation

The simulation of a pendulum swinging in water using the Coupled Eulerian-Lagrangian (CEL) method in Abaqus provides a foundational understanding of fluid-structure interactions (FSI). In this simulation, the pendulum is modeled as a Lagrangian element, representing its solid, rigid structure, while the water container is modeled as an Eulerian domain to capture the fluid dynamics. The process begins with creating the geometries of the pendulum and the rectangular water container, followed by defining the material properties

e-ISSN: 2582-5208
International Research Journal of Modernization in Engineering Technology and Science
( Peer-Reviewed, Open Access, Fully Refereed International Journal )
Volume:06/Issue:07/July-2024 Impact Factor- 7.868 www.irjmets.com

for both the solid pendulum and the fluid water. Initial conditions, such as the pendulum's starting angle and water level, are set to simulate realistic interactions. Dynamic loading is applied, including gravity and initial angular velocity, to initiate the pendulum's swing.

The simulation leverages Abaqus/Explicit for its efficiency in handling transient dynamics and complex interactions. Contact interactions between the pendulum and the water are defined to accurately model the forces and motions. The Eulerian Volume Fraction tool is utilized to initialize the water within the container. During the analysis, the solver processes the coupled equations of motion, capturing the fluid-structure interaction in detail. Post-processing involves extracting and analyzing key parameters such as angular displacement, fluid velocity fields, and pressure distribution. Visualizations, including animations and contour plots, illustrate the interaction and dynamic behaviour of the pendulum and the surrounding fluid. This trial successfully demonstrates the capability of the CEL method to model complex FSI problems, providing valuable insights for advanced engineering applications

**4.3 Modelling**

The CEL method in Abaqus involves the following key components:

1. Eulerian Domain for Fluids: The fluid (e.g., water in the tank) is modeled in an Eulerian domain. The Eulerian mesh is fixed in space, and the fluid material flows through this mesh. This setup efficiently handles large deformations and fluid movements, such as sloshing.
2. Lagrangian Domain for Structures: The tank structure is modeled in a Lagrangian domain, where the mesh moves with the material. This approach accurately captures the structural deformations and stresses.
3. Coupled Interaction: The interaction between the Eulerian and Lagrangian domains is defined to simulate the fluid-structure interaction. The pressure exerted by the sloshing fluid on the tank walls and the resulting structural response are computed iteratively.

**4.3.1 Assembly of the structure**

The tank structure, including its supporting columns and foundation, is modeled using appropriate geometric representations. The internal water volume is also defined.The assembly of the model consists of fiour parts viz.:

1. The Eulerian: This is modelled so as to encorporate the movement of fluid inside the tank when it will be subjected to seismic vibrations. The Eulerian is modelled as a cuboid of dimensions 5m x 5m x 4.8m. The Eulerian part is 3D by default.

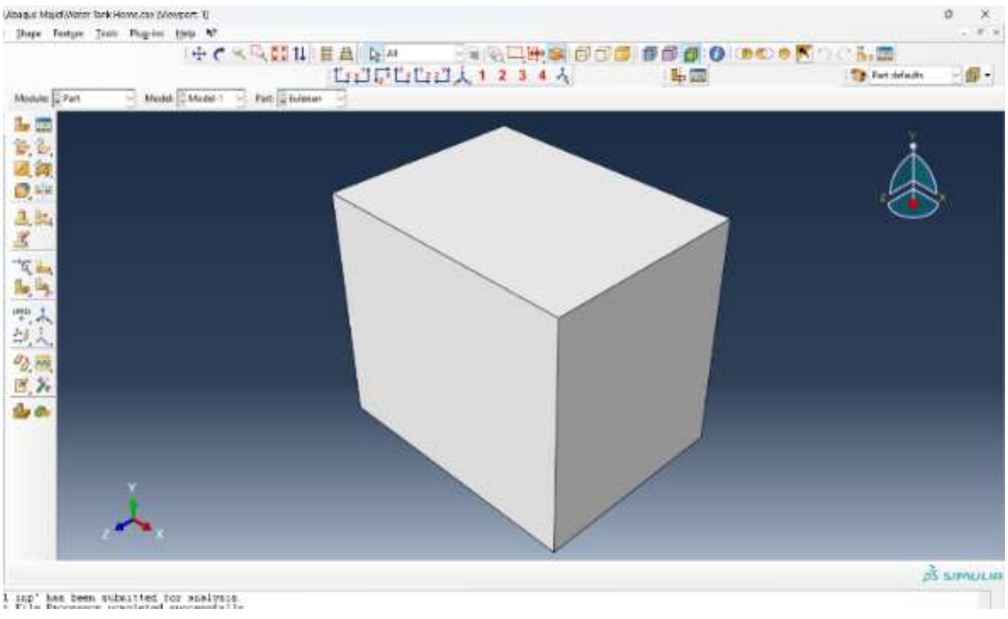


**Fig 4.1:** Eulerian Part

2. Supports: A central support of 8m height is assigned with steel properties and four rectangular supports are attached at four corners of the structure.

e-ISSN: 2582-5208
International Research Journal of Modernization in Engineering Technology and Science
( Peer-Reviewed, Open Access, Fully Refereed International Journal )
Volume:06/Issue:07/July-2024 Impact Factor- 7.868 www.irjmets.com

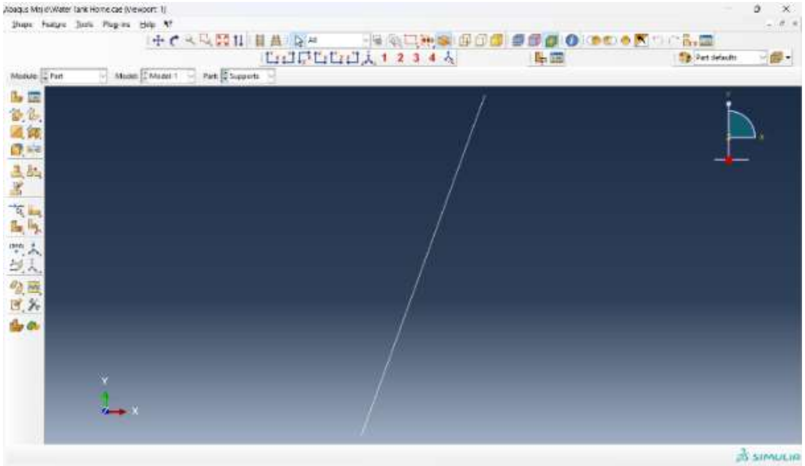


**Fig 4.2:** Support

**3.** Tank; A circular tank with 6m diameter is modelled with steel properties.

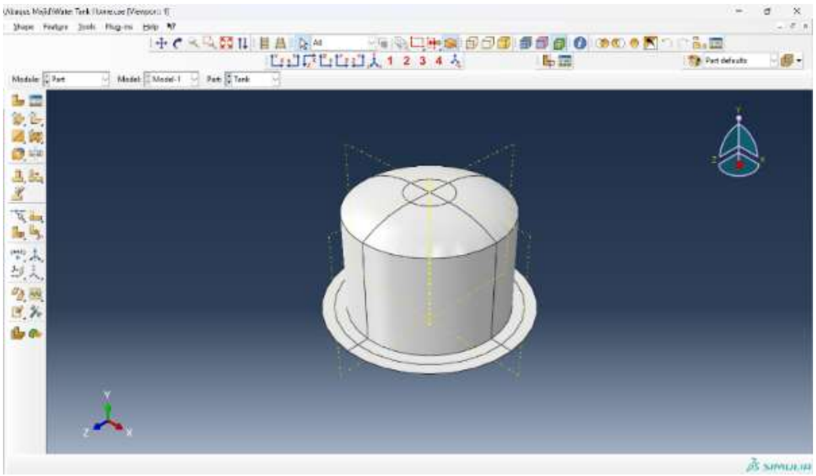


**Fig 4.3:** Water Tank Part

**4.** Water: This part represents the level of water. The tank is 60% filled with water. The properties defined for water are as below:

**1.** Density: 1000kg/$m^3$

**2.** Equation of state: $C_0$=1450, s=0, $\gamma_0$=0

**3.** Coefficient of Dynamic Viscosity=0.001Pa-s

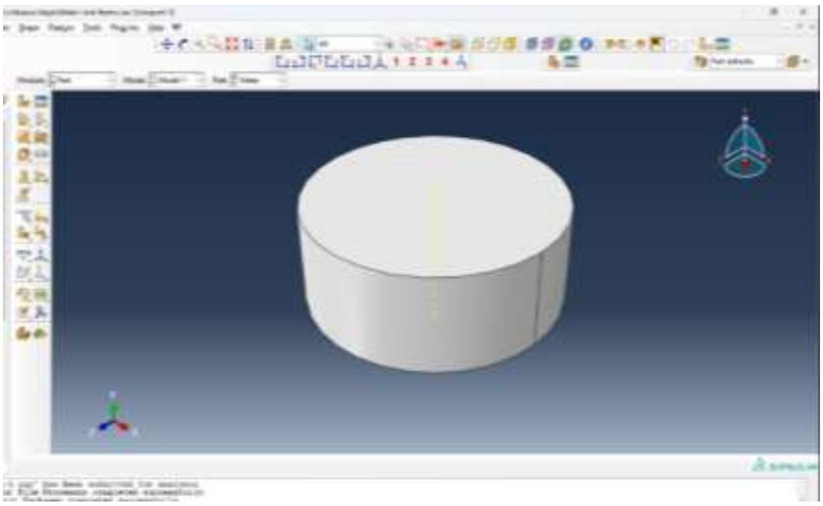


**Fig 4.4:** Water Part

e-ISSN: 2582-5208
International Research Journal of Modernization in Engineering Technology and Science
( Peer-Reviewed, Open Access, Fully Refereed International Journal )
Volume:06/Issue:07/July-2024 Impact Factor- 7.868 www.irjmets.com

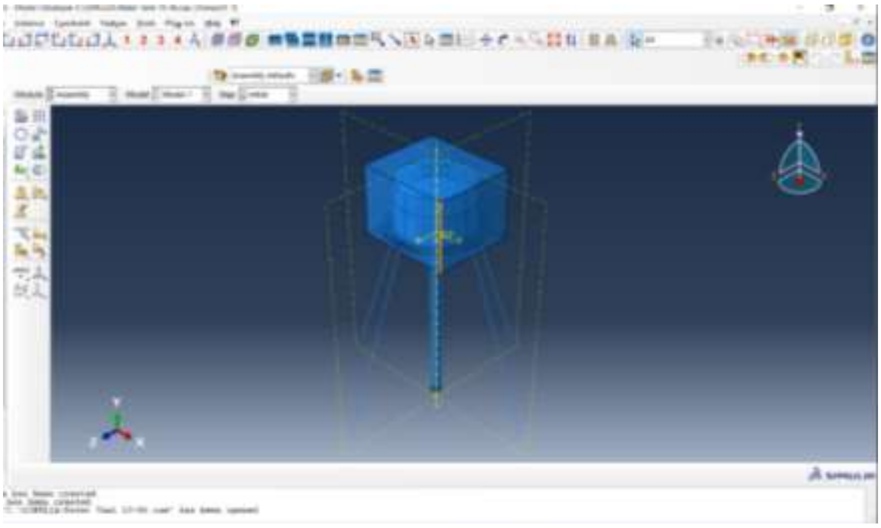


**Fig 4.5:** Assembly of all parts with Eulerian

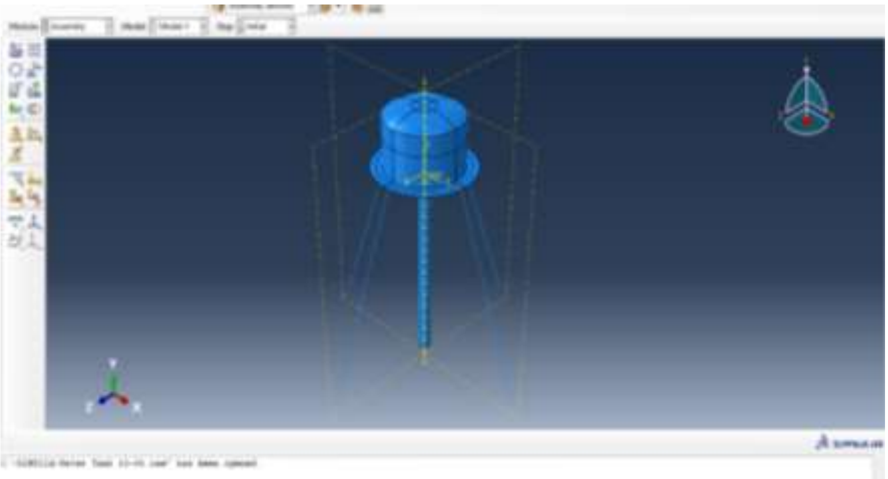


**Fig 4.6:** Assembly of all parts without Eulerian

### 4.3.2 Step Module

- Step: A Dynamic Explicit Analysis was requested with Non-Linear geometry with a time period of 20 seconds.
- Field Output Manager: The Field Outputs requested were Stresses, Strains, Displacement/Velocity/ Acceleration, Forces/Reactions with the whole model as the domain with 200 evenly spaced time intervals.

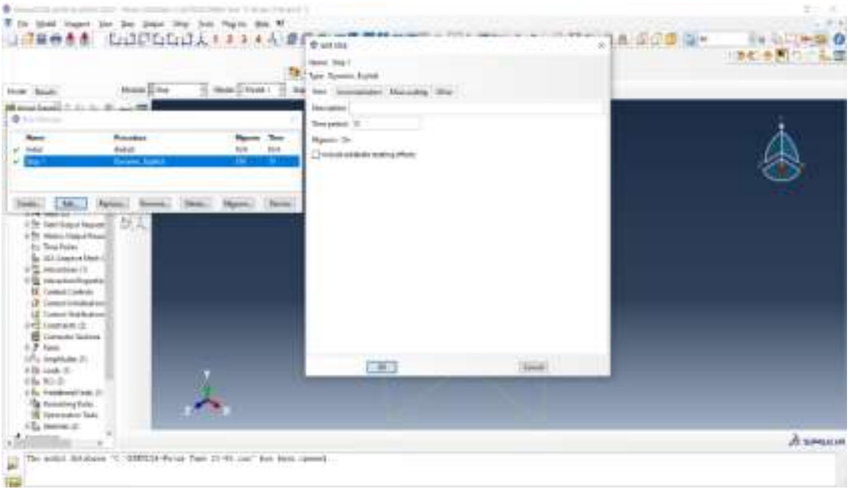


**Fig 4.7:** Dynamic Explicit step in Step Manager

e-ISSN: 2582-5208
International Research Journal of Modernization in Engineering Technology and Science
( Peer-Reviewed, Open Access, Fully Refereed International Journal )
Volume:06/Issue:07/July-2024 Impact Factor- 7.868 www.irjmets.com

### 4.3.3 Interaction module:

The interaction between the tank structure and the water is defined using the CEL method, which is described in detail in the following section.

- Interaction Property: An Explicit general contact of the whole model is given. It automatically detects and enforces contact interactions between all surfaces in the model.
- Constraints: The supports are integrated with the tank using Tie constraint which is used to simulate the connection between two surfaces or edges in a model, ensuring that they move together as if they were glued or welded.

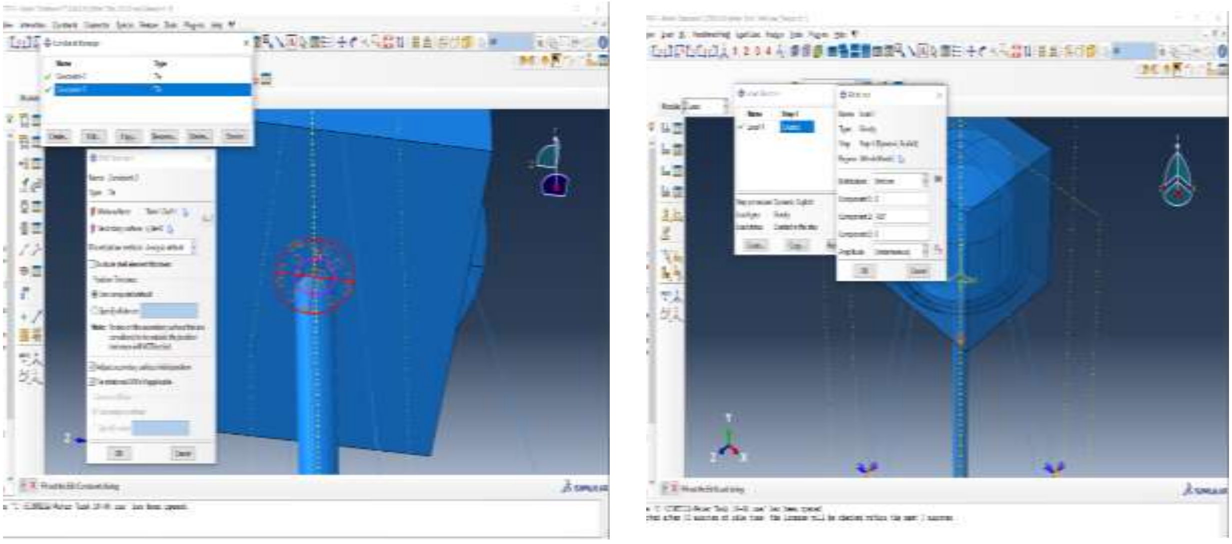


**Fig 4.8:** Tie Constraints applied at the supports

### 4.3.4 Load Module

Appropriate boundary conditions were applied to simulate the real-world constraints of the tank. Additionally, contact interactions between the tank walls and the water were defined to allow for fluid-structure interaction.

- The basic load of gravity is applied as $9.81 m/s^2$.
- Boundary conditions are applied to all the five suppport elements to simulate fixity in all directiions except x-direction and then to apply Earthquake acceleration in the x-direction. The Earthquake data used is of the Quebec Earthquake of 2005.

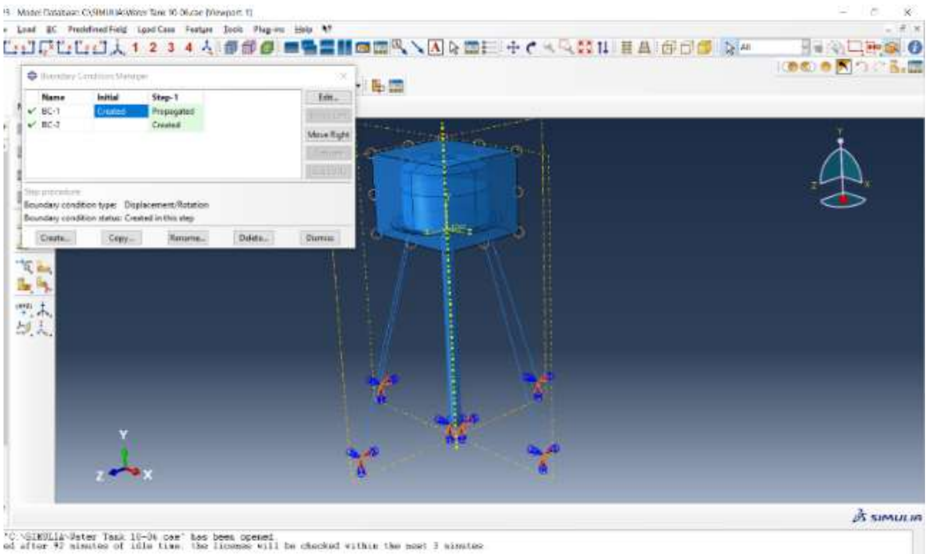


**Fig 4.9:** Fixity applied to all directions except x-direction

e-ISSN: 2582-5208
International Research Journal of Modernization in Engineering Technology and Science
( Peer-Reviewed, Open Access, Fully Refereed International Journal )
Volume:06/Issue:07/July-2024 Impact Factor- 7.868 www.irjmets.com

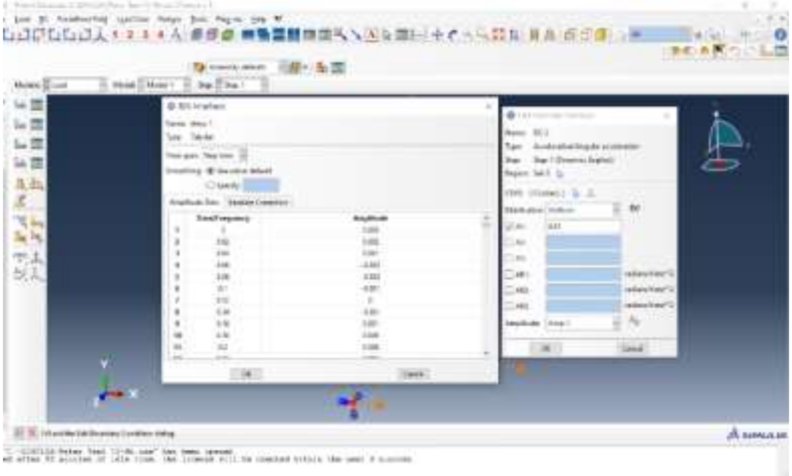
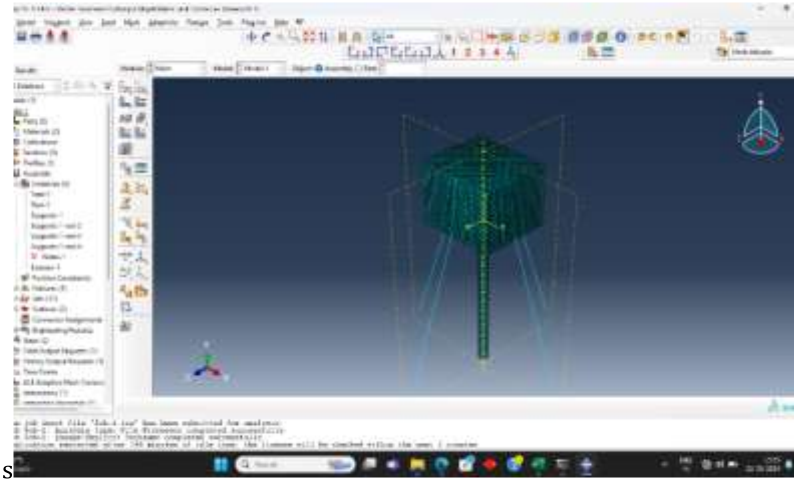


**Fig 4.10:** Earthquake Data

### 4.3.5 Mesh Module

A finite element mesh is generated for both the tank structure and the water volume using Quad shaped structured elements. The mesh density is usually chosen to balance computational efficiency and accuracy. A finer mesh was made for the Eulerian part due to the detailed fluid interaction expected.



S

**Fig 4.11:** Meshing of the whole model

### 4.3.6 Job Module

This module is the one which carries out the analysis. A job for full analysis was created and executed.

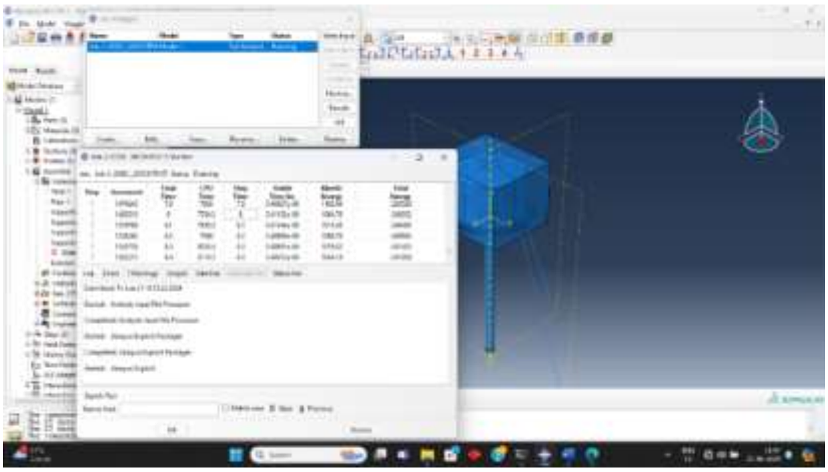


**Fig 4.12:** Job running with monitoring

e-ISSN: 2582-5208
International Research Journal of Modernization in Engineering Technology and Science
( Peer-Reviewed, Open Access, Fully Refereed International Journal )
Volume:06/Issue:07/July-2024 Impact Factor- 7.868 www.irjmets.com

## V. RESULTS AND DISCUSSIONS

In this chapter, the comprehensive results and detailed analysis derived from dynamic simulations conducted on an elevated water tank modeled using Abaqus software are presented. The primary objective of this study is to assess the tank's dynamic response to base excitation and to evaluate its potential effectiveness as a Tuned Liquid Damper (TLD), considering the intricate influence of sloshing dynamics. The study compares the dynamic behavior of the tank with and without water, focusing on the velocity, acceleration, and displacement responses over time. The key findings highlight the damping effects of the water content on the tank's dynamic response. Abaqus also provides the simulation of the Water Tank with and without water under base motion.

### 5.1 Response to Base Motion

Detailed examination of the tank's response under base motion scenario of seismic excitations with and without water are carried out. Analysis includes amplitude spectra, velocity responses, and acceleration responses of the tank's motion relative to the applied base motions. Insights are drawn regarding amplification and damping characteristics observed in operational condition wherein the tank is 60% full. Quantitative assessment of the tank's damping performance as a Tuned Liquid Damper, particularly focusing on its ability to mitigate structural vibrations is carried out.

The Unique Nodals selected to extract the data of the tank motion with and without water are highlighted with red in the figures shown below:

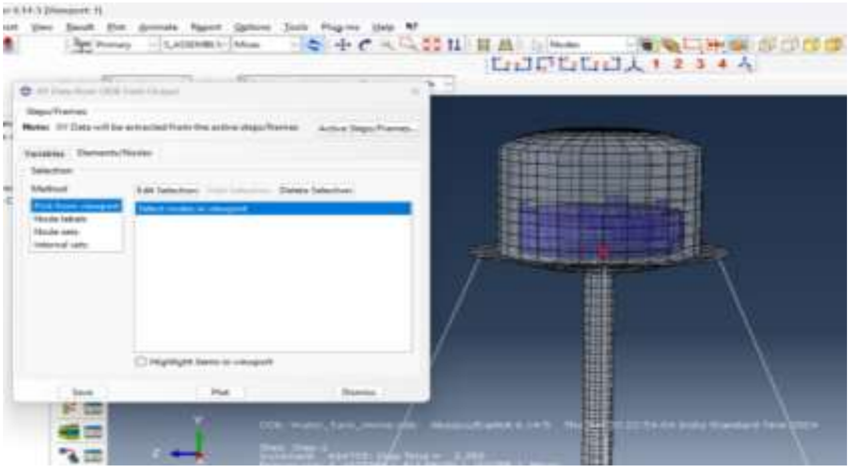


**Fig 5.1:** Unique Nodal for Tank with water

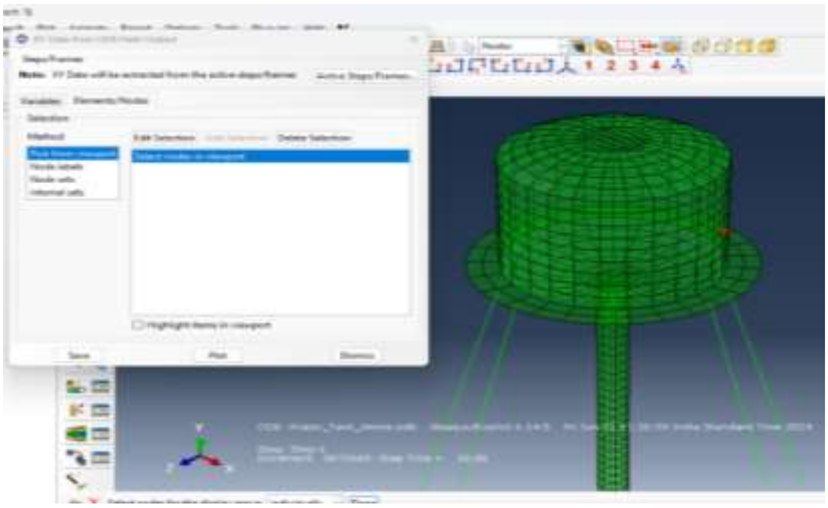


**Fig 5.2:** Unique Nodal for Tank without water

#### 5.1.1 Velocity Response

The velocity response of the elevated water tank with and without water is depicted in Figure. The graph shows the velocity of the tank versus time under the applied base motion.

1. Tank without Water:

- The velocity response exhibits significant oscillations due to the applied base motion.
- The amplitude of the oscillations decreases over a large time only damping effects of structural and aerodynamic resistances.
- The graph shows the velocity remains significantly undamped in the 20 second period with velocities of 1m/s approximately.

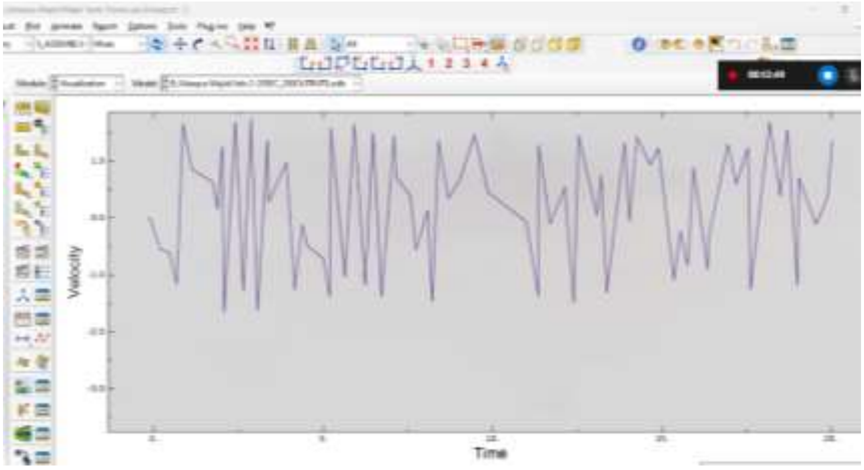



**Fig 5.3:** Velocity vs. Time Plot

2. Tank with 60% Water:

- The presence of water introduces additional damping due to sloshing effects.
- The velocity response shows a rapid decrease in amplitude, indicating a quicker dissipation of energy.
- The velocity remains below 1m/s for the most part of the motion.
- The energy dissipation occurs after around 12 seconds.

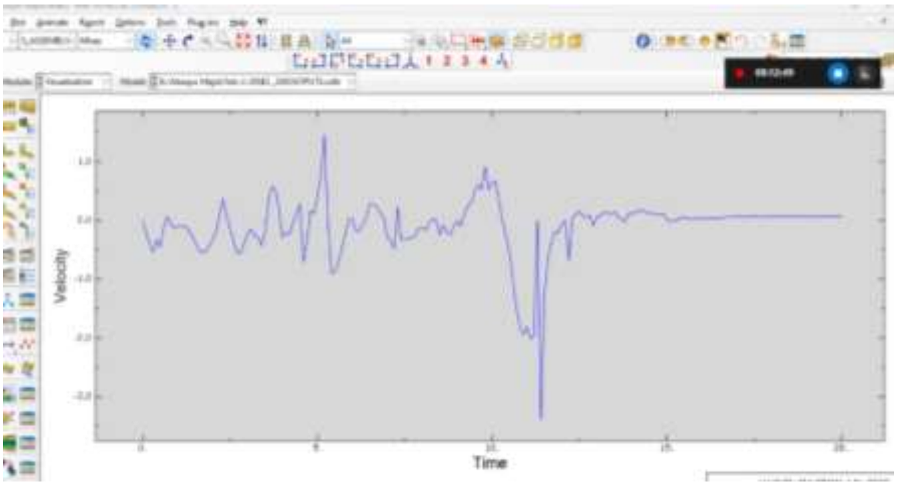



**Fig 5.4:** Velocity vs. Time Plot

In the tank without water, the velocity dampens to zero slowly, with oscillations persisting for a longer duration compared to the tank with water. Whereas the velocity dampens to zero faster than the empty tank, demonstrating the effective damping contribution of the water

### 5.1.2 Acceleration Response

The acceleration response of the elevated water tank is illustrated in Figure 2. The graph plots the acceleration of the tank against time for both scenarios.

1. Tank without Water:

- The acceleration response initially follows the base motion closely, with high-amplitude oscillations.

e-ISSN: 2582-5208
International Research Journal of Modernization in Engineering Technology and Science
( Peer-Reviewed, Open Access, Fully Refereed International Journal )
Volume:06/Issue:07/July-2024 Impact Factor- 7.868 www.irjmets.com

- Over time, the oscillations reduce in amplitude but remain significant for a prolonged period.
- The acceleration of the tank over the period has an average value of 1.5m/s$^2$.

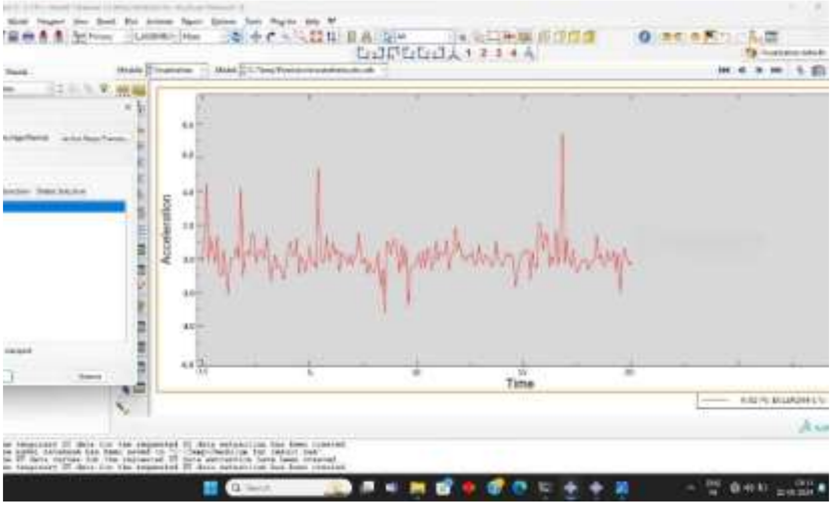



**Fig 5.5:** Acceleration vs. Time Plot

2. Tank with 60% Water:

- The water introduces a damping mechanism that mitigates the acceleration peaks.
- The acceleration response shows a rapid decline in amplitude, with oscillations reducing significantly over time.
- The acceleration dampens out almost completely after 15 seconds.

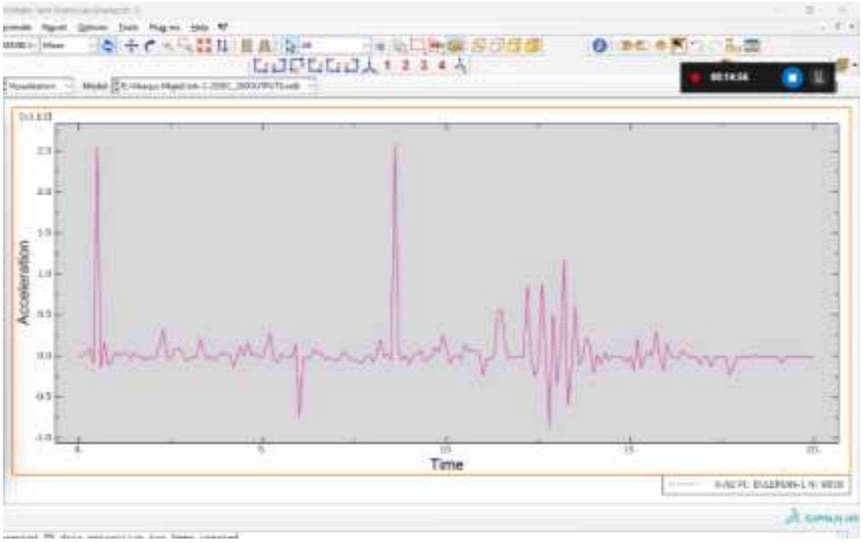



**Fig 5.6:** Acceleration vs. Time Plot

The acceleration dampens to zero more quickly compared to the empty tank, underscoring the damping effect of the water. The damping of acceleration to zero is gradual, indicating less effective damping in the absence of water.

### 5.1.3 Displacement Response

The displacement response of the elevated water tank is shown in Figure 3. The graph presents the displacement of the tank versus time for both conditions.

1. Tank without Water:

- The displacement response features pronounced oscillations due to the applied base motion.
- The displacement value remains around 5mm throughout the period of 20 seconds.
- The amplitude of oscillations decreases slowly, with the tank taking longer to reach a state of rest.

e-ISSN: 2582-5208
International Research Journal of Modernization in Engineering Technology and Science
( Peer-Reviewed, Open Access, Fully Refereed International Journal )
Volume:06/Issue:07/July-2024 Impact Factor- 7.868 www.irjmets.com

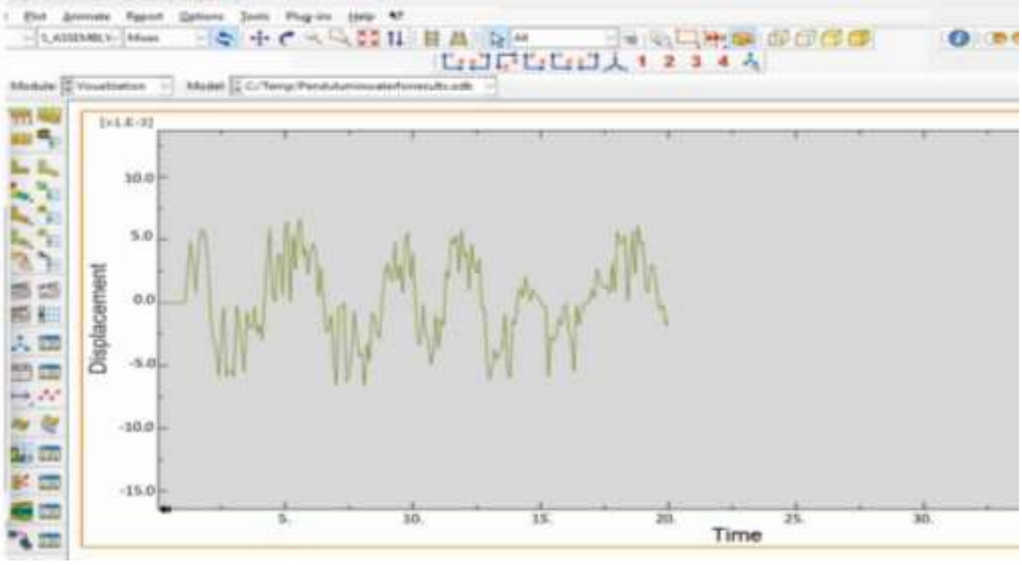



**Fig 5.7:** Displacement vs. Time Plot

2. Tank with 60% Water:

- The water's sloshing behavior provides an effective damping mechanism that reduces the displacement oscillations.
- The displacements reduce in huge proportion with only around 1mm of displacements.
- The displacement response demonstrates a swift reduction in amplitude, indicating quicker stabilization of the tank.

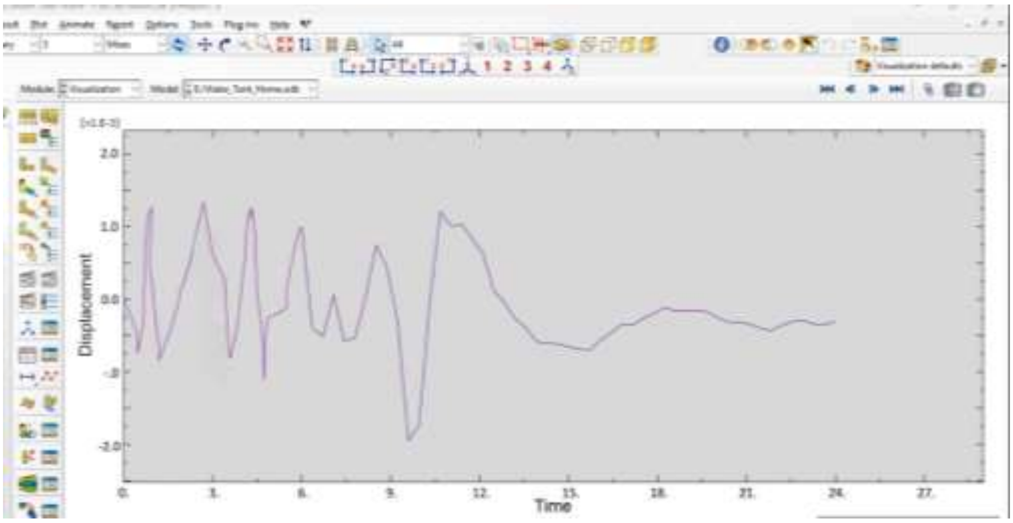



**Fig 5.8:** Displacement vs. Time Plot

The displacement dampens to zero gradually in the empty tank, reflecting the lower damping efficiency without water. Whereas in case of 60% full tank, the displacement dampens to zero more rapidly, confirming the enhanced damping effect of the water.

**5.2 Comparative Analysis**

The comparative analysis of the velocity, acceleration, and displacement responses clearly indicates that the presence of water significantly enhances the damping characteristics of the elevated water tank. The sloshing effect of the water acts as a natural damper, absorbing and dissipating the energy induced by the base motion more effectively than the empty tank.

1. Velocity Damping: The water-filled tank exhibits a faster reduction in velocity oscillations, highlighting the superior damping capacity introduced by the water.
2. Acceleration Damping: The acceleration response of the water-filled tank shows a quicker attenuation of

peaks, reducing the dynamic loads transmitted to the tank structure.

**3.** Displacement Damping: The displacement response indicates that the water-filled tank stabilizes more rapidly, achieving a state of rest sooner than the empty tank.

## VI. CONCLUSION

The comprehensive investigation into the dynamic behavior of elevated water tanks under seismic loading conditions using Abaqus software has provided valuable insights into the role of fluid-structure interactions and the effectiveness of TLDs in enhancing seismic resilience. The key conclusions drawn from this study are:

1. The interaction between the water and the tank structure plays a critical role in influencing the dynamic response under seismic loading. Proper consideration of these interactions is essential for accurate seismic analysis and design.
2. TLDs have been shown to be highly effective in reducing vibration amplitudes and enhancing the seismic resilience of elevated water tanks. Their application can lead to significant improvements in the structural performance and safety of these critical infrastructure components.

### 6.1 Future scope of work

Based on this study, future research can explore:

**1.** To investigate different water fill percentages to determine their impact on sloshing dynamics and seismic performance, identifying optimal levels for enhanced resilience.

**2.** Apply the fluid-structure interaction model to high-rise buildings with TLDs to assess their effectiveness in reducing seismic vibrations and improving structural resilience through detailed simulations and experiments.

## VII. REFERENCE

[1] Chirag N. Patel ,Burhan Kanjetawala ,H. S. Patel " Influence of frame type tapered staging on sloshing behaviour of elevated water tank". International Journal of Advanced Engineering Research and Studies /Vol. II/ Issue I/Oct.- Dec.,2012/64-67.

[2] M. V. WAGHMARE, S.N.MADHEKAR, "Behaviour of elevated service reservoir under sloshing effect ", International Journal of Advanced Technology in Civil Engineering, ISSN: 2231 –5721, Volume-2, Issue-1, 2013,pg.no.51-54.

[3] Gaikwad Madhukar V., Prof. Mangulkar Madhuri N. "Comparison between static and dynamic analysis of elevated water tank " International Journal of Civil Engineering and Technology (IJCIET), ISSN 0976 – 6316 Volume 4, Issue 3, May - June (2013),pg.no.12-29.

[4] H. Shakib , F. Omidinasab1 and M.T. Ahmadi "Seismic Demand Evaluation of Elevated Reinforced Concrete Water Tanks " International Journal of Civil Engineerng. Vol. 8, No. 3, September 2010, pg.no.204-220