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# SEISMIC ANALYSIS OF RCC ELEVATED LIQUID STORAGE TANK WITH DIFFERENT SUPPORTING SYSTEMS AND THEIR BEHAVIOUR IN VARIOUS EARTHQUAKE ZONES

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**ABSTRACT**
As we know from past records, many of reinforced concrete elevated water tanks were heavily damages or collapsed during the earthquakes all over the world. General observations are pointing out the reasons towards the failure of supporting system which reveals that the supporting system of the elevated tanks has more critical importance than the other structural parts of tanks. Most of the damages observed during the seismic events arise was might be due to the lack of knowledge regarding the proper behaviour of supporting system of the tank against dynamic effect and due to improper geometrical selection of supporting/staging patterns. The main objective of this study is to understand the behaviour of supporting system which is more effective under different earthquake characteristics or earthquake zones with STAAD.Pro V8i software. A sample of a reinforced concrete elevated water tank (Intz type), with 900 cubic meters and with a height of 18m from ground level is considered. Here two different staging patterns such as radial bracing and cross bracing are compared with basic supporting system for various fluid filling conditions. The seismic zones of Zone-III & Zone-V and the corresponding earthquake characteristics have been taken from IS 1893 (PART 1)-2002 & draft code IS 1893 (Part 2). Consequently, the water mass has been considered in two parts as impulsive and convective suggested by GSDMA guidelines. Tank responses including base shear, overturning moment and roof displacement have been observed, and then the results have been compared. The result shows that the structure responses are exceedingly influenced by the presence of water and the earthquake characteristics. Finally, study discloses the importance of suitable staging configuration to remain withstands against heavy damage or failure of elevated water tank during seismic events.

## 1.0 INTRODUCTION

The term ‘Liquid storage tank’ refers to distinctive liquid retaining structure. Many new ideas and innovation have been made for the storage of water and other liquid materials in different forms and fashions. Water is human basic needs for daily life. Sufficient water distribution depends on design of a water tank in certain area. Water tank has been developed about 80 years ago and recognized as well-designed, efficient, and economical unit for commercial as well as residential use. Also, it is inevitable part of water supply system, and extensively used for storage and processing of variety of liquid like material such as water, petroleum product, liquefied natural gas, chemical fluid, and wastage of different forms. Thus, Water tanks are very important for public utility and for industrial structure.

### Elevated water tank, and Earthquake Influence

Water supply is a lifeline facility that must remain functional following disaster. Most municipalities in India have water supply system which depends on elevated tanks for storage. Elevated water tank is a large elevated water storage container constructed for the purpose of holding a water supply at a height sufficient to pressurize a water distribution system. In major cities the main supply scheme is augmented by individual supply systems of institutions and industrial estates for which elevated tanks are an integral part. Elevated water storage tanks features to look for are strength and durability, and of course leakages can be avoided by identifying good construction practices.

**Significance and Scope of present Study**

The study of damage histories revealed damage/failure of reinforced concrete elevated water tanks of low to high capacity. Investigating the effects of earthquakes has been recognized as a necessary step to understand the natural hazards and its risk to the society in the long run. Most water supply systems in developing countries, such as India, depend on reinforced cement concrete elevated water tanks. The strength of these tanks against lateral forces, such as those caused by earthquakes, needs special attention. It is particularly important to analyse reinforced cement concrete elevated water tank properly. The elevated tanks are frequently used in seismic active regions also hence seismic behaviour of them must be investigated in detail. Due to the lack of knowledge of supporting system some of the water tank were collapsed or heavily damages. So, there is need to focus on seismic safety of lifeline structure using with respect to alternate supporting system which are safe during earthquake and take more design forces. Therefore, the present study is to identify the behaviour of elevated water tank under different acceleration time history or earthquake characteristics with consideration and modelling of impulsive and convective water masses inside the container using FEM structural software STAAD.Pro V8i.

**Objectives:**

The main objective of this study is to understand the behaviour of supporting system of Elevated liquid storage tanks, which is more effective under different earthquake characteristics or earthquake zones as per draft code of IS 1893 (Part 2) and GSDMA guidelines.

A reinforced concrete elevated water tank, (Intz type) with 900 cubic meters and with a staging height of 18m and 22.35m from ground level is considered. Here two different supporting systems such as radial bracing and cross bracing are compared with basic supporting system for various fluid filling conditions. The seismic zones of Zone-III & Zone-V and the corresponding earthquake characteristics have been taken from IS 1893 (Part 1)-2002 & draft code IS 1893 (Part-2).

The main objectives of the present study are

- To analyse the stiffness of staging for Basic, Radial, Cross type bracings of elevated water tanks in Earthquake zones of Zone-III & Zone-V as per IS: 1893 Part-2 draft codal guide lines by using Staad.Pro.V8i.
- To evaluate the Base shear at the bottom of the staging in impulsive mode and convective mode and the total lateral base shear as per IS: 1893 Part-2 draft codal guidelines.
- To evaluate the total overturning moment at the bottom of the staging in impulsive mode and convective mode and the total overturning moment as per IS: 1893 Part-2 draft codal guidelines.
- To analyse the Roof displacement for Basic, Radial, cross type bracings of elevated water tanks in Earthquake zones of Zone-III & Zone-V
- A comparative study between supporting systems of Basic, Radial, Cross type bracings in terms of Stiffness, Base shear, Base moment, and Roof displacements in two earthquake zones Zone-III & Zone-V.

## 2.0 LITERATURE REVIEW:

The term ‘Elevated liquid storage tanks” generally refers to distinctive liquid retaining structure. It has been developed about 80 years ago and recognized as well-designed, efficient, and economical unit for commercial as well as residential use. Also, it is inevitable part of water supply system, and extensively used for storage and processing of variety of liquid like material such as water, petroleum product, liquefied natural gas, chemical fluid, and wastage of different forms.

**Chirag N. Patel and H. S. Patel (India, 2012)** have investigated on behaviour and suitability of supporting system of reinforced concrete elevated/overhead tanks during vulnerable force events like earthquake with some unusual alteration. General observations are pointing out the reasons towards the failure of supporting system which reveals that the supporting system of the elevated tanks has more critical importance than the other structural types of tanks.

**Ayazhussain M. Jabar and H. S. Patel (India, 2012)** have investigated the behaviour of supporting system which is more effective under different earthquake time history records with SAP 2000 software. Here two different supporting systems such as radial bracing and cross bracing are compared with basic supporting system for various fluid level conditions. Tank responses including base shear, overturning moment and roof displacement have been observed, and then the results have been compared and contrasted. The result shows that the structure responses are exceedingly influenced by the presence of water and the earthquake characteristics.

**F. Omidinasab and H. Shakib (China, 2008)** have researched, a sample of a reinforced concrete elevated water tank, with 900 cube meters under seven earthquake records have been studied and analyzed in dynamic time history and the tank’s responses including base shear, overturning moment, tank displacement, and sloshing displacement under these seven record have been calculated, and then the results have been compared and contrasted.

**H. Shakib, F. Omidinasab and M.T. Ahmadi (Iran, 2010)** have investigated, the seismic demands of the elevated water tanks were determined using the nonlinear time history analysis. Three reinforced concrete elevated water tanks, with a capacity of 900 cubic meters and height of 25, 32 and 39 m were subjected to an ensemble of earthquake records. The behavior of concrete material was assumed to be nonlinear Seismic demand of the elevated water tanks for a wide range of structural characteristics was assessed.

## 3.0 RCC ELEVATED WATER TANKS & SEISMIC ANALYSIS

Classification of Elevated Water tanks

The most common types of elevated water tanks are,

- Circular tank
- Intz type tank
- Conical or funnel shaped tank.

**Circular tank:**

Circular tanks with a horizontal or flat floor slab is economical for smaller storage capacity of up to 200,000 litres and with diameters in the range of 5 to 8 m. The depth of storage is generally between 3 to 4 m. The side walls are designed for circumferential hoop tension and bending moment since the walls are fixed to the floor slab at the junction. The circular floor slab of the tank is designed for circumferential and radial moments developed in the slab.

**Figure: 3.1 Circular tank**

**Intz type tank:**

**Figure: 3.2 Intz type tank**

In the case of large diameter elevated circular tanks, thicker floor slabs are required resulting in uneconomical designs. In such cases, Intz type tank with conical and bottom spherical domes provides an economical solution, The proportions of the conical and the spherical bottom domes are selected so that the outward thrust from the bottom dome Balances the inward thrust due to the conical domed part of the tank floor.

**Conical or funnel shaped tank:**

Conical or funnel shaped elevated water tanks are often preferred to other shapes mainly due to their aesthetic and superior architectural features in comparison with other types of elevated water tanks. For supporting towers higher than 25 m, reinforced concrete cylindrical shells are economical and can be rapidly constructed using the slip form process of casting. The conical shell walls are sloping at 45° to the horizontal and the thickness of the walls gradually increased towards the bottom of the tank and designed for hoop tension and meridional thrust. The top and bottom ring beams are designed for hoop tension. The supporting cylindrical shell tower is designed for combined thrust and bending due to wind and seismic forces. A rigid raft slab foundation is provided to support the shaft.

**Figure: 3.3 Conical shape tank**

**Seismic Analysis Procedure**

When a tank containing liquid vibrates, the liquid exerts impulsive and convective hydrodynamic pressure on the tank wall and the tank base in addition to the hydrostatic pressure. In order to include the effect of hydrodynamic pressure in the analysis, tank can be idealized by an equivalent two mass model, which includes the effect of tank wall – liquid interaction. The parameters of this model depend on geometry of the tank and its flexibility. These hydrodynamic forces are evaluated with the help of two mass model of tank

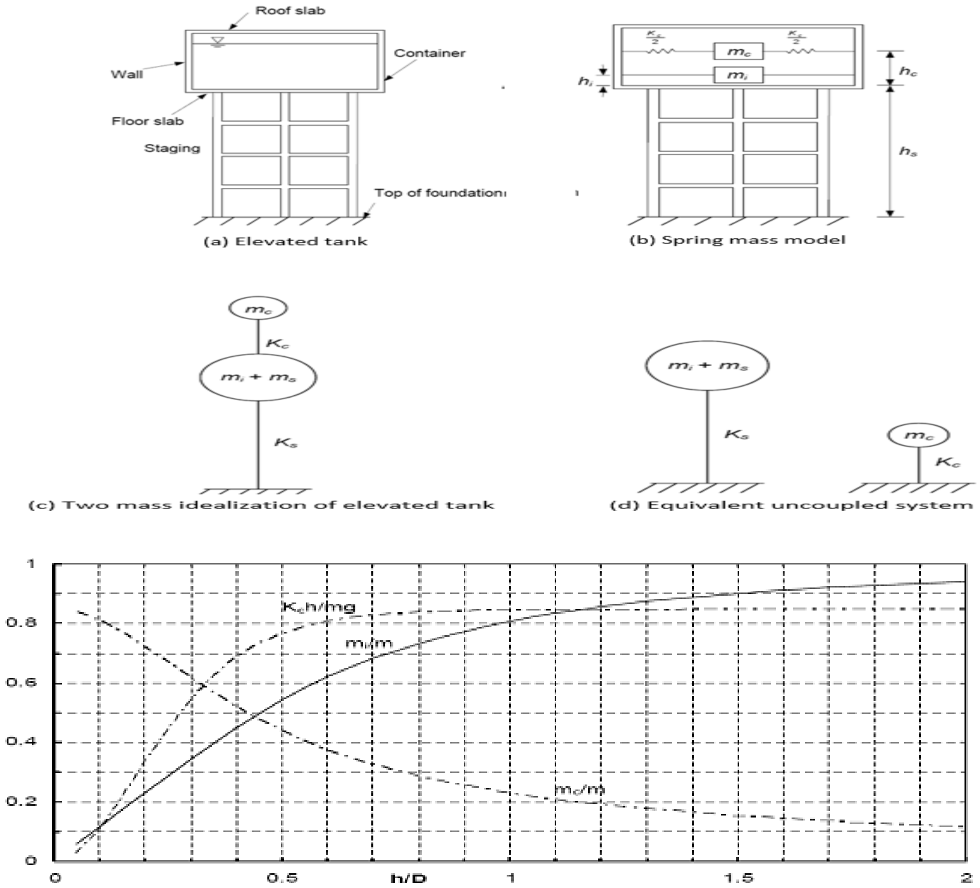


**Figure: 3.4 Two mass idealization for elevated tank**

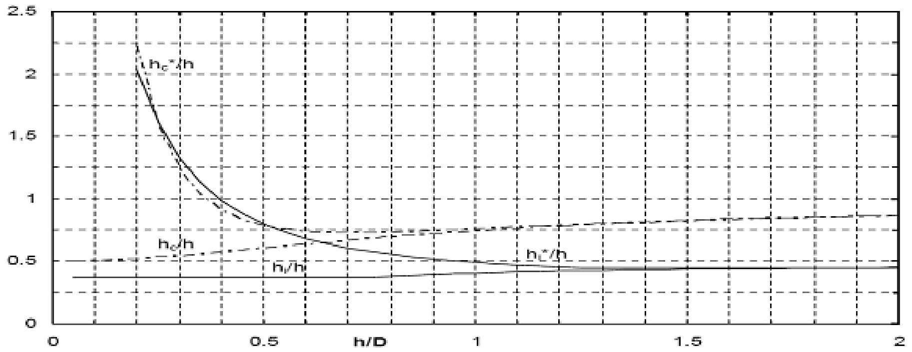


**Figure: 3.5 Parameters of the spring mass model for circular tank**

For tank shapes other than circular and rectangular (like Intz, Truncated conical shape), the value of h /D shall correspond to that of an equivalent circular tank of same volume and diameter equal to diameter of tank at top level of liquid; and *mi*, *mc*, *hi*, *hi**, *hc*, *hc** and *Kc* of equivalent circular tank shall be used.

**Lateral stiffness of Staging**

Lateral stiffness of the staging is the horizontal force required to be applied at the CG (center of gravity) of the tank to cause a corresponding unit horizontal displacement. In this study, CG of tank is taken as CG of empty container. Finite element software is used to model the staging is shown in Figure: Since container portion is quite rigid, a rigid link is assumed from top of staging to the CG of tank. From this analysis horizontal displacement of CG of tank due to an arbitrary 10 kN force is obtained.

Thus, lateral stiffness of staging, *Ks* = 10 / Displacement.

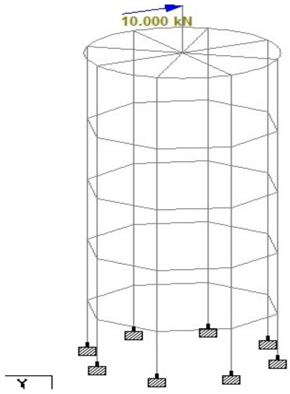


**Figure 3.6 Stadd model of staging**

Time periods

Time periods for the Impulsive and Convective modes can be calculated by using the following expressions. Time period of Impulsive mode, $T_i$ in seconds, is given by

$$T_i = 2\pi\sqrt{\frac{m_i + m_s}{K_s}}$$

where

$m_i$ = Impulsive mass of the liquid, (can be obtained from Fig. 3.5a)

$m_s$ = mass of container plus one-third mass of staging, and

Ks = lateral stiffness of staging.

Time period of Convective mode, $T_c$ in seconds, is given by

$$T_c = 2\pi\sqrt{\frac{m_c}{K_c}}$$

where

Kc = Spring stiffness of convective mode, and

$m_c$ = Convective mass of the liquid.

## 4.0 MODEL DESCRIPTION, STAGING PATTERNS & SEISIMIC ZONES

4.1.1. Geometric Data

An Intz type Elevated water tank is considered for analysis.

| | | | |
|---|---|---|---|
| Capacity of water tank | = | 900 | cu.m |
| Height of staging | = | 18 | m |
| Diameter of the Cylindrical Portion (D1) | = | 14 | m |
| Height of water in the Cylindrical Portion (h1) | = | 4.8 | m |
| Height of the Conical Portion (h2) | = | 2 | m |
| Diameter of the tank at base of Conical portion (D2) | = | 10 | m |

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| | | | |
|---|---|---|---|
| Height of the Bottom Dome (h3) | = | 1.4 | m |
| Radius of Bottom Dome (R1) | = | 9.63 | m |
| Height of the Top Dome (h4) | = | 1.8 | m |
| Radius of Top Dome (R2) | = | 14.51 | m |
| Cylindrical Wall Thickness | = | 250 | mm |
| Conical slab Thickness | = | 350 | mm |
| Thickness of Bottom Dome | = | 250 | mm |
| Thickness of Top Dome | = | 125 | mm |
| Ring Beams at Bottom slab level | = | 500 | X 1000 mm |
| Column size | = | 500 | X 500 mm |
| Brace Beams | = | 300 | X 500 mm |
| Ring Beams at Top slab level | = | 250 | X 450 mm |

**Material Properties**

| | | |
|---|---|---|
| Grade of Concrete (fck) | = | M30 |
| Poisson's Ratio (μ) | = | 0.17 |
| Damping | = | 5% |
| Grade of steel (fy) | = | FE-415 (i.e., fy = 415 N/mm2) |

## Staging Patterns

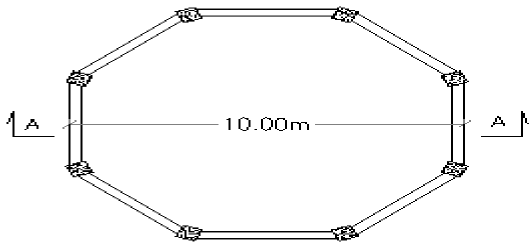


**Figure 4.1: basic bracing**

## Finite Element Model of Elevated Water tank

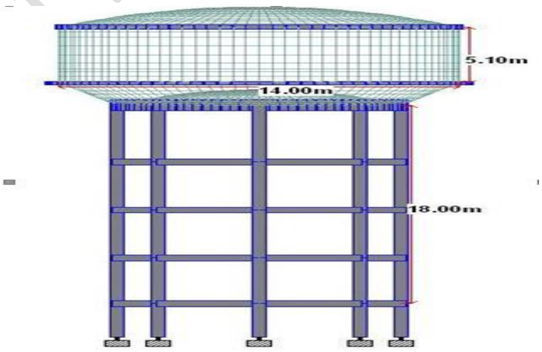


**Figure: 4.2 FEM Model of Elevated Water tank**

Finite element modelling procedure is adopted for analysis and finite element model is prepared in Staad Pro V8i software by using members and plane elements. The Figure: 4.4 shows the Columns, bracing beams, floor beams and finite element mesh generated to model tank portion. The diameter of the staging is 10m and height staging is 18m and 22.35m. The bottom dome, conical slab, side wall and top dome are modelled in staad pro with 4 noded plate elements.

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**Finite element model of different staging patterns**

The staad FEM modelling for Basic, Cross and Radial bracing staging patterns are shown in Figures:

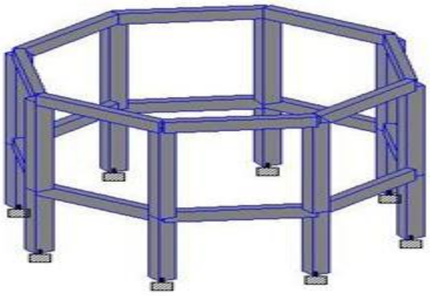

**Figure: 4.3 FEM Model of Basic staging pattern**

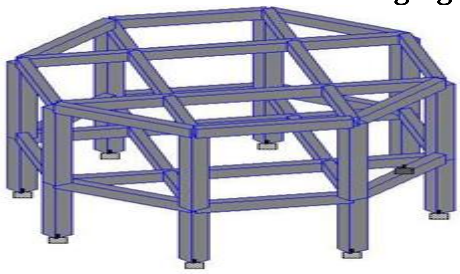

**Figure: 4.4 FEM Model of Cross bracing staging patterns**

## 5.0 ANALYSIS OF SATGINGS AND DISCUSSIONS ON RESULTS

In this present study, the behaviour of supporting system under different earthquake characteristics for an elevated water tank is described in two cases.

- Elevated water tank of capacity 900 cu.m with the Staging height of 18m.
- Elevated water tank of capacity 900 cu.m with the Staging height of 22.35m.

The above two cases are analysed in two Earthquake zones (Zone III & Zone V). Here two different staging patterns such as radial bracing and cross bracing are compared with basic supporting system for various fluid filling conditions. The seismic zones of Zone-III & Zone-V and the corresponding earthquake characteristics have been taken from IS 1893 (PART 1)-2002 & draft code IS 1893 (Part Consequently the water mass has been considered in two parts as impulsive and convective masses. In this analysis the elevated water tank is modelled in Staad pro V8i, to find out lateral stiffness of staging, Roof displacements and to compare the seismic forces on the tank in Tank full, Tank half and Tank full conditions.

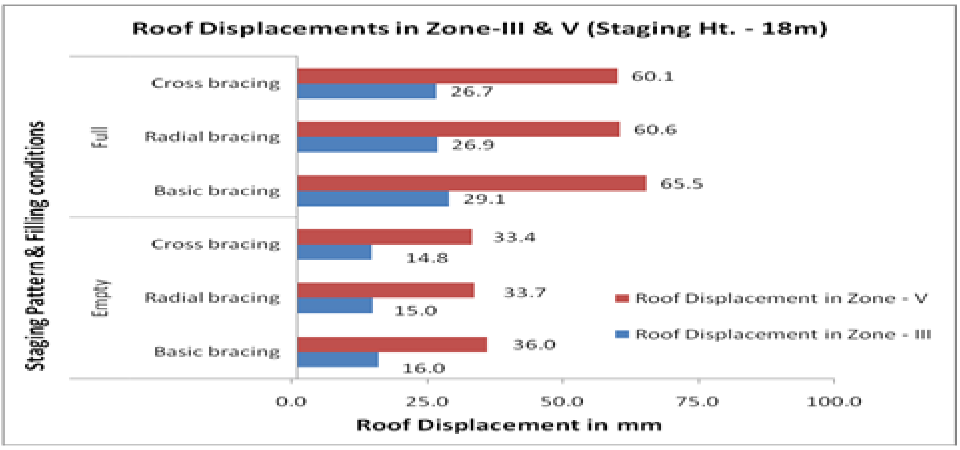


**Figure: Comparison of Roof Displacement in Zone- III & V (Height -18m)**

The Figure shows the comparison of Roof displacement versus the type of staging patterns and the various tank filling conditions for Zone-III and Zone-V. The Roof displacement of Radial and Cross bracing have decreased by 8% and 9% respectively compared to basic type staging pattern in two zones, Zone-III and Zone-V. Tank full condition is the severest condition for Roof displacements.
The Figure the comparison of Roof displacement versus the type of staging patterns and the various tank filling conditions in Zone-V. The Roof displacement of Cross bracing have decreased by 9% compared to basic type staging pattern in 5bays and 6bays of bracing. The Roof displacement for Cross bracing (6 bays) is decreased by 19% compared to 5 bays of bracing in basic pattern.

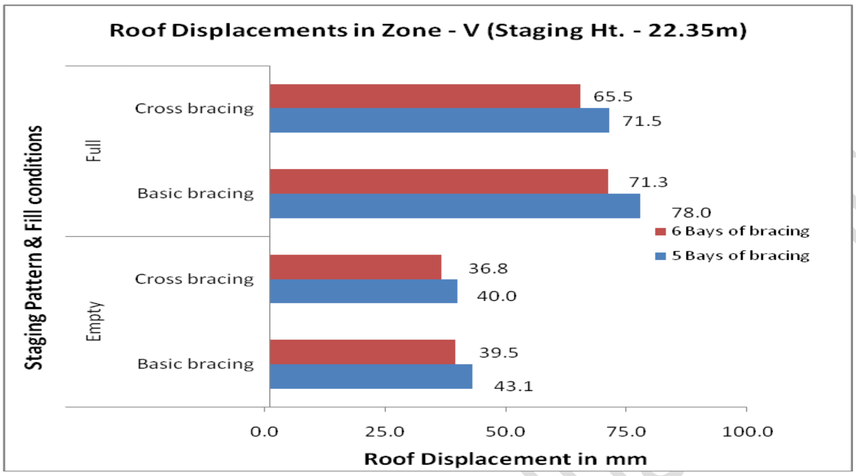


**Figure: Comparison of Roof Displacement in Zone- V (Height - 22.35m)**

As per the GSDMA guidelines to the IS 1893 (Part-2) draft code, P-delta effect could be significant in elevated tanks with tall staging. P-delta effect can be minimized by restricting total lateral deflection to h/500, where is height of tank. Hence the roof displacements are within the limits in Case study-2 for cross bracing type with the 6 bays of modified bracing beam sizes. It is observed that, the minimum value of staging stiffness shall not be less than 11013kN/m to make roof displacements within the allowable limits.

## CONCLUSIONS

The above study demonstrates the considerable change in seismic behavior of elevated tanks with consideration of responses like stiffness, base shear, base moment, displacement etc. when supporting system is used with appropriate modifications. Finally, study discloses the importance of suitable supporting configuration to remain withstand against heavy damage/failure of elevated water tanks during seismic events.

- Earthquake characteristics in two different zones, which cause excitation of responses such as base shear force, overturning moment and roof displacement, are compared and following conclusions are obtained.
- In Zone-V for the same Case study-1 of ESR with 18m height of staging, the roof displacements for Basic (65mm), Radial (61mm) and Cross (60mm) type of bracings are exceeding the limiting value (54mm). Hence, an increase in number bays from 4 to 5nos, it is observed that, the roof displacements are within the allowable limit. (Basic=53mm,
- In Case study-1 & 2 the Base shear and Base moments are higher in Radial and Cross bracing type compared to the Basic type of bracing which will affect the reinforcement design of staging members.

**Future Scope:**

As per the above case studies, frame type staging with a single row of columns placed along the tank periphery, are suitable for low to medium range of storage capacities. For higher capacities this configuration may not be adequate. Hence alternate innovative configurations of staging patterns (2 rows, 3 rows of columns) are required to be put in practice for better performance during earthquakes.

**REFENCES:**

1. Chirag N. Patel, Shashi N. Vaghela, H. S. Patel (2012). "Sloshing Response of Elevated Water Tank over alternate column proportionality", *International Journal of Advanced Engineering Technology*, IJAERS, Vol.III, Issue IV, Oct.-Dec., 60-63.
2. Durgesh C Rai (2003). "Performance of elevated tanks in $M_w$ 7.7 Bhuj earthquake of January 26th, 2001". *Department of Civil Engineering, IIT Kanpur*, 112, No. 3, pp. 421-429.
3. F. Omidinasab and H. Shakib (2008). "Seismic Vulnerability of Elevated Water Tanks Using Performance Based-Design", *The 14th World conference on Earthquake Engineering*, October 12-17.
4. George W. Housner (1963). "The Dynamic behaviour of Water Tanks", Bulletin *of the Seismological Society of America*, Vol. 53, No. 2, pp. 381-387.
5. H. Shakib, F. Omidinasab and M.T. Ahmadi (2010). "Seismic Demand Evaluation of Elevated Reinforce Concrete Water tanks", *International Journal of Advanced Engineering Research and Studies*, Vol. 8, No. 3.
6. Konstantin Meskouris, Britta Holtschoppen, Christoph Butenweg, Julia Rosin (2011). "Seismic analysis of Liquid storage tanks", *2nd INQUA-IGCP-567 International Workshop on Active Tectonics, Earthquake Geology, Archaeology and Engineering*, Corinth, Greece.