Seismic Analysis and Earthquake Characteristics of RCC Elevated Liquid Storage Tank with Different Bracings and Staging Patterns

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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 also due to improper geometrical selection of 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 and contrasted. 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.

Keywords: Earthquake Characteristics, RCC Elevated Liquid Storage Tank

I. INTRODUCTION

Water supply is a life line 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. But in reality these structures do not often last as long as they are designed for. These structures have a configuration that is especially vulnerable to horizontal forces like earthquake due to the large total mass concentrated at the top of slender supporting structure. So it is important to check the severity of these forces for particular region.

Water supply is essential for controlling fires that may occur during earthquakes, which cause a great deal of damage and loss of lives. Therefore, elevated tanks should remain functional in the post-earthquake period to ensure water supply is available in earthquake-affected regions. Nevertheless, several elevated tanks were damaged or collapsed during past earthquakes.

In general, water retaining structure distress has been observed very early even in 9 to 10 years of service life due to some problems related to structural aspects and over emphasis of seismic analysis in earthquake prone zones. During the past earthquakes, tanks have suffered with varying degree of damages, which include: Buckling of ground supported slender tanks, rupture of steel tank shell at the location of joints with pipes, collapse of supporting tower of elevated tanks, cracks in the ground

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supported RC tanks, etc. Water tanks can experience distress in different components due to several reasons such as improper structural configuration design, inferior materials and workmanship, corrosion of reinforcement, wind forces, earthquake forces etc.

II. Literature Review

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.

Generally, when earthquake occur major failures of elevated water tank take place due to failure of supporting systems, as they are to take care for seismic forces. Therefore supporting structures of elevated water tanks are extremely vulnerable under lateral forces due to an earthquake. The elevated water tank with only frame type staging with a single row of columns placed along the periphery of a circle, are not adequate to support container of elevated water tanks. Apart from that, it is required to identify suitable modified water tank staging system by determining what improvements or added features are necessary for staging part of water tank for better performance during earthquake. Also, alternate or innovative configurations are also required to put in practice.

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

III. Experimental Analysis

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

In the present study an elevated water tank of capacity $900m^3$ with staging heights of 18m and 22.35m is considered. These tanks are analysed with three different types of staging patterns namely Basic, Radial and Cross bracing systems in earthquake zones Zone-III and Zone-V as per IS 1893 (Part-2) codal guidelines. In this analysis FEM model by using structural software Staad pro is generated, and the Seismic forces are applied to the FEM model for various tank filling conditions, such as Tank empty, Tank half and Tank full conditions.

- The staging behaviour of an elevated water tank with different earthquake characteristics in various tank filling conditions are analysed.
- A comparative study of different staging patterns of Basic, Radial and cross type bracings in Zone-III and Zone-V with 18m height of staging.
- A comparative study of two different staging patterns of Basic and cross type bracings in Zone-V with 22.35m height of staging and increasing number of bracing bays.

IV. Experimental Results and Discussions

The above analysis represents the staging behavior of an elevated water tank with different patterns for different earthquake characteristics. Comparative study of three different staging patterns of Basic, Radial and cross type bracings in Zone-III and Zone-V with 18m and 22.35 heights of staging in terms of Stiffness of staging, Base shear, Base moment and Roof Displacements can described as follows.

- Case Study– 1: Elevated water tank with staging height of 18m for Basic, Radial and Cross bracing systems in Zone-III and Zone-V.
- Case Study – 2: Elevated water tank with staging height of 22.35m for Basic and Cross bracing systems with 5bays and 6bays of bracings in Zone-V.

A. *Stiffness of the staging*

1) *For Case Study-1*

Table - 1
Lateral stiffness of staging in Zone-III & Zone-V (Height -18m)

Staging pattern	*Lateral Displacement of staging in (mm)*	*Stiffness of Staging (Ks) in kN/m*
Basic bracing	*1.237*	*8084.07*
Radial bracing	*1.038*	*9633.91*
Cross bracing	*1.023*	*9775.17*

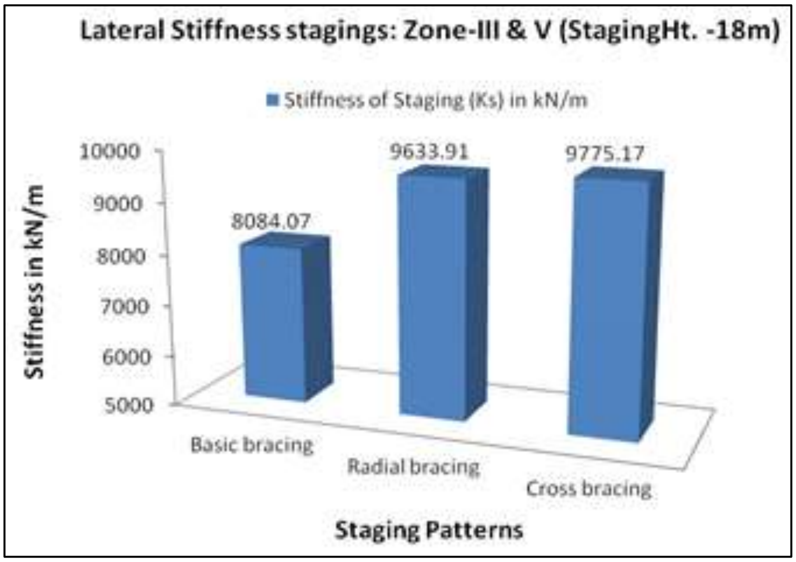

Fig. 1: Comparison of Lateral Stiffness of stagings in Zone-III & V (Height – 18m)

The lateral stiffness of staging of height 18m for the earthquake characteristics of Zone-III and Zone-V is given Table 5.24. The lateral stiffness is calculated from the lateral displacement of staging of FEM model in Staad pro. There are variations in the lateral displacement and respective stiffness of stagings, for the Basic, Radial and cross bracing systems. The lateral stiffness of Basic bracing is lower than the Radial bracing and the same for cross bracing is higher than radial bracing.

The Fig 1 shows the variation of stiffness of staging versus the type of staging patterns for three staging systems. The stiffness of Radial and Cross bracing have increased by 19% and 21% respectively compared to basic type staging pattern.

2) *For Case Study-2*

Table – 2
Lateral stiffness of staging (kN/m) in Zone-V (Height -22.35m)

Staging pattern	*Stiffness of staging (kN/m) Bracing with 5 Bays*	*Stiffness of staging (kN/m) Bracing with 6 Bays*
Basic bracing	*6901.31*	*8312.55*
Cross bracing	*8382.23*	*10111.22*

Table 2 shows the lateral stiffness of stagings of height 22.35m for the earthquake characteristics of Zone-V. The lateral stiffness is calculated for Basic and cross bracing patterns with 5 bays of bracing 6 bays of bracing. There are variations in the lateral stiffness of stagings, for the Basic and cross bracing systems. The lateral stiffness of Basic bracing is lower than cross bracing and Stiffness is higher for 6 bays of bracing compared to 5 bays of bracing in both staging patterns.

The Fig 2 shows the variation of stiffness of staging versus the type of staging patterns and number bays in bracing. The stiffness of staging for Cross bracing is increased by 21% compared to basic type staging pattern in 5bays of bracing and also in 6 bays of bracing. The stiffness of staging for 6 bays bracing is increased by 20% compared to 5 bays of bracing in basic and cross bracing patterns.

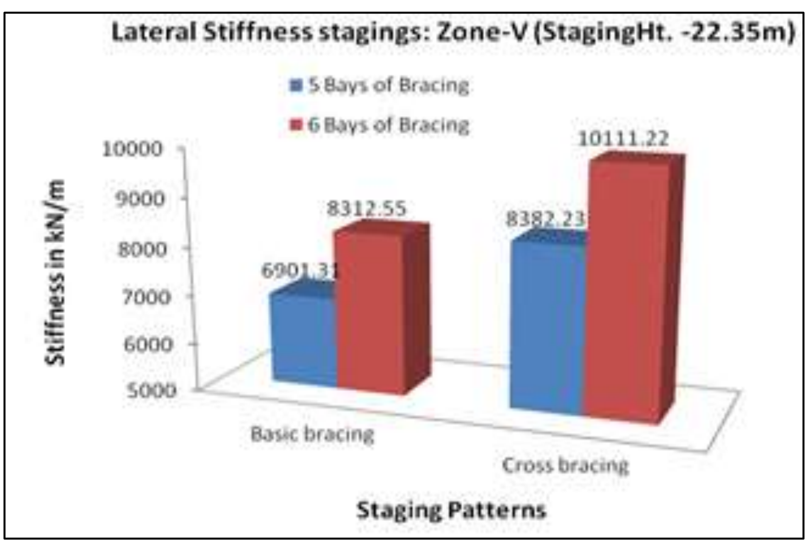

Fig. 2: Comparison of Lateral Stiffness of stagings in Zone - V (Height – 22.35m)

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V. 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-III for Case study-1 of ESR with 18m height of staging, Basic type of bracing (Ks= 8084kN/m) is sufficient and more appropriate compared to Radial bracing (Ks= 9633kN/m) and Cross bracing (Ks= 9775kN/m).
- 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, Radial=49mm, Cross=48mm, and Staging Stiffness: Basic=10101kN/m, Radial=12048kN/m, Cross=12255 kN/m respectively).
- In Zone-V for Case study-2 of ESR with 22.35m height of staging (5 bracing bays), the roof displacements for Basic (78mm) and Cross (71mm) type of bracings are exceeding the limiting value (63mm). Hence an increase in number bays from 5 to 6nos, it is observed that, the roof displacements are still exceeding the limiting values. (Roof Displacements: Basic=72mm, Cross=66mm, and Staging stiffness: Basic=8312 kN/m, Cross=10111 kN/m respectively). Hence it suggests modification of configuration ESR itself (Staging pattern/Column sizes/bracing beams sizes), which will end up with enhancement of staging stiffness.
- In Zone-V for the same Case study-2 of ESR with 22.35m height of staging, after modification of bracing beam sizes, it is observed that, the minimum value of staging stiffness (Ks) shall not be less than 11013kN/m to make roof displacements within the allowable limits.
- 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.

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