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# Comparative Analysis of Sloshing Impact on Rectangular Overhead Water Tank with Different Types of Bracings by Using STAAD.Pro

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## ABSTRACT

Water supply is a life line facility that must remain functional in natural disaster. These structures have large mass concentrated at the top of slender supporting structure hence these structure are especially vulnerable to horizontal forces due to earthquakes. The rectangular water tank were collapsed or heavily damaged during the earthquakes because of unsuitable design of supporting system or wrong selection of supporting system and underestimated demand or overestimated strength. So, it is very important to select proper supporting system and also need to study the response of rectangular water tank subjected to seismic forces in different zones and to find out the design parameters for seismic analysis. It is also necessary to consider the sloshing effect on top and bottom slab of water tank. The effect of hydrodynamic pressure and pressure due to wall inertia & effect of vertical ground acceleration in the seismic analysis must be considered in the seismic analysis of rectangular water tank. This paper presents analysis to study the effects of sloshing in overhead liquid storage tank. In such structure a large mass concentrated at the top of slender supporting structure makes the structure vulnerable to horizontal forces e.g. due to earthquakes. This study focuses mainly on the response of the elevated rectangular type water tank to dynamic forces by both equivalents static method and finite element analysis using STAAD.Pro software.

To find out the design parameters for seismic analysis and also the importance in the sloshing effect consideration during the design. Here an elevated rectangular type water tank is analysed with X bracing, V bracing and diagonal bracings. The analysis is carried out for X bracing, V bracing and diagonal bracings considering only the hydrostatic effects on STAAD Pro. Maximum Absolute Stresses in X bracing is 9.79 N/mm2 and Maximum Principle Major Stresses in X bracing is 8.12 N/mm2. Maximum Absolute Stresses in V bracing is 9.8 N/mm2 and Maximum Principle Major Stresses in X bracing is 8.12 N/mm2. Maximum Absolute Stresses in Diagonal bracing is 9.69 N/mm2 and Maximum Principle Major Stresses in X bracing is 8.04 N/mm2. It means that stresses are near about same in X bracing and in V bracing. But in diagonal bracing stresses are less as compared to X bracing and V bracing. The displacement is maximum in diagonal bracing but stresses are minimum in diagonal bracing. Whereas X bracing and V bracing gives same performance in maximum absolute stresses and maximum principle major stresses. The results under tank full condition shows higher values and such values decreases under tank $^3/_4$, $^1/_2$, and $^1/_4$ condition.

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***KEYWORDS:*** *Sloshing Impact, Water Tank, Bracings, Earthquake, STAAD.Pro, Equivalent Static Method, etc*

## INTRODUCTION

The presence of a free fluid surface which allows motions related to container called liquid sloshing. Seismic ground motion cause hydrostatic and hydrodynamic pressure on the tank which depend on the dimension of tank, the percentage of liquid, properties of liquid, fluid tank interaction, etc. Most of the people developed a mathematical model, theoretical solution for calculating or studying sloshing effects. Therefore an understanding of earthquake damage for elevated service reservoir requires information about dynamic forces, staging height associated with sloshing liquid is important. Main objective of seismic design of structure is to ensure that the structure even though does not fully resist the earthquake force it at least has an acceptable performance when subjected to various intensity earthquakes and the probability of such occurrences during its lifetime. Indian sub-continent is highly vulnerable to natural disasters like earthquake, draughts, floods, cyclones etc. According to IS code 1893 (Part 1): 2016, more than 60% of India is prone to earthquakes.

The earthquake of 26 January 2010 in Gujarat was unprecedented for the entire country, then public learnt first time that the scale of disaster could have been far lower had the construction in the region compiled with codes of practice for earthquake prone regions. These natural calamities are causing many casualties and innumerable property loss every year. After an earthquake the loss which cannot be recovered are the life loss. Collapse of structures causes people to life loss. Hence it becomes important to analyze the structures properly. Seismic safety of liquid storage tanks is of considerable importance, as tanks storing highly concentrated liquids in industries, or in transporting vehicles, ships can cause considerable harm for human society if damaged. Water supply being the lifeline facility must remain functional following disaster to carter the need of drinking and firefighting. These structures have large mass concentrated at the top of slender supporting structure hence these structure are especially vulnerable to horizontal forces due to earthquake as they act as the inverted pendulum like structure.

### A. Slosh Dynamics

In fluid dynamics, slosh refers to the movement of liquid inside another object (which is, typically, also undergoing motion).Strictly speaking, the liquid must have a free surface to constitute a slosh dynamics problem, where the dynamics of the liquid can interact with the container to alter the system dynamics significantly.

Important examples include propellant slosh in spacecraft tanks and rockets (especially upper stages), and the free surface effect (cargo slosh) in ships and trucks transporting liquids (for example oil and gasoline). However, it has become common to refer to liquid motion in a completely filled tank, i.e. without a free surface, as "fuel slosh".

Such motion is characterized by "inertial waves" and can be an important effect in spinning spacecraft dynamics. Extensive mathematical and empirical relationships have been derived to describe liquid slosh. These types of analyses are typically undertaken using computational fluid dynamics and finite element methods to solve the fluid-structure interaction problem, especially if the solid container is flexible. Relevant fluid dynamics non-dimensional parameters include the Bond number, the Weber number, and the Reynolds number.

Sloshing refers to the movement of the free surface of a liquid due to the movement of its container. Liquid sloshing is an important factor to be considered in various areas such as aircraft fuel tank designs, tankers transporting water and other liquids, sloshing of cargo in ships etc. a swimming pool is another such container of large volume of water where sloshing forces can be significant when subjected to lateral deflections. The large liquid movement during sloshing can result in high impact stresses in the walls of the pool. And in extreme cases can cause sufficient moment to negatively affect the stability of the supporting structure. This paper investigates the additional stresses developed in the additional stresses developed in structures due to sloshing.

**Fig. 1 Sloshing of Water in Tank**

### B. Horizontal Bracing Systems

This consists of bracing at each floor in the horizontal planes thus providing load paths so that the horizontal forces can be transferred to the planes of vertical bracing.

The horizontal bracing system is too divided into two major types namely:
A. Diaphragms and
B. Discrete triangulated bracing

Some floor systems provide perfect horizontal diaphragm while others like precast concrete slabs require specific measures. It can be understood by the example of steelwork and precast concrete slab as these must be joint together properly to avoid relative movements. Horizontal bracing systems purpose is the transfer of horizontal loads from columns at the perimeter of the structure to the planes of vertical bracing.

Discrete triangulated bracing is taken into consideration when the floor system cannot be used as a horizontal bracing system.

### C. Vertical Bracing Systems

Vertical bracing are diagonal bracings installed between two lines of columns. Not only does it transfer horizontal loads to the foundations (create load path for horizontal forces) but also it withstands overall sway of the structure. Configurations of vertical bracings include cross diagonals (cross bracing) and single diagonal. In the former case, bracings are slender and withstand tension forces only, so they will not resist compression forces. Therefore, tensile diagonals provide necessary lateral stability in addition to the floor beams that act as a part of bracing system As far as the single diagonal bracing is concerned; it is designed to resist both tension forces and compression forces. The arrangement of diagonal bracing is illustrated in figure. Bracing elements are commonly placed at nearly 45$^o$ because it not only offers an efficient system compare with other systems but also strong and compact connections between bracing member and beam-column junction will be achieved. It is worth mentioning that, if the bracing member inclination is smaller than 45$^o$ (angle from vertical), then the sway sensitivity of the structure would be increased whereas wider bracing member arrangement provide greater structural stability.

Vertical bracing systems are required to be designed to resist wind forces, equivalent horizontal forces that represent the influence of initial imperfections and second order effects caused by frame sway in the case of the flexible frame. The location of vertical planes of bracing should be determined carefully. It is advised to place the vertical bracing planes at furthest point of the structure to withstand torsion forces that may occur due to horizontal forces. In vertical planes, there are bracing between column lines which provide load paths that are used to transfer horizontal forces to ground level. This system aims to transfer horizontal loads to the foundations and withstanding the overall sway of the structure. These are the bracings placed between two lines of columns.

It can also be studied in two types namely:
A. Cross bracing and
B. Single diagonal

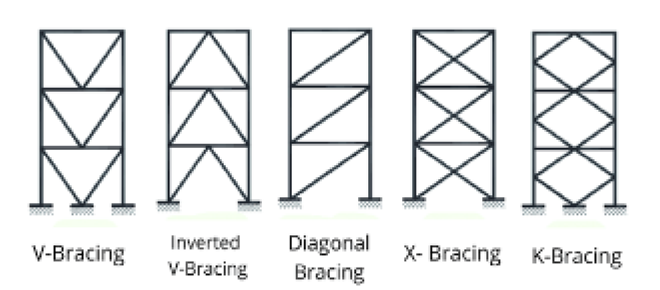



**Fig. 2 Types of Vertical Bracing Sytsems**

Cross bracing is slender withstanding tension forces only and not compression forces, it also provides necessary lateral stability depending on the direction of loading. Unlike Cross bracing, Single diagonal bracing is designed to resist both tension forces and compression forces. In this, diagonal structural members are inserted into rectangular areas of a structural frame which is good for stabilization of the frame. For fulfilling the requirement of a comparatively efficient system, bracing elements are placed at nearly 45 degrees. This arrangement is strong and compact.

Vertical Bracing system is designed to resist:
A. Wind forces
B. Equivalent horizontal forces
C. The number of vertical planes required to be installed:
D. A minimum of two vertical planes in each orthogonal direction are provided so that to avoid disproportionate collapse.
E. At least three vertical bracings are provided so that to generate adequate resistance in both directions in plan and against torsion forces around the vertical axis of the structure.
F. A higher number of vertical planes of bracing will enhance structural stability.

## METHODOLOGY

### A. Problem Statement

Liquid storage tanks are considered essential lifeline structures. Water tanks, in particular, are important to the continued operation of water distribution system in event of earthquakes. Most of the failures of large tanks after earthquakes are suspected to have resulted from the dynamic buckling caused by overturning moments of seismically induced liquid inertia and surface slosh waves. Recent earthquakes have shown that liquid storage tanks are found to be vulnerable to damage. It is noted that under dynamic loads i. e. due to earthquake, there is chances of failure of water tanks due to sloshing.

### B. Objectives of the Study

The main purpose of analysis is to compare different types of bracings on rectangular overhead water tanks due to sloshing effect.

Following are the objectives of the present study:-
A. To analyze effect of sloshing on overhead rectangular water tank with X bracings at columns with tank full condition, tank three-fourth ($^3/_4$) condition, tank one-half ($^1/_2$) condition and tank one- fourth ($^1/_4$) condition,
B. To analyze effect of sloshing on overhead rectangular water tank with V bracings at columns with tank full condition, tank three-fourth ($^3/_4$) condition, tank one-half ($^1/_2$) condition and tank one- fourth ($^1/_4$) condition,

C. To analyze effect of sloshing on overhead rectangular water tank with diagonal bracings at columns with tank full condition, tank three-fourth ($^3/_4$) condition, tank one-half ($^1/_2$) condition and tank one- fourth ($^1/_4$) condition,

D. To compare X bracings, V bracings and diagonal bracings with respect to displacement, maximum absolute stresses and maximum principle major stresses for different conditions like with tank full condition, tank three-fourth ($^3/_4$) condition, tank one-half ($^1/_2$) condition and tank one- fourth ($^1/_4$) condition.

### C. Scope of the Work
There are many load conditions that can affect the behavior of a structure. Two load conditions that affect the dynamic response of a water tank structure include ambient wind and the water level inside the tank. Other load conditions that are beyond the scope of this project and have the potential to affect the dynamic response of this type of structure include sloshing.

### D. Methodology of the Work
The different phases of this project of work are shown in the following diagram. The figure simply describes the experimental strategy of this study step by step.

A. Review the existing literatures of sloshing impact on water tanks,

B. Select type of structure for carrying seismic analysis,

C. Study of the different factors which are responsible for analysis of water tanks,

D. Analysis of effect of sloshing on overhead rectangular water tank with X bracings, V bracings and diagonal bracings at columns with different tank conditions,

E. Comparative analysis of X bracings, V bracings and diagonal bracings with respect to displacement, maximum absolute stresses and maximum principle major stresses for different tank conditions.

F. Interpretation of results and conclusion.

### E. Configuration of the Models
In the current study, water tanks are modeled using STAAD.Pro software. The analytical models of the water tank include all components that influence the mass, strength, stiffness and deformability of structure. The water tank structural system consists of beams, columns, walls and slab. The non-structural elements that do not significantly influence the building behavior are not modeled. Modal analysis and seismic coefficient analysis are performed on models. It is proposed to study the effectiveness of X bracings, V bracings & diagonal bracings. The beam, wall, slab and columns are modeled are two noded line element with 6 DOF at each node. The wall & slab is modeled using 4 noded area elements.

In present work, reinforced concrete rectangular water tank with X bracing, V bracing and diagonal bracing are taken which has situated in zone V (very severe zone), is taken for the study.

Details of models are shown below:

**1. Model 1:** Rectangular Overhead Water Tank with X Bracing,
   A. **Model 1 (A):** Rectangular Overhead Water Tank with X Bracing with tank full condition,
   B. **Model 1 (B):** Rectangular Overhead Water Tank with X Bracing with tank three-fourth ($^3/_4$) condition,
   C. **Model 1 (C):** Rectangular Overhead Water Tank with X Bracing with tank one-half($^1/_2$) condition,
   D. **Model 1 (D):** Rectangular Overhead Water Tank with X Bracing with tank one- fourth ($^1/_4$) condition.

**2. Model 2:** Rectangular Overhead Water Tank with V Bracing,

A. **Model 2 (A):** Rectangular Overhead Water Tank with V Bracing with tank full condition,

B. **Model 2 (B):** Rectangular Overhead Water Tank with V Bracing with tank three-fourth ($^3/_4$) condition,

C. **Model 2 (C):** Rectangular Overhead Water Tank with V Bracing with tank one-half ($^1/_2$) condition,

D. **Model 2 (D):** Rectangular Overhead Water Tank with V Bracing with tank one- fourth ($^1/_4$) condition.

**3. Model 3:** Rectangular Overhead Water Tank with Diagonal Bracing.

A. **Model 3 (A):** Rectangular Overhead Water Tank with Diagonal Bracing with tank full condition,

B. **Model 3 (B):** Rectangular Overhead Water Tank with Diagonal Bracing with tank three-fourth ($^3/_4$) condition,

C. **Model 3 (C):** Rectangular Overhead Water Tank with Diagonal Bracing with tank one-half ($^1/_2$) condition,

D. **Model 3 (D):** Rectangular Overhead Water Tank with Diagonal Bracing with tank one- fourth ($^1/_4$) condition.

**Table -1: Structural Data for All Models**

| Sr. No. | Description | Specifications |
|---|---|---|
| 1 | Type of Structure | RC Structure |
| 2 | Capacity of Tank | 360000 Litre (360 cu.m.) |
| 3 | Height of Tank from Ground | 9 m |
| 4 | Ground Water Level | 3 m Below Existing Ground |
| 5 | Free Board | 0.3 m |
| 6 | Width of Gallery | 1.2 m |
| 7 | Types of Staircase | Spiral Staircase |
| 8 | Excavation | Up to 3.30 m |
| 9 | Size of Beams | 230 mm X 230 mm |
| 10 | Size of Columns | 300 mm X 300 mm |
| 11 | Thickness of Top Slab (Cover Slab) | 150 mm |
| 12 | Thickness of Bottom Slab | 200 mm |
| 13 | Wall Thickness | 230 mm |
| 14 | Size of Bracings | 150 mm x 150 mm |
| 15 | Tank Dimensions<br>a) Length (L)<br>b) Width (B)<br>c) Height (H) | 12 m x 6 m x 5 m<br>12 m<br>6 m<br>5 m |
| 16 | Density of Concrete | 25 kN/m$^3$ |
| 17 | Concrete Grade | M 25 |
| 18 | Grade of Steel | Fe 500 |
| 19 | Unit Weight of Concrete | 25 kN/m$^3$ |
| 20 | Unit Weight of Steel | 78.5 kN/ m$^3$ |

The plan of rectangular overhead water tank with X bracing, V bracing and diagonal bracing is as follows:

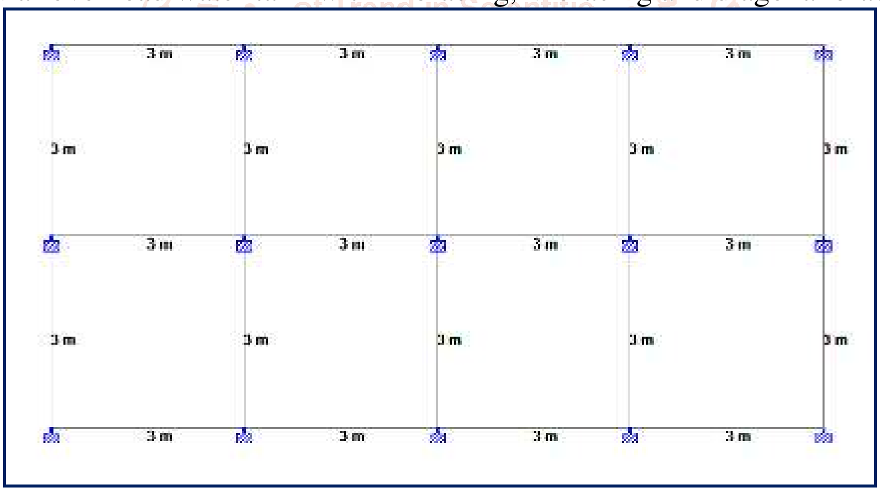



**Fig. 3 Plan of Model 1, Model 2 and Model 3**

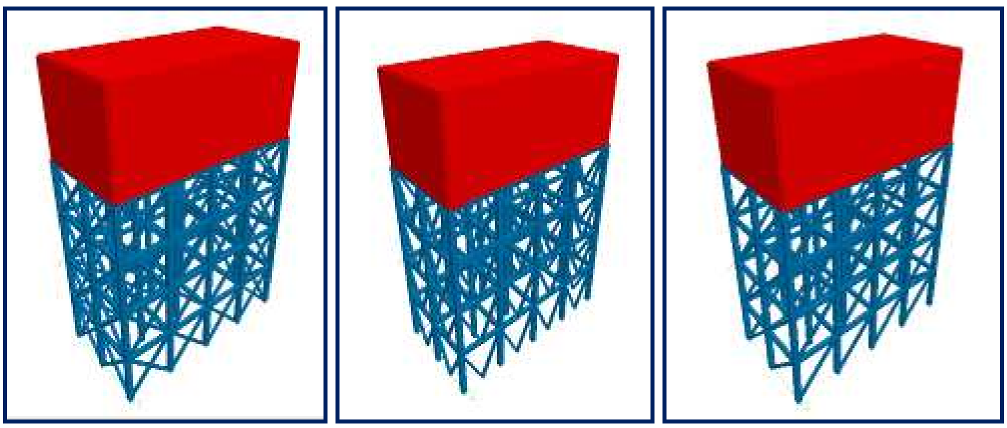
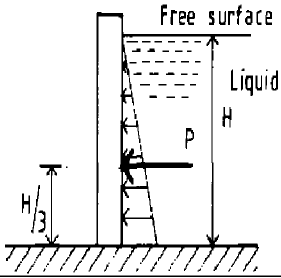


**Fig. 4 Rendered Views of Model 1, Model 2 and Model 3: Rectangular Overhead Water Tank with X, V and Diagonal Bracing**

## PERFORMANCE ANALYSIS

### A. Loading on Model 1, Model 2 and Model 3

**Table -2: Loading on Models**

| Sr. No. | Loads | Specifications |
|---|---|---|
| 1 | Self-Weight of the Frame Elements & Slabs | It is calculated & used automatically during analysis by the STAAD.Pro software |
| 2 | Super-Imposed Dead Load<br>(IS 875 Part I : 1987) | Floor Finish = 1.5 kN/m$^2$ |
| 3 | Live Load (IS 875 Part II : 1987) | Live Load for Top Slab = 2.0 kN /m$^2$ |
| 4 | Wind Load (IS 875 Part III : 2015) | a) $V_b$, Basic Wind Speed = 39 m/sec (Pune City)<br>b) Probability Factor, $k_1 = 1$<br>c) Terrain Roughness and Height Factor, $k_2 = 1$ (Terrain Category = III)<br>d) Topography factor, $k_3 = 1$<br>e) Importance Factor, $k_4 = 1$<br>*Design Wind Speed,* $V_z = V_b \cdot k_1 \cdot k_2 \cdot k_3 \cdot k_4$<br>$V_z = 39 \times 1 \times 1 \times 1 \times 1$<br>$V_z = 39$ m/sec$^2$<br>*Design Wind Pressure,* $P_z = 0.6 \times V_z^2$<br>$P_z = 0.6 \times 39^2$<br>$P_z = 912.6$ N/m$^2$ = 0.912 kN/m$^2$ |
| 5 | Earthquake Load or Seismic Load (IS 1893 Part I: 2016) | a) Seismic Zone = Zone V (Very Severe Zone)<br>b) Zone Factor , $Z = 0.36$<br>c) Importance Factor, $I = 1.2$<br>d) Damping Ratio = 0.05 (5%)<br>e) Response reduction Factor, $R = 5$ (SMRF)<br>f) Soil Type = II, Medium or Stiff Soils<br>g) Seismic Source Type = B<br>h) Period in $X$ – *direction* = $0.09h / \sqrt{dx}$ seconds = 0.442 seconds<br>i) Period in $Y$ – *direction* = $0.09h / \sqrt{dy}$ seconds = 0.625 seconds<br>Where,<br>$h$ = height of the building<br>$dx$ = length of building in x direction<br>$dy$ = length of building in y direction |
| 6 | Water Load<br>(IS 3370 Part I and II: 2009) | a) Height of Tank Wall = 5 m<br>b) Unit weight of Water = 9.81kN/m$^3$<br>c) Water Load at top of Wall = 9.81 x 0 = 0 kN/m$^2$<br>d) Water Load at bottom of Wall = $\gamma h$ = 9.81 x 5 = 49.05 kN/m$^2$ acting inclined to surface of wall<br> |

**B. Analysis Results of Model 1: Rectangular Overhead Water Tank with X Bracing**

1. Analysis Results of Rectangular Overhead Water Tank with X Bracing with Tank Full Condition

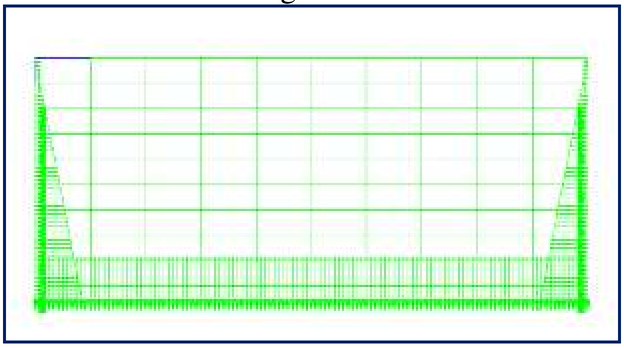


**Fig. 5 Loading under Tank Full Condition**

The results obtained for Model 1 (A): Rectangular Overhead Water Tank with X Bracing with tank full condition is as follows:

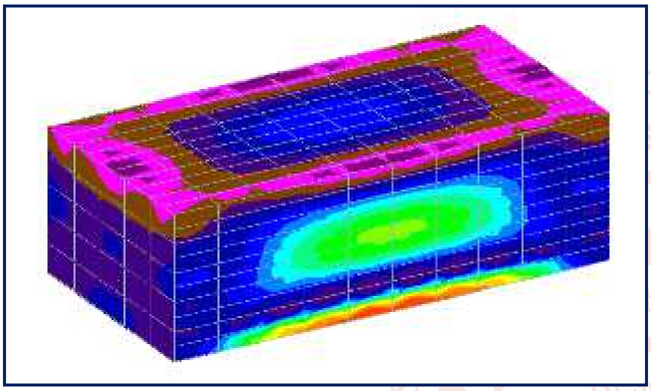


**Fig. 6 Analysis Results of Maximum Absolute Stresses in Model 1 (A)**

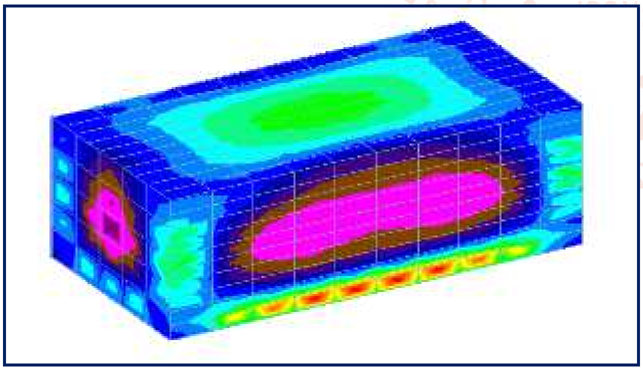


**Fig. 7 Analysis Results of Maximum Principle Major Stresses in Model 1 (A)**

**Table -3: Analysis Results of Stresses in Model 1 (A)**

| Sr. No. | Type | Values |
|---|---|---|
| 1 | Maximum Absolute Stresses | 9.79 N/mm$^2$ |
| 2 | Maximum Principle Major Stresses | 8.12 N/mm$^2$ |

2. Analysis Results of Rectangular Overhead Water Tank with X Bracing with Tank three-fourth $(^3/_4)$ condition

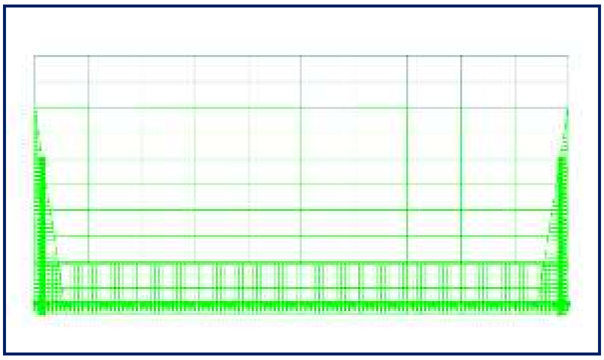


**Fig. 8 Loading under Tank $(^3/_4)$ Condition**

**Fig. 9 Analysis Results of Maximum Absolute Stresses in Model 1 (B)**

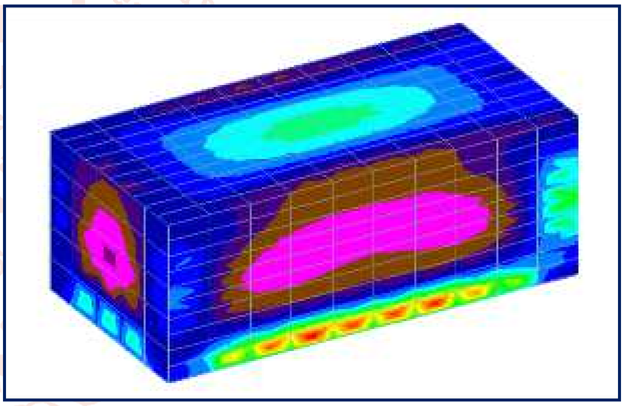


**Fig. 10 Analysis Results of Maximum Principle Major Stresses in Model 1 (B)**

**Table -4: Analysis Results of Stresses in Model 1 (B)**

| Sr. No. | Type | Values |
|---|---|---|
| 1 | Maximum Absolute Stresses | 7.12 N/mm$^2$ |
| 2 | Maximum Principle Major Stresses | 6.58 N/mm$^2$ |

3. Results of Rectangular Overhead Water Tank with X Bracing with Tank One-half $(^1/_2)$ condition

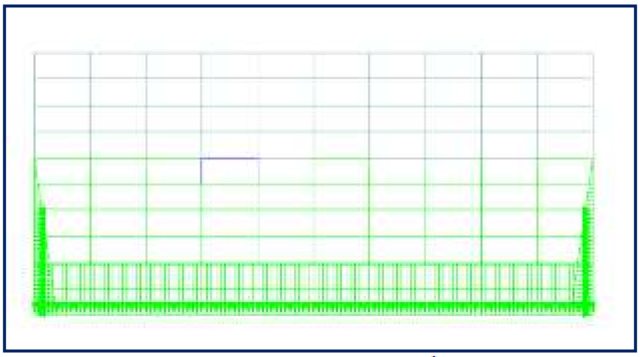


**Fig. 11 Loading under Tank ($^1/_2$) Condition**

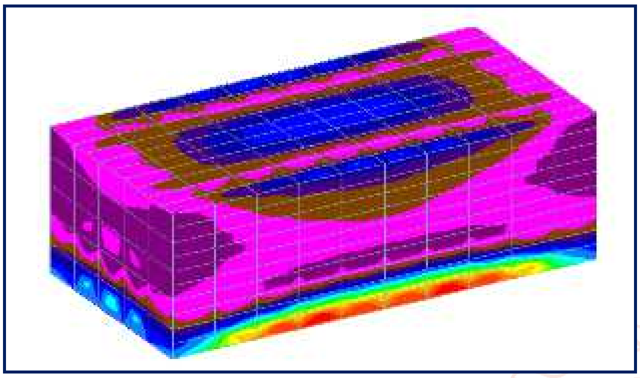


**Fig. 12 Analysis Results of Maximum Absolute Stresses in Model 1 (C)**

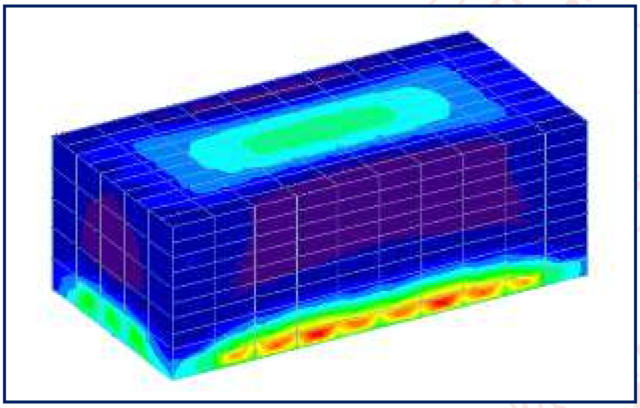


**Fig. 13 Analysis Results of Maximum Principle Major Stresses in Model 1 (C)**

**Table -5: Analysis Results of Stresses in Model 1 (C)**

| Sr. No. | Type | Values |
|---|---|---|
| 1 | Maximum Absolute Stresses | 5.41 $N/mm^2$ |
| 2 | Maximum Principle Major Stresses | 4.73 $N/mm^2$ |

4. Results of Rectangular Overhead Water Tank with X Bracing with Tank One-fourth ($^1/_4$) condition

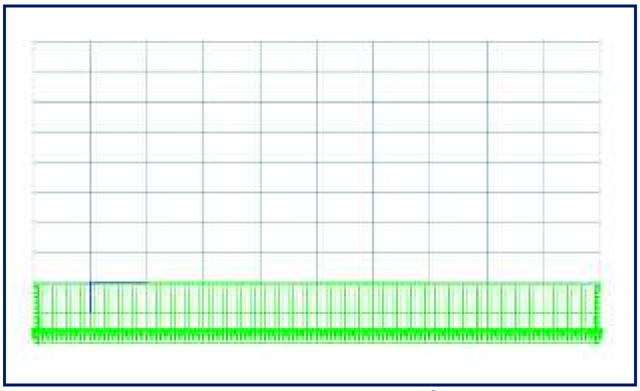


**Fig. 14 Loading under Tank ($^1/_4$) Condition**

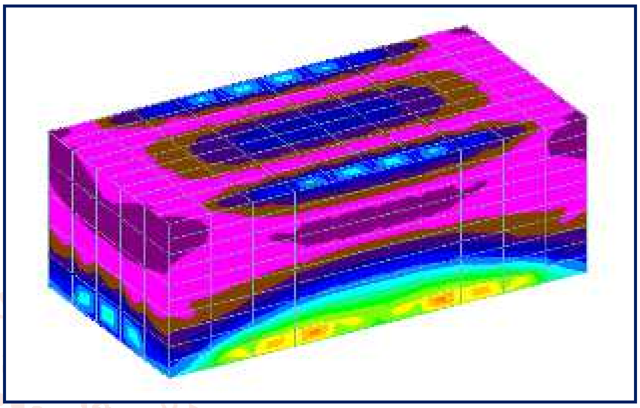


**Fig. 15 Analysis Results of Maximum Absolute Stresses in Model 1 (D)**

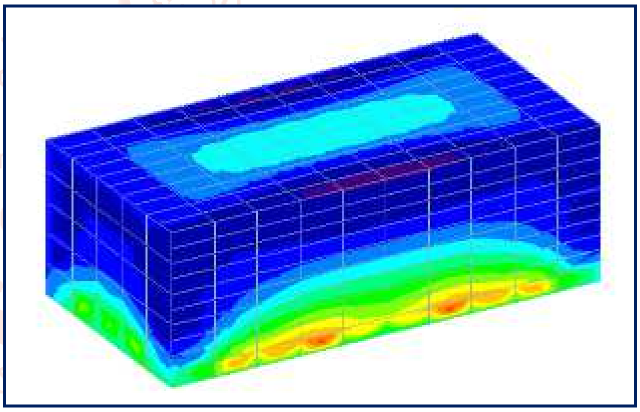


**Fig. 16 Analysis Results of Maximum Principle Major Stresses in Model 1 (D)**

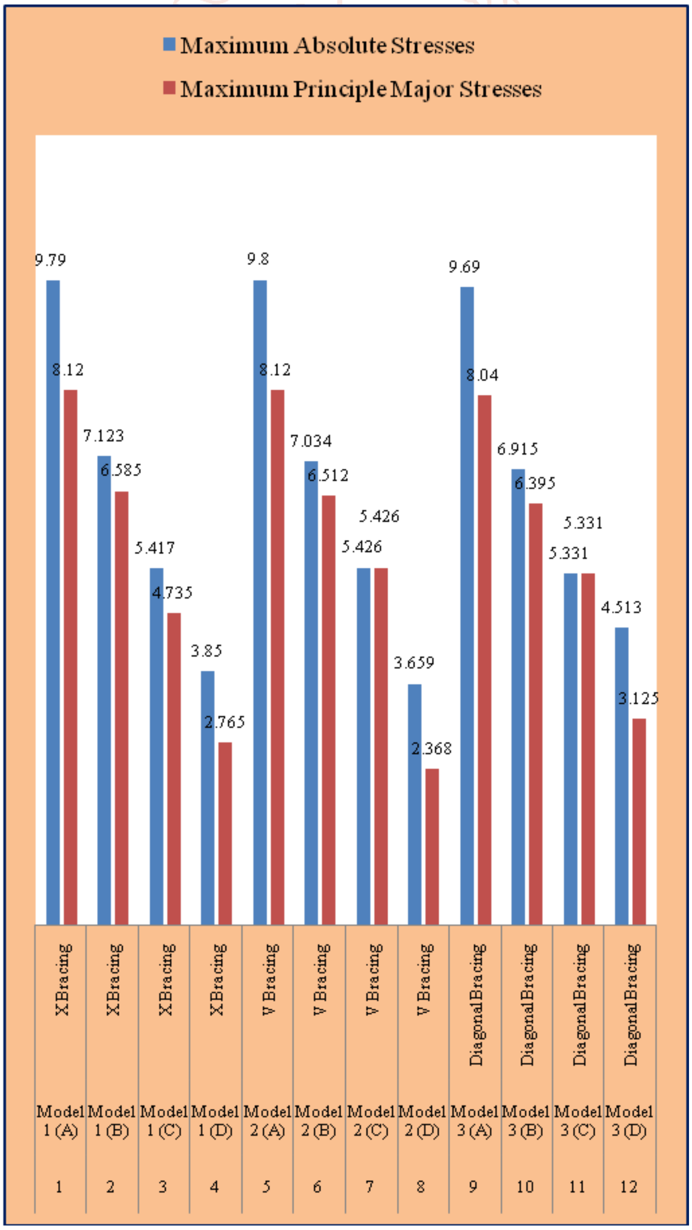
**Table -6: Analysis Results of Stresses in Model 1 (D)**

| Sr. No. | Type | Values |
|---|---|---|
| 1 | Maximum Absolute Stresses | 3.85 $N/mm^2$ |
| 2 | Maximum Principle Major Stresses | 2.76 $N/mm^2$ |

### C. Summary of Analysis Results of Maximum Absolute Stresses and Maximum Principle Major Stresses

**Table -7: Analysis Results of Maximum Absolute Stresses and Maximum Principle Major Stresses**

| Sr. No. | Type | Tank Condition | Maximum Absolute Stresses | Maximum Principle Major Stresses |
|---|---|---|---|---|
| **X Bracing** | | | | |
| 1 | Model 1 (A) | Full | 9.79 N/mm$^2$ | 8.12 N/mm$^2$ |
| 2 | Model 1 (B) | ($^3/_4$) | 7.123 N/mm$^2$ | 6.585 N/mm$^2$ |
| 3 | Model 1 (C) | ($^1/_2$) | 5.417 N/mm$^2$ | 4.735 N/mm$^2$ |
| 4 | Model 1 (D) | ($^1/_4$) | 3.850 N/mm$^2$ | 2.765 N/mm$^2$ |
| **V Bracing** | | | | |
| 5 | Model 2 (A) | Full | 9.800 N/mm$^2$ | 8.120 N/mm$^2$ |
| 6 | Model 2 (B) | ($^3/_4$) | 7.034 N/mm$^2$ | 6.512 N/mm$^2$ |
| 7 | Model 2 (C) | ($^1/_2$) | 5.426 N/mm$^2$ | 5.426 N/mm$^2$ |
| 8 | Model 2 (D) | ($^1/_4$) | 3.659 N/mm$^2$ | 2.368 N/mm$^2$ |
| **Diagonal Bracing** | | | | |
| 9 | Model 3 (A) | Full | 9.690 N/mm$^2$ | 8.040 N/mm$^2$ |
| 10 | Model 3 (B) | ($^3/_4$) | 6.915 N/mm$^2$ | 6.395 N/mm$^2$ |
| 11 | Model 3 (C) | ($^1/_2$) | 5.331 N/mm$^2$ | 5.331 N/mm$^2$ |
| 12 | Model 3 (D) | ($^1/_4$) | 4.513 N/mm$^2$ | 3.125 N/mm$^2$ |

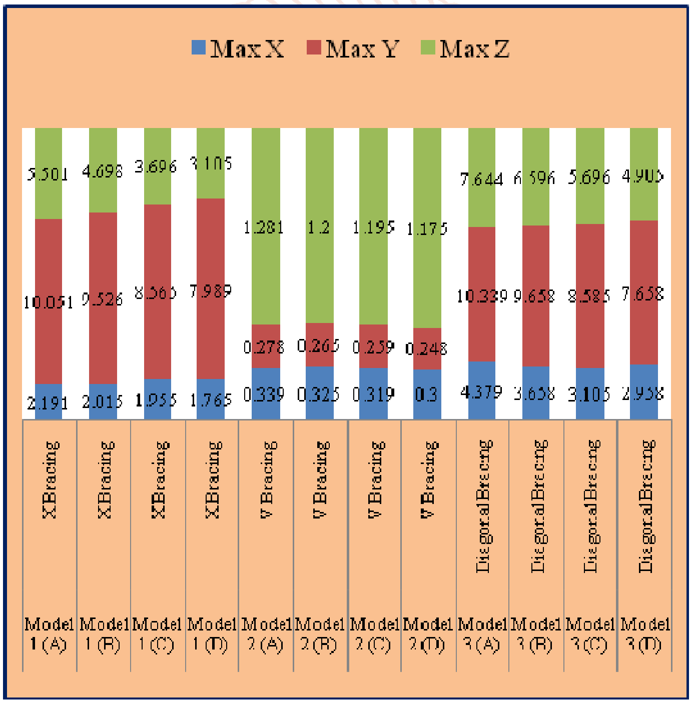



**Graph 1 Maximum Absolute Stresses and Maximum Principle Major Stresses**

### D. Displacement Results

**Table -8: Results of Maximum Displacement**

| Sr. No. | Type | Tank Condition | Max X | Max Y | Max Z |
|---|---|---|---|---|---|
| **X Bracing** | | | | | |
| 1 | Model 1 (A) | Full | 2.191 | 10.051 | 5.501 |
| 2 | Model 1 (B) | ($^3/_4$) | 2.015 | 9.526 | 4.698 |
| 3 | Model 1 (C) | ($^1/_2$) | 1.955 | 8.565 | 3.696 |
| 4 | Model 1 (D) | ($^1/_4$) | 1.765 | 7.989 | 3.105 |
| **V Bracing** | | | | | |
| 5 | Model 2 (A) | Full | 0.339 | 0.278 | 1.281 |
| 6 | Model 2 (B) | ($^3/_4$) | 0.325 | 0.265 | 1.200 |
| 7 | Model 2 (C) | ($^1/_2$) | 0.319 | 0.259 | 1.195 |
| 8 | Model 2 (D) | ($^1/_4$) | 0.300 | 0.248 | 1.175 |
| **Diagonal Bracing** | | | | | |
| 9 | Model 3 (A) | Full | 4.379 | 10.339 | 7.644 |
| 10 | Model 3 (B) | ($^3/_4$) | 3.658 | 9.658 | 6.596 |
| 11 | Model 3 (C) | ($^1/_2$) | 3.105 | 8.585 | 5.696 |
| 12 | Model 3 (D) | ($^1/_4$) | 2.958 | 7.658 | 4.905 |




**Graph 2 Maximum Displacement**

## CONCLUSION

Maximum Displacement in X type of bracing along X direction is 2.191 mm, along Y direction is 10.051 mm and along Z direction is 0.339 mm. Maximum Displacement in V type of bracing along X direction is 0.339 mm, along Y direction is 0.278 mm and along Z direction is 1.281 mm. Maximum Displacement in Diagonal bracing along X direction is 4.379 mm, along Y direction is 10.339 mm and along Z direction is 7.644 mm. It means that displacement is minimum in V bracing and maximum in diagonal bracing. Maximum Absolute Stresses in X bracing is 9.79 N/mm$^2$ and Maximum Principle Major Stresses in X bracing is 8.12 N/mm$^2$. Maximum Absolute Stresses in V bracing is 9.8 N/mm$^2$ and Maximum Principle Major Stresses in X bracing is 8.12 N/mm$^2$. Maximum Absolute Stresses in Diagonal bracing is 9.69 N/mm$^2$ and Maximum Principle Major Stresses in X bracing is 8.04 N/mm$^2$. It means that stresses are near about same in X bracing and in V bracing. But in diagonal bracing stresses are less as compared to X bracing and V bracing. The displacement is maximum in diagonal bracing but stresses are minimum in diagonal bracing. Whereas X bracing and V bracing gives same performance in maximum absolute stresses and maximum principle major stresses. The sloshing effect of water inside the reservoir is a strange phenomenon but has been captured in this thesis work using STAAD.Pro and this study can become a strong base to avoid the spillage of water from any type of reservoir especially for reservoir trucks carrying liquids from one place to another.

The results under tank full condition shows higher values and such values decreases under tank $^{3}/_{4}$, $^{1}/_{2}$, and $^{1}/_{4}$ condition.

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**References**

[1] I. H. Cho, *"Liquid Sloshing in a Swaying or Rolling Rectangular Tank with a Flexible Porous Elastic Baffle"*, Science Direct, Marine Structures 75, 102865, 2021.

[2] Wen-Huai Tsao and Yuan-Lei Huang, *"Sloshing Force in a Rectangular Rank with Porous Media"*, Science Direct, Results in Engineering 11, 100250, 2021.

[3] Dr. K Naresh, *"Seismic Analysis of Over Head Intze Water Tank Subjected to Sloshing Effect"*, International Journal of Innovative Research in Technology (IJIRT), Volume 6, Issue 3, pp. 105-112, August 2019.

[4] Vinod Sharma, Aamir Mirza Biag, *"A Study of Hydrodynamic Behaviour of Liquid in Overhead Tank as Per IS 1893-Part II (2014)"*, International Journal of Engineering Research & Technology (IJERT), Volume 8, Issue 09, pp. 597-604, September 2019.

[5] Chia-Ren Chu, Yi-Ru Wu, Tso-Ren Wu and Chung-YuWang, "Slosh-induced Hydrodynamic Force in a Water Tank with Multiple Baffles", Science Direct, Ocean Engineering, Volume 167, pp. 282-292, November 2018.

[6] Ratna Kumar Gotru and Dr. P. Ravindra Babu, *"Study of Sloshing Impact on the Tanker Wall for Different Fluids with Varying Accelerations"*, International Journal for Innovative Research in Science & Technology (IJIRST), Volume 4, Issue 2, pp. 10-16, July 2017.

[7] A. C. Chougule, P. A. Chougule and S. A. Patil, *"Study of Seismic Analysis of Water Tank at Ground Level"*, International Research Journal of Engineering and Technology (IRJET), Volume 04, Issue 07, pp. 2895-2900, July 2017.

[8] Akshit Lamba and L. P. Shrivastava, *"Design, Analysis and Optimization of Intze Type Water Tank With Sloshing Effect"*, International Research Journal of Engineering and Technology (IRJET), Volume 04, Issue 06, pp. 236-2370, June 2017.

[9] Eiji Suzuki, *"Effect of Liquid Viscosity on Sloshing in A Rectangular Tank"*, International Journal of Research in Engineering and Science (IJRES), Volume 5, Issue 8, pp. 32-39, August 2017.

[10] Soorya Elizabath G. and Dr. Sheeja Janardhanan, *"Estimation of Structural Strength of Tanks under Sloshing Loads"*, International Journal of Innovative Research in Science, Engineering and Technology, Volume 5, Issue 9, pp. 16037-16050, September 2016.

[11] Gayathri Suja and Dr K Subha, *"Sloshing Behaviour of Water in Water Tanks and Swimming Pools Subjected to Earthquake"*, International Journal of Scientific & Engineering Research, Volume 7, Issue 10, pp. 43-47, October 2016.

[12] Miss. S. A. Patil, Prof. A. H. Kumbhar, Prof. T. F. Mujawar, *"Elevated Water Tank under Sloshing Effect"*, International Journal for Scientific Research & Development (IJSRD), Volume 4, Issue 05, pp. 90-93, 2016.

[13] Dushyant Kumar Sahu, Hina Gupta, Nirendra Dev and Alok Verma, *"A Comparative Analytical and Experimental Analysis of Sloshing Waves in Rectangular Tank Under Seismic Condition"*, International Journal of Research in Engineering and Technology (IJRET), Volume 05, Issue 06, pp. 319-324, June 2016.

[14] Bojja Devadanam, M K M V Ratnam and Dr.U Ranga Raju, *"Effect of Staging Height on the Seismic Performance of RC Elevated Water Tank"*, International Journal of Innovative Research in Science, Engineering and Technology, Volume 4, Issue 1, pp. 18568-18575, January 2015.

[15] P. Muthu Vijay and Amar Prakash, *"Analysis of Sloshing Impact on Overhead Liquid Storage Structures"*, IMPACT: International Journal of Research in Engineering & Technology (IMPACT: IJRET), Volume 2, Issue 8, pp. 127-142, August 2014.

[16] Prof. Wakchaure M. R. and Besekar Sonal S., *"Behaviour of Elevated Water Tank under Sloshing Effect"*, International Journal of Engineering Research & Technology (IJERT), Volume 3, Issue 2, pp. 374-378, February 2014.

[17] Uma Chaduvula, Deepam Patel and N. Gopalakrishnan, *"Fluid-Structure-Soil Interaction Effects on Seismic Behaviour of Elevated Water Tanks"*, Science Direct, Non-Circuit Branches of the 3rd Nirma University International Conference on Engineering (NUiCONE 2012), Procedia Engineering 51, pp. 84 – 91, 2013.

[18] Nauman Mohammed and Islam Nazrul, *"Behaviour of Multistorey RCC Structure with Different Type of Bracing System (A Software Approach)"*, International Journal of Innovative Research in Science, Engineering and Technology, Volume 2, Issue 12, pp.7465-7478, December 2013.

[19] Syed Saif Uddin, *"Seismic Analysis of Liquid Storage Tanks"*, International Journal of Advanced Trends in Computer Science and Engineering, Special Issue of ICACSE 2013 - Held on 7-8 January, 2013 in Lords Institute of Engineering and Technology, Hyderabad, Volume 2, No.1, pp. 357 – 362, 2013.

[20] A. Vakilaad Sarabi & M. Miyajima and K. Murata, *"Study of the Sloshing of Water Reservoirs and Tanks due to Long Period and Long Duration Seismic Motions"*, 15 WCEE, LISBOA 2012.