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# Seismic Evaluation of Base Isolated Overhead Water Storage Tank

**[1]Arfat Rafiq, [2]Mir Tabish Altaf, [3]Shahid Rafeeq, [4]Dr. Mohammad Umair**

*[1]M Tech student, Department of Civil Engineering, Jamia Millia Islamia, New Delhi, India*
*[2] M Tech student, Department of Civil Engineering, Jamia Millia Islamia, New Delhi, India*
*[3] B E student, Department of Civil Engineering, Jadavpur University, Kolkata, India*
*[4]Assistant Professor, Department of Civil Engineering, Jamia Millia Islamia, New Delhi, India*

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**Abstract -** *This paper presents the seismic analysis of reinforced concrete overhead water tank. An overhead water tank is analyzed for seismic zone V as per IS 1893: 2016 using SAP 2000 software. Non-linear time history analysis has been conducted to evaluate the behavior the OWT (Overhead Water Tank) at different water levels under the base fixed condition and base isolated conditions. The main parameters consider in this seismic analysis of OWT are lateral displacement, base shear and time period. From the analysis it is found that the response of the tank depends upon the support conditions, type of the quake, depth of water level in the tank and shows a complex behavior. The tank with fully filled gives maximum displacement in both the cases, maximum base shear and maximum time period. Tank with 75% water gives less displacement as compared to 50% water that is mainly due to strong sloshing effects in case of tank containing 75% water. Base isolation of overhead water tank does not give us rigid body motion of superstructure. There is a large relative displace at the staging levels.*

***Key Words***: OWT (Overhead Water Tank), Earthquake, SAP 2000, Time history analysis, Displacement, Time periods, Base shear.

## 1.INTRODUCTION

Elevated reservoirs are considered important structures that must continue to function as soon as a large earthquake happens, among other reasons to aid in relief operations and stop fires from spreading. The reservoirs are raised by creating a circular shaft or by staging. The columns and horizontal braces of the structural framework used for staging normally transfer the load to the foundation. Reinforced concrete elevated water tanks were proven to perform poorly under jolts of earthquakes. Previous earthquakes damaged the supports of multiple tall water tanks despite their moderate magnitude and large epicentral distances. Because of this, the columns and braces are essential components of such structures and are built to withstand loads from wind and earthquakes.

Expected seismic load is dependent on a number of factors, including the area's seismicity, the kind of soil, the structure's dynamic properties, etc. The structure's natural time period and damping, which have a significant impact on the anticipated seismic load, are its dynamic properties. The seismic code IS: 1893(Part I): 2016 states that more than 60% of India is earthquake-prone. Elevated water tanks' seismic analyses differ from those of other structures in two ways:

(i) Other constructions are not subject to the sloshing effects that occur when the fluid inside the tank exerts hydrodynamic force on the tank walls during seismic excitation.

(ii) Elevated liquid storage tanks require more design seismic forces than other structures because they are less ductile and redundant, necessitating rigorous seismic analysis and exact determination of the design earthquake load.

It has been determined to implement the "Indian Institute of Technology, Kanpur-Gujarat State Disaster Management Act" because the Indian Standard (IS) code for seismic design does not have a provision on the seismic design of OWTs. (IITK-GSDMA 2007) guidelines for the seismic design of overhead liquid storage tanks (Moslemia et al. 2019).

### 1.1 SPRING-MASS IDEALIZATION OF OVERHEAD WATER TANK

The idealized two DOF systems for OWTs with and without water is composed of the impulsive mode and convective mode, as well as a single DOF. There won't be convective mode in the empty tank. Figure 1.4 illustrates the OWT's idealized structural design. When an OWT with enough free surface and water for the entire height is subjected to ground acceleration from an earthquake, the tank wall and water will both be excited horizontally. The water present in the tank's lower container will function as a mass that is rigidly attached to the tank wall during the earthquake excitation. It is known as impulsive mass. The sloshing effects will have an impact on the water in the upper part of the tank, and this mass is known as convective mass. Impulsive hydrodynamic pressure and convective hydrodynamic pressure, respectively, are terms used to describe the hydrodynamic pressure caused by impulsive mass and convective mass. When analyzing the modal behavior of filled tanks, a two-DOF system is split into two single-DOF systems, and the responses of the two systems are computed independently. Using the SRSS combination rule, they are combined to obtain the entire response.

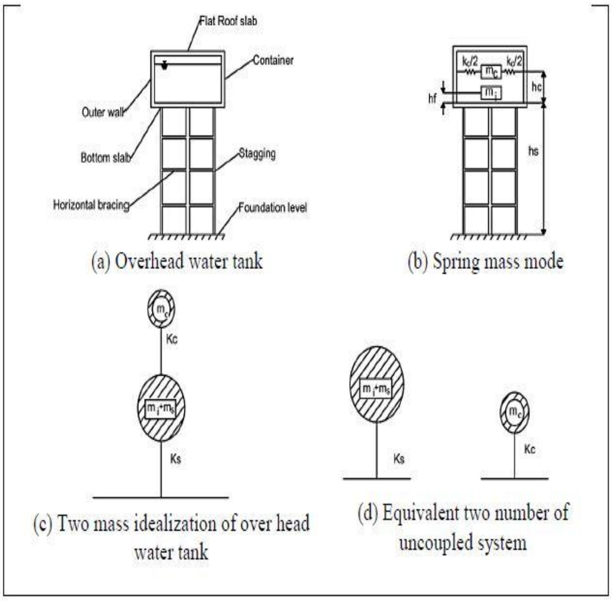



**Figure 1:** Structural idealization of an overhead water filled tank.

## 1.2 BASE ISOLATION

Base isolation systems' principal purpose is to separate the superstructure from the substructure, which is mostly exposed to seismic excitation. As a result, some of the energy that would have been delivered to the superstructure will be lost. The foundation slab's mass and the isolation devices' lateral stiffness must be fixed as necessary. When isolation is offered, displacement at the level of the isolation devices will be extremely high, and the behavior of the superstructure will appear to be that of a rigid body. However, this rigid movement is questionable in the case of a highly elevated water tank since the bulk is concentrated at the top. This study's primary goal is to examine how elevated water tanks function during earthquakes, both with and without base isolation, and how that performance varies over a fundamentally natural time span.

## 2. OBJECTIVES

In the absence of soil structure interaction, an elevated reservoir is modeled as having a fixed base. We'll analyses the elevated reservoir with its fluctuating water level. The finite element approach will be used to analyses the raised storage reservoir because it is the most effective analytical technique currently available. Any combination and type of loading can be analyzed using this method. In light of these realities, the ensuing goals have been proposed. To study the dynamic response of elevated water reservoir.

1. By considering variations in water levels, such as for tank empty condition, 25%, 50%, 75% water levels, and for full tank condition, the elevated reservoir in linked condition (fixed base) will be analyzed for a Bhuj earthquake using SAP2000.
2. In order to determine the seismic behavior under all the aforementioned situations, SAP2000 will also be used to analyze the elevated reservoir in an uncoupled condition (base isolated using a rubber base isolator).

In order to compare the maximum base shear, maximum displacement, relative displacement, and time for all the aforementioned examples in both coupled and decoupled settings.

## 3. STRUCTURAL MODELLING AND ANALYSIS

**Table -1:** Dimensions of Elevated Reservoir

| | |
|---|---|
| Capacity ($m^3$) | 9000$m^3$ |
| Total height of tank(m) | 29m |
| Diameter of tank vessel(m) | 12m |
| Depth of vessel(m) | 8m |
| Diameter at bottom of vessel(m) | 8.60m |
| Diameter at ground level(m) | 11.00m |

**Table -2:** Height of Staging Beams w.r.t Ground Level.

| Components | Height w.r.t ground (m) |
|---|---|
| Staging beam 1 | 5 |
| Staging beam2 | 10 |
| Staging beam 3 | 15 |
| Top ring beam | 20 |

**Table -3:** Member Properties

| | |
|---|---|
| Column | 700mmx700mm |
| Staging beams | 600mmx500mm |
| Top ring beam | 600mmx400mm |
| Top container dimensions | |
| Top slab thickness | 200mm |
| Bottom slab thickness | 250mm |
| Thickness of wall of vessel | 250mm |

**Table -4:** Seismic Properties

| Properties | Values |
|---|---|
| Seismic Zone | V |
| Zone factor | 0.36 |
| Soil type | II |
| Response reduction factor | 2.5 |
| Importance factor | 1.5 |

**Table -5:** Material Properties

| | |
|---|---|
| Grade of concrete | M30 &M25 |
| Grade of Rebar | Fe550, Fe500 |

**Table -6:** Properties of Isolator

| | |
|---|---|
| Type of isolator | Lead Rubber Bearing (LRB) |
| Effective Stiffness in vertical direction (U1) | 18073.750 N/m |
| Effective stiffness in lateral direction (U2) | 1087.157 N/m |
| For Nonlinear Analysis | |
| Stiffness (each column) | 5561.2N/m |
| Yield strength | 54004.6N |

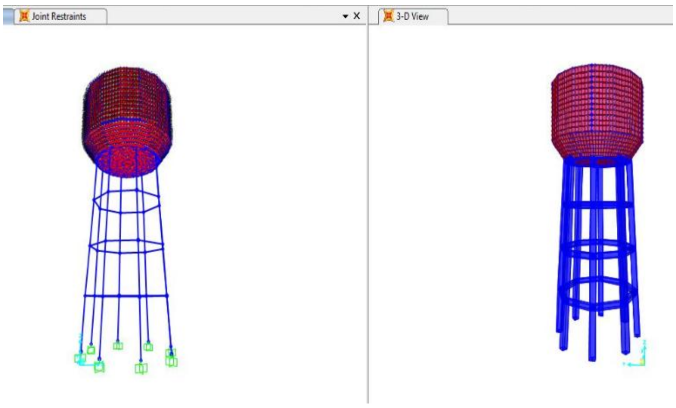



**Figure 2:** Model of overhead water tank with base Fixed

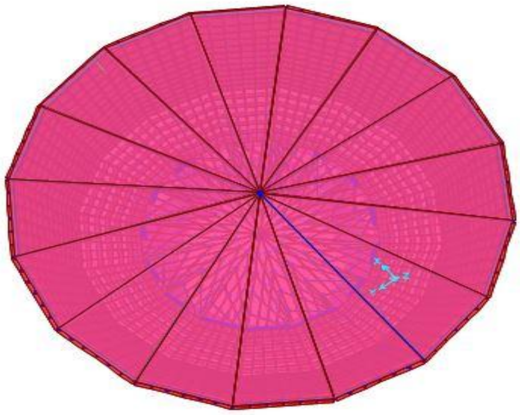


**Figure 3:** Plan of overhead water tank.

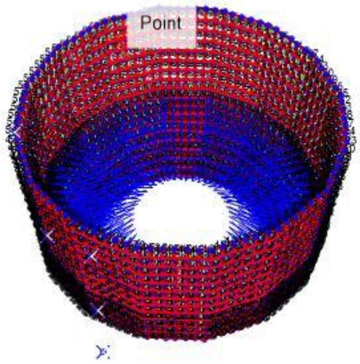



**Figure 4:** Assigning water pressure(25%full)

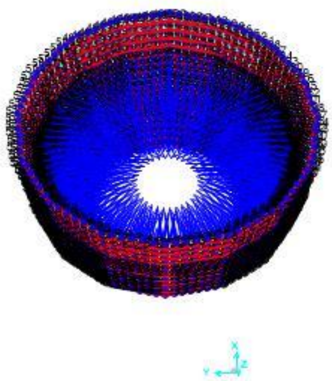


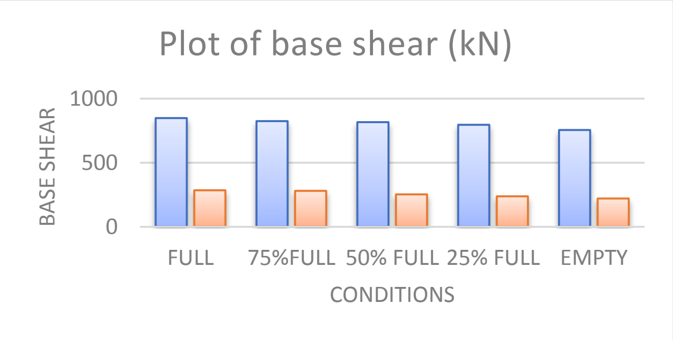
**Figure 5:** Assigning water pressure(75%full)

## 4.STRUCTURAL MODELLING AND ANALYSIS

### 4.1 BASE SHEAR (kN)

**Table -7:** Maximum Base shear in X-Direction

| Base shear (KN) | FULL | 75% FULL | 50% FULL | 25% FULL | EMPTY |
|---|---|---|---|---|---|
| FIXED | 847.6 | 823.9 | 815.9 | 795.3 | 754.7 |
| ISOLATED | 284.2 | 279.8 | 252.1 | 236.9 | 220.0 |




**Graph1:** Plot between base shear and water level in tank

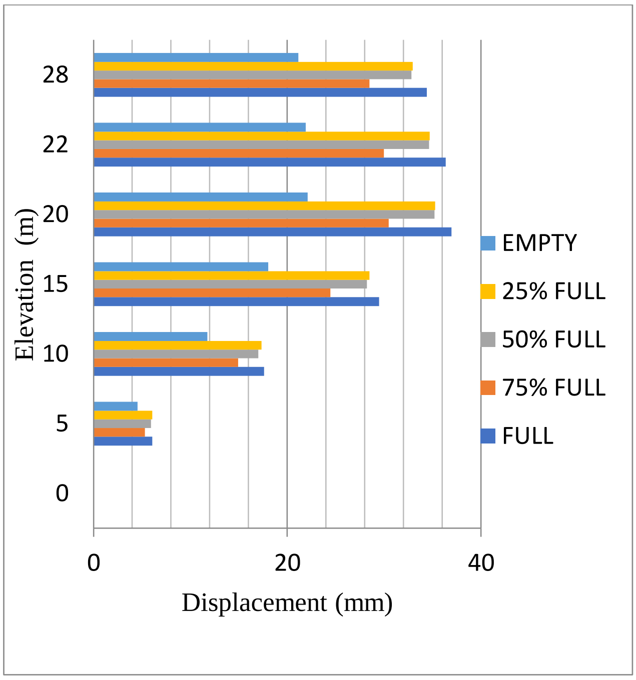
### 4.2 MAXIMUM DISPLACEMENT (mm)

#### 4.2.1 Base fixed

Maximum displacement is the measurement of the lateral displacement that can occur along an elevation when a lateral load is applied. Time history analysis is used to determine the elevated tank's maximum displacement in the X direction.

**Table -8:** Maximum displacement in the X direction

| Joint no. | Elevation m | Full mm | 75% full mm | 50% full mm | 25% full mm | Empty mm |
|---|---|---|---|---|---|---|
| 4 | 28 | 34.4 | 28.5 | 32.8 | 32.9 | 21.2 |
| 3 | 22 | 36.4 | 29.9 | 34.6 | 34.7 | 21.9 |
| 2 | 20 | 36.9 | 30.5 | 35.2 | 35.2 | 22.1 |
| 190 | 15 | 29.5 | 24.5 | 28.2 | 28.5 | 18.1 |
| 182 | 10 | 17.6 | 14.9 | 17.1 | 17.3 | 11.7 |
| 174 | 5 | 6.1 | 5.3 | 5.9 | 6.1 | 4.5 |
| 1 | 0 | 0 | 0 | 0 | 0 | 0 |

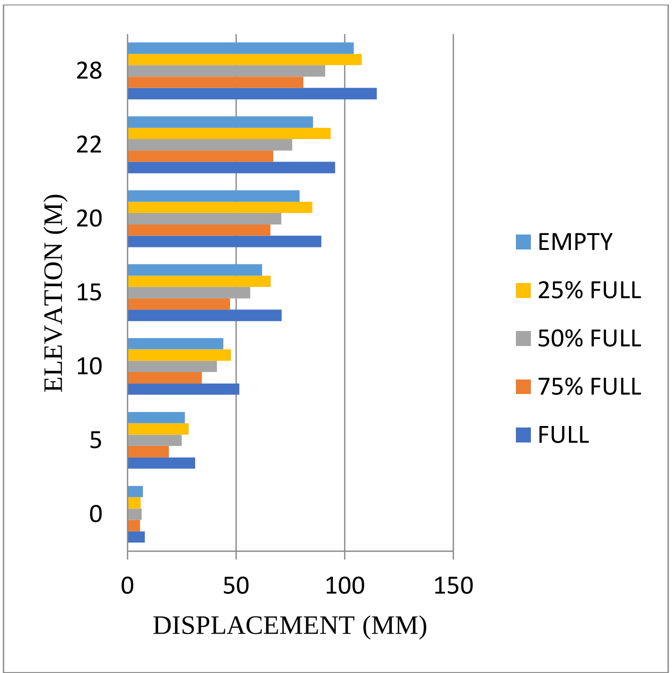



**Graph 2:** Plot of Maximum Lateral Displacements (mm) versus elevations

#### 4.2.2 Base Isolated

**Table -9:** Maximum displacement in the X direction

| Joint no. | Elevation (m) | Full mm | 75% full mm | 50% full mm | 25% full mm | Empty mm |
|---|---|---|---|---|---|---|
| 4 | 28 | 114.8 | 81.1 | 91.3 | 107.8 | 104.1 |
| 3 | 22 | 95.6 | 67.2 | 75.9 | 93.6 | 85.4 |
| 2 | 20 | 89.3 | 65.7 | 70.9 | 85.1 | 79.2 |
| 190 | 15 | 70.9 | 47.2 | 56.5 | 65.9 | 61.9 |
| 182 | 10 | 51.5 | 34.2 | 41.2 | 47.6 | 44.1 |
| 174 | 5 | 31.1 | 19.1 | 25.1 | 28.2 | 26.4 |
| 1 | 0 | 8.0 | 5.7 | 6.9 | 6.0 | 7.1 |



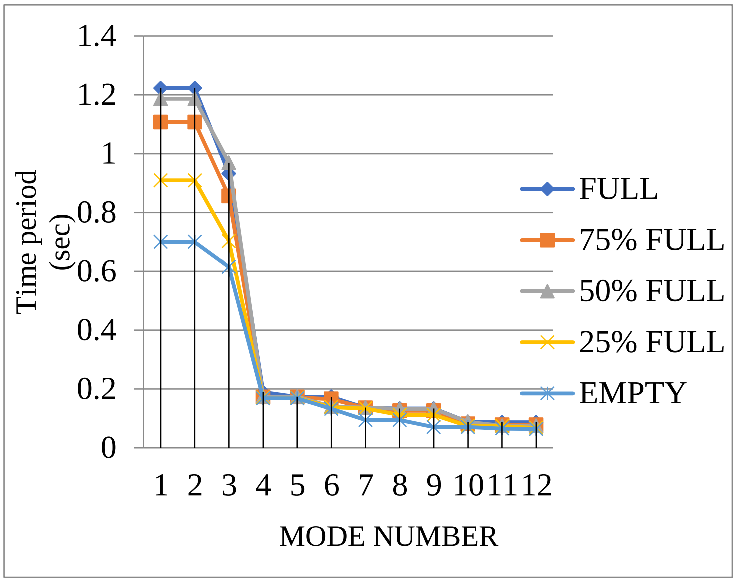

**Graph 3:** Plot of Maximum Lateral Displacements (mm) versus elevations

## 4.3 TIME PERIOD (mm)

### 4.3.1 Base Fixed

**Table -10:** Time period (sec) for fixed base at different filled conditions

| MODE SHAPES | FULL | 75% FULL | 50% FULL | 25% FULL | EMPTY |
|---|---|---|---|---|---|
| 1 | 1.222367 | 1.106954 | 1.186606 | 0.909437 | 0.699998 |
| 2 | 1.222367 | 1.106954 | 1.186606 | 0.909437 | 0.699998 |
| 3 | 0.932209 | 0.85528 | 0.969135 | 0.702328 | 0.614996 |
| 4 | 0.18888 | 0.172141 | 0.174282 | 0.169879 | 0.16821 |
| 5 | 0.173292 | 0.172125 | 0.174266 | 0.169863 | 0.168194 |
| 6 | 0.173276 | 0.165701 | 0.140213 | 0.13839 | 0.13259 |
| 7 | 0.136432 | 0.135877 | 0.136656 | 0.134185 | 0.094457 |
| 8 | 0.133322 | 0.125749 | 0.132711 | 0.111601 | 0.094453 |
| 9 | 0.133307 | 0.125748 | 0.132697 | 0.111597 | 0.070637 |
| 10 | 0.088029 | 0.08056 | 0.088308 | 0.074178 | 0.070541 |
| 11 | 0.086878 | 0.07797 | 0.074685 | 0.07412 | 0.065851 |
| 12 | 0.086877 | 0.077957 | 0.074625 | 0.067512 | 0.063705 |

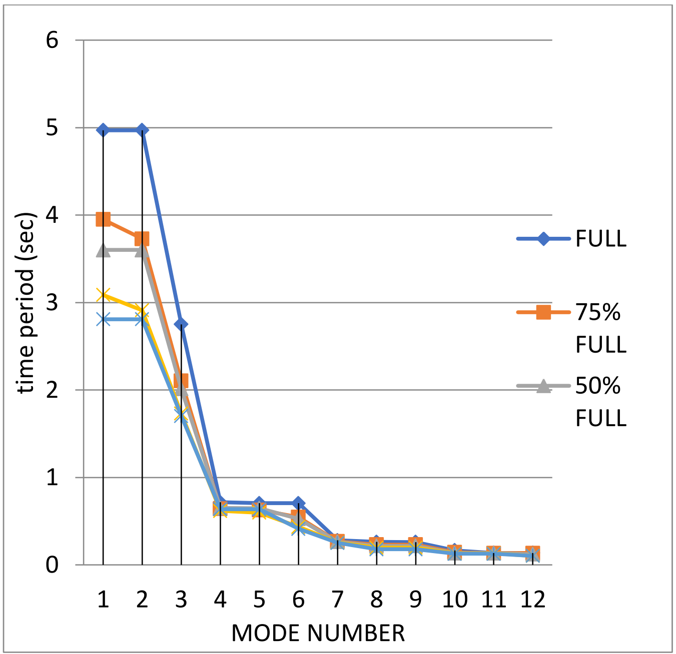



**Graph 4:** Time period of base fixed elevated water tank

### 4.3.2 Base Isolated

**Table -11:** Time period (sec) for base isolated tank at different filled conditions

| MODE SHAPES | FULL | 75% FULL | 50% FULL | 25% FULL | EMPTY |
|---|---|---|---|---|---|
| 1 | 4.969896 | 3.949627 | 3.601914 | 3.08715 | 2.809277 |
| 2 | 4.96971 | 3.729102 | 3.601657 | 2.912267 | 2.808933 |
| 3 | 2.751693 | 2.104742 | 2.012307 | 1.731251 | 1.704274 |
| 4 | 0.717368 | 0.642221 | 0.650298 | 0.618473 | 0.637443 |
| 5 | 0.705939 | 0.628704 | 0.64931 | 0.598503 | 0.636513 |
| 6 | 0.704874 | 0.546941 | 0.528231 | 0.435632 | 0.413725 |
| 7 | 0.281336 | 0.268785 | 0.265608 | 0.255758 | 0.252149 |
| 8 | 0.263346 | 0.232845 | 0.218478 | 0.197491 | 0.178578 |
| 9 | 0.262277 | 0.231853 | 0.218435 | 0.196742 | 0.178486 |
| 10 | 0.166644 | 0.143799 | 0.13506 | 0.132462 | 0.127978 |
| 11 | 0.136909 | 0.135149 | 0.134634 | 0.131706 | 0.127385 |
| 12 | 0.136502 | 0.134812 | 0.122312 | 0.10436 | 0.104484 |




**Graph 5:** Time period of base isolated elevated water tank

## 3. CONCLUSIONS

Utilizing the technique of Time history Analysis, the seismic performances of OWTs subjected to the Bhuj earthquake have been examined. Different seismic reaction characteristics, such as base shear, maximum displacement, time period, etc., were considered. The resulting results are as follows, which are presented.

- In the case of the basic fixed condition, the time period is maximum for a fully filled above water tank and asynchronous for other circumstances, such as when the tank is only 75% full. This may be mostly because the 75% full tank has severe sloshing effects.
- When compared to a base fixed elevated reservoir, the time period is longer in the case of a base separated overhead water tank. The time period likewise grows with the depth of the water level in the base-isolated elevated water tank.
- In the case of a base-fixed elevated reservoir, the base shear rises with tank depth; it is maximum for fully filled tanks and minimum for empty ones.
- Although the base shear can be reduced by utilizing a base isolator, the behavior is still comparable to that of a base-fixed elevated reservoir, i.e., maximal for a fully filled state and decreasing with a drop in the tank's water level.
- In the case of a fixed support system, the location where the supporting system joins the container experiences the most displacement.
- In the case of a base-isolated overhead water tank, the system's greatest displacement occurs at the roof level, with maximum displacement occurring in the full condition and decreasing percentages of 25%, 50%, and 75% in that order.
- No stiff body movement was seen in the base isolated OWT under earthquake excitation.

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## BIOGRAPHIES

**ARFAT RAFIQ**,
MTech (Earthquake Engineering)
Dept. of Civil Engineering,
Jamia Millia Islamia, New Delhi.


**MIR TABISH ALTAF**,
MTech (Earthquake Engineering)
Dept. of Civil Engineering,
Jamia Millia Islamia, New Delhi.

**SHAHID RAFEEQ**,
B E (Civil Engineering)
Dept. of Civil Engineering,
Jadavpur university, Kolkata.

**DR. MOHAMMAD UMAIR**,
Assistant Professor
Dept. of Civil Engineering,
Jamia Millia Islamia, New Delhi.