Analysis of Elevated Water Tank by Considering Slab, Wall, and Capacity in Seismic Zones

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Abstract Elevated water tanks are subjected to dynamic loads with varying capacity and located in different seismic zones. The history of the earthquake demonstrates that it has inflicted numerous losses to the life of people and has imposed damages caused to the public utility services such as water tanks. These buildings are particularly sensitive to horizontal wind pressures because of the considerable mass concentrated at the top of the narrow supporting structure. The structural parts of the elevated water tank have been subjected to rigorous computational testing in order to establish how well they function when subjected to wind loads. Four raised water tanks are modelled using finite element analysis and examined in the cloud. An axial load variation investigation of the columns with various staging heights is conducted after the completion of analysis. Results from this research will help better understand raised water tanks and how to construct them so that they can withstand wind loads.

1 Introduction

For liquid storage, there are a variety of tanks that can be found in practice, such as those that are either elevated or submerged in water. Among the various types of tanks, elevated tanks are the most important because of their high tank capacity and their ability to meet the demand of the public or industry. Patel [1] studied that water tanks play an important part in public utility and industrial structures, as they are essential for providing a steady flow of water over an extended distance with appropriate static head. Shakib and Omidinasab [2] said that reservoirs that hold water and other liquids are located on the ground and in the air. Reservoirs and tanks have a similar force analysis regardless of the chemical composition of the product. To prevent leaks, all tanks are constructed with no cracks or crevices. If

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the reinforcement is well maintained, reinforced concrete can be used to build walls and slabs for the storage of water or petroleum products. Vyankatesh and Varsha [3] proposed that a additional treatment is needed on the concrete surface since water and petroleum react with it. Upadhyay and Chirag [4, 5] suggested that overhead distribution systems are often lower in size because they rely on gravity to distribute products.

1.1 Types of Bracing Systems Used

Different models are used for calculating base shear and nodal displacements for staging with cross bracing, staging with chevron bracing, staging with diagonal bracing, staging with k-type bracing, and staging with v-type bracing.

1.2 Response Spectrum Analysis

In order to perform the seismic analysis and design of a structure to be built at a particular location, the actual time history record is required. Nemade [6] suggested that, however, it is not possible to have such records at each and every location. Further, the seismic analysis of structures cannot be carried out simply based on the maximum values of the ground acceleration as the response of the structure depends upon the frequency content of ground motion and its own dynamic properties. Mhetre [7] proposed that to resolve these difficulties, earthquake response spectrum is the most popular tool in the seismic analysis of structures. Yogeshwarana [8] mentioned that there are many advantages in using the response spectrum method of seismic analysis for prediction of displacements and member forces in structural systems. The method of analysis involves calculation of only the maximum values of the displacements and member forces in each mode of vibration using smooth design spectra that are the average of several earthquake motions. Gandhi [9] illustrated that the response spectral values depend upon energy release mechanism, epicentral distance, focal depth, soil condition, Richter magnitude, damping in the system, and time period of the system.

2 Literature Review

Upadhyay and Chirag [5] proposed that when an elevated water tank is subjected to away earthquakes, the response of the elevated water tank is examined and an evaluation of seismological response to the same. For earthquake-prone areas, tanks should be designed so that their tops are large enough to develop the seismic-weakness

constructions. Haroun MA and Ellaithy [10] studied the soil and foundation structure interactions during earthquakes which were examined by Reheat and Sunna for an elevated rectangular tank. Sloshing effects on the raised tanks' seismic behaviour and the soil's radiation dampening impact were ignored. The dynamic interaction between the tower and the supporting soil-foundation system was studied by Haroun and Temraz using two-dimensional X-braced elevated tank models supported on isolated footings. However, the sloshing effects were completely neglected [11]. Marashi and Shakib carried out an ambient vibration test to evaluate the dynamic characteristics of elevated tanks. Dutta et al. [12] examined the structural stability of elevated tanks as a part of their research. A set of estimated empirical equations for the stiffness of different frame supporting systems was proposed by the researchers. It was also studied how the tank system with unintentional eccentricity alters in torsional behaviour as the number of panels grows. Soil-structure interaction (SSI) has been shown to enhance base shear, particularly for tanks with high structures and short structural periods (Dutta et al. 2012). Additionally, the study found that disregarding the effect of SSI could result in high tensile strains in some of the staging columns due to seismic loads. For fluid-elevated tank-foundation-soil systems, they proposed a straightforward analytical approach and employed this approximation in selected tanks. Marashi and Shakib [13].

In this review work, Bansode [14] titled seismic investigation of raised water tank with variable staging design. Using staad-pro v8i 2007, he investigated the behaviour of several staging systems under various tank conditions. Response Spectrum Analysis was performed on three different types of bracing systems of elevated water tanks for various types of zones. He compared the base shear and nodal displacement of an elevated water tank while it was empty and full. Rajesh [15] published a review study on the behaviour of elevated water tanks at various staging heights. They concentrated on the behaviour of raised tanks under varied loads and the safer design of structures in their research. In his review paper titled "Seismic Analysis of RC Elevated Water Tank Using Different Staging Pattern", Quandri [16] considered different parameters such as water storage capacity, water tower height as consistent and variation in number of segment h/d ratio, and staging arrangement such as normal staging, hexagonal staging, cross staging, and radial staging with central column. Dhage [17] labelled her research "dynamic analysis of RCC elevated water tank". In her study, she considered two situations with the same tank capacity and found that changes in geometric features of the container can cause changes in the response of the elevated water tank. Gujar [18] laboured to secure a direct source of water from the rain for the water tank. Using water from a tank for irrigation is cost effective in areas where building a well is prohibitively expensive. The water obtained from the high water tank was suitable for home usage, for example, drinking, cooking, and washing. Using water from a tank for irrigation is cost effective in areas where building a well is prohibitively expensive. The water obtained from the high water tank was suitable for home usage, for example, drinking, cooking, and washing.

3   Methodology

The process comprises the simulation of a 100 mm^3-litre water tank. These overhead water tanks are analysed at staging heights of 15 m, 18 m, 21 m, and 25 m, accordingly. It is observed at a wind speed of 44 m/s. Wind load dynamic analysis is done using the Staad.Pro software. The design of the water tank must be able to endure earthquake loads, which increases as the seismic zones increase.

Methods of seismic analysis

Main two different types of design analysis are as follows.

Equivalent static analysis

Water tanks with an elevated water level can be effectively appealed statistically. When the seismic load is represented in the form of identical static loads, it is necessary, to get an accurate estimate, and it only needs one degree of freedom in the estimation in relation to the tank.

$$K = P/\Delta$$

where

  K = Lateral stiffness of staging
  P = Applied lateral force
  Δ = Deflection in mm

Dynamic analysis

Water tanks with an elevated water level can be effectively applied numerically. When the seismic load is represented in the form of identical static loads, it is necessary to get an accurate estimate. It only needs one degree of freedom in the estimation in relation to the tank.

Seismic Analysis of Elevated Water Tank

Equivalent static analysis of raised water tanks is used to convert seismic loads into equivalent static loads, which is the most common method of analysing tanks. The method for analysing an elevated water tank for seismic loading has been provided by IS: 1893–2002. Seismic loads have historically been measured in terms of equivalent static accelerations, which were affected by a variety of factors, including the location's seismicity, soil qualities, the natural frequency of the building, and its proposed usage. When a water tank is elevated, it can be analysed in both the full and empty states. A single-mass tank can be ideal for both conditions. Although both water and structure are assumed to be adhered to the container, the water-structure interaction indicates that both water and structure acquire picks at the same time for an identical static analysis.

General specifications

The dimensions of the circular and rectangular water tanks are regarded the same for all the different stage heights. The foundation, columns, and bracing all have a role in supporting the weight of the tanks above. Structural elements used to construct the water tank's staging must be strong enough to withstand axial loads, moments, and shear forces.

Foundation

Bottom of foundation 2 m

Centre of plinth beam 0 006D

Width of plinth beam 0.25 m

Depth of plinth beam 0.5 m

Columns

Diameter of the column 0.55 m

Bracing

Width of bracing beam 0.25 m

Depth of bracing beam 0.5 m

- **Floor beam**

Width of floor beam 0.3 m

Depth of floor beam 0.7 m

- **Floor slab**

Thickness of floor slab 0.2 m

- **Walking gallery**

Thickness of gallery 0.2 m

- Cylindrical wall or rectangular wall

Top width of wall 0.2 m

Bottom width of wall 0.2 m

Height of wall 4.2 m

- **Roof Slab**

Table 1 Weight of various components in kN of elevated service reservoir having Circular tank-1 of capacity 100m³ l for different walls and floor slabs

Various components	15 m	25 m
Roof slab	2503	2503
Wall	1665	1665
Floor slab	2503	2503
Floor beam	1106	1106
Gallery	401	410
Water	19,640	19,640
Columns	2123	3459
Braces	2789	4463
Staging	4912	7922
Empty tank	8772	8772
Total weight	33,324	36,334

Thickness of roof slab 0.2 m

Weight of components

The weight of the components is determined by calculating the volume of the elements by the density weight of the concrete. Imperviousness is a condition for any water tank design. Wider fractures in the water tanks should be avoided, if possible, to make them impenetrable. M30 grade concrete which has a density of 25kN/m³ is considered. Empty tank weight plus one-third of staging weight is included in the structural calculation procedure. A water load is considered a dead load. Furthermore, the freeboard is not considered in the depth of water while conducting dynamic analysis (Tables 1, 2, 3 and 4).

Table 2 Weight of various components in kN of elevated service reservoir having Circular tank-2 of capacity 100m³ l for different walls and floor slabs

Various components	15 m	25 m
Roof slab	2503	2503
Wall	1890	1890
Floor slab	2500	2500
Floor beam	1106	1106
Gallery	401	410
Water	19,640	19,640
Columns	2123	3459
Braces	2789	4463
Staging	4912	7922
Empty tank	8772	8772
Total weight	33,324	36,334

Table 3 Weight of various components in kN of elevated service reservoir having rectangular tank of capacity 1 lakh litres for different walls and floor slab

Various components	15 m	25 m
Roof slab	2500	2500
Wall	1665	1665
Floor slab	2503	2503
Floor beam	919	919
Gallery	460	460
Water	19,620	19,620
Columns	2547	4150
Braces	3828	6125
Staging	6375	10,275
Empty tank	8982	8982
Total weight	34,977	38,877

Table 4 Weight of various components in kN of elevated service reservoir having rectangular tank of capacity 100 mm^3 l for different walls and floor slabs

Various components	15 m	25 m
Roof slab	2500	2500
Wall	1890	1890
Floor slab	2500	2500
Floor beam	919	919
Gallery	460	460
Water	19,620	19,620
Columns	2547	4150
Braces	3828	6125
Staging	6375	10,275
Empty tank	8982	8982
Total weight	34,977	38,877

Centre of gravity

The stability of objects is affected by their centre of gravity. Centre of gravity greatly simplifies calculations involving gravity and dynamics, allowing us to regard an object's mass as though it is concentrated at one location. Product of distance from top of floor beam to components of empty tank and component weights divided by total empty tank weight yields centre of gravity of empty tank.

Wind Force

According to a building's or structure's effective frontal area Ae and design wind pressure P_d, total wind load on that particular building or structure can be calculated using force coefficients (Figs. 1, 2 and Table 5).
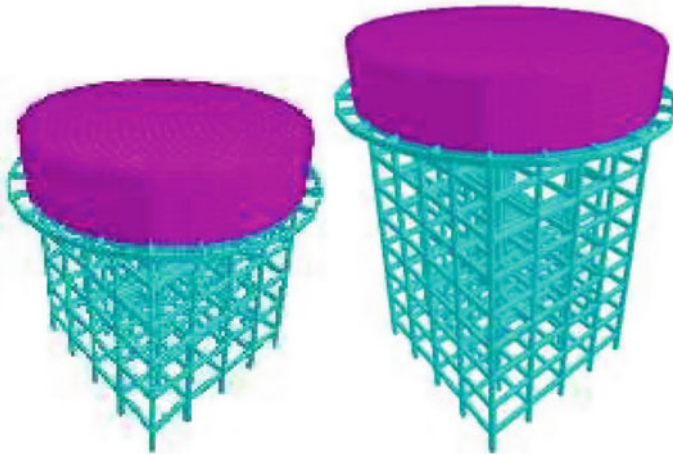
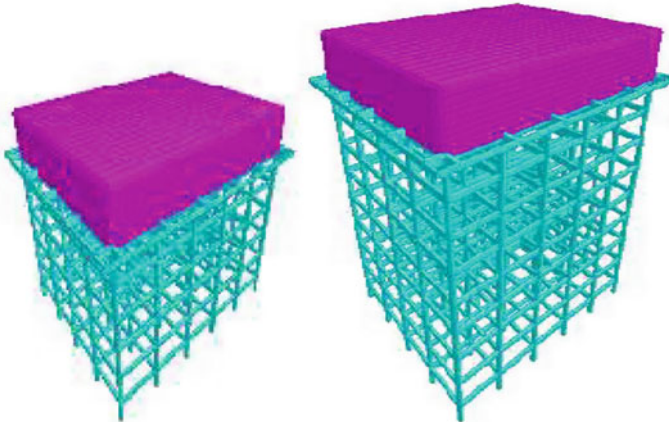**Fig. 1** Circular tanks of capacity 100 m³ l on staging heights 15 m and 25 m, respectively

Fig. 2 Rectangular water tanks of capacity 100 m³ l on staging heights 15 m and 25 m, respectively

Table 5 Calculation of centre of gravity from top of the floor beam for circular tank

Components	Distance	Weight	Distance × Weight
Roof slab	4.3	2503	10,762.9
Cylindrical wall	2.1	1665	3496.5
Floor slab	0.1	2503	250.3
Floor beam	0.35	1106	387.1
Gallery	0.05	401	20.05

4 Results and Discussions

The 100 mm^3 tank models are created and analysed in the software for the staging heights of 15 and 25 m, respectively. The x- and z-direction moments for the circular and rectangular tanks are compared to see how they are different. Circular and rectangular raised service reservoirs on different staging heights are studied in the maximum axial stress acting on the column RC 100 mm^3 capacity circular and rectangular water container. For all seismic zones, the tank is situated on a medium-soil base. Staging concrete is graded M30, and steel is graded Fe415, correspondingly. Concreting is 25 kN/m^3 in density, and the tanks are analysed for vibrations (Fig. 3 and Tables 6, 7).

Inferences

1. Displacement of Circular tank-1 > Circular tank-2 > Rectangular tank-1 > Rectangular tank-2.
2. In all the cases, displacement in full condition is more and in empty condition is less.
3. For staging height 15 m < staging height 25 m, i.e. 13 mm and 17 mm (Fig. 4 and Table 8).

Inferences

1. Base shear is more for Circular tank-2 and Rectangular tank-2 due to more wall thickness of 1890 mm.
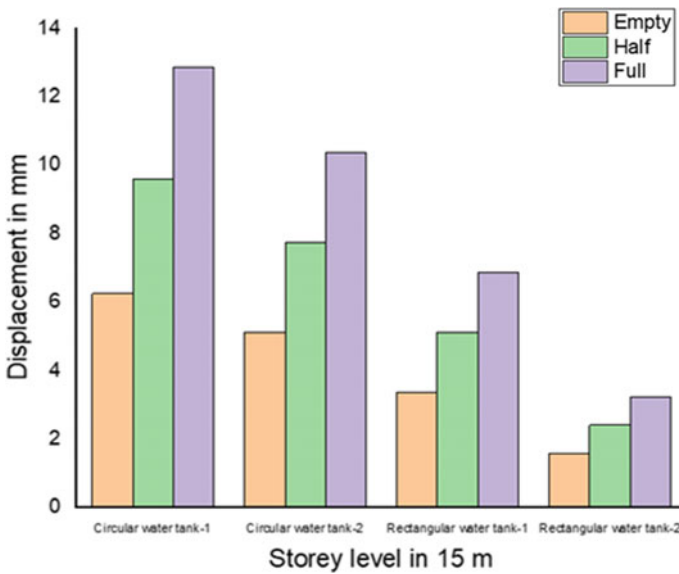

Fig. 3 Displacement (mm) versus storey level

Table 6 Zone II different storey levels in m

Storey level in m	Condition	Displacement (mm)		Base shear (kN)		Shear force (kN)	
		Stage-15 m	Stage-25 m	Stage-15 m	Stage-25 m	Stage-15 m	Stage-25 m
Circular water tank-1	Empty	6.26	6.32	275	278	285	289
	Half	9.58	11.59	210	212	225	233
	Full	12.85	16.93	220	222	239	242
Circular water tank-2	Empty	5.13	5.16	326	323	338	342
	Half	7.76	9.42	273	374	281	395
	Full	10.36	13.74	286	275	292	305
Rectangular water tank-1	Empty	3.37	3.41	270	272	284	295
	Half	5.13	6.37	205	208	258	285
	Full	6.86	9.30	208	210	252	279
Rectangular water tank-2	Empty	1.59	2.61	215	220	245	263
	Half	2.42	2.92	260	264	292	308
	Full	3.23	4.25	360	362	315	321

Table 7 Displacement (mm) Zone II in 15 m

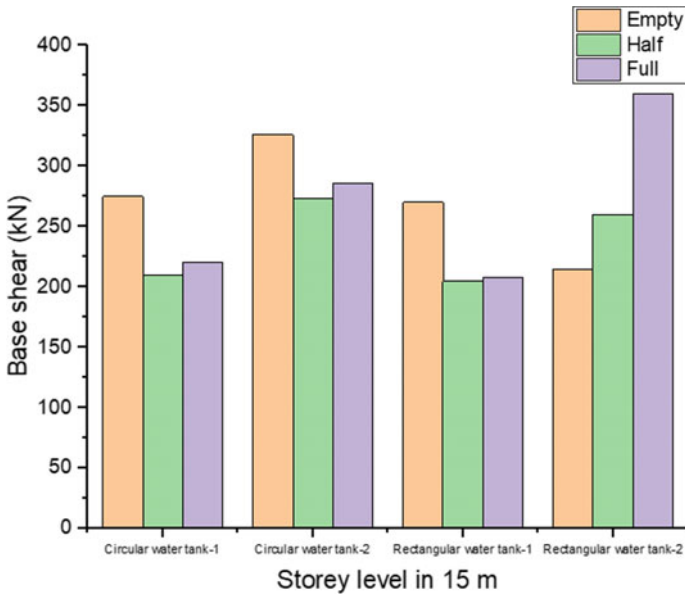| Storey level in 15 m	Empty	Half	Full
Circular water tank-1	6.26	9.58	12.85
Circular water tank-2	5.13	7.76	10.36
Rectangular water tank-1	3.37	5.13	6.86
Rectangular water tank-2	1.59	2.42	3.23

Fig. 4 Base shear (kN) versus storey level

Table 8 Base shear (kN) Zone II in 15 m

Storey level in 15 m	Empty	Half	Full
Circular water tank-1	275	210	220
Circular water tank-2	326	273	286
Rectangular water tank-1	270	205	208
Rectangular water tank-2	215	260	360

2. Circular tank-1 and Rectangular tank-1 show less base shear value due to less wall thickness of 1665 mm.
3. Base shear of staging height 15 m is almost equal to staging height 25 m (Fig. 5 and Table 9).

Inferences: Regarding Base Shear

1. Circular tank-2 and Rectangular tank-2 show more shear force values.
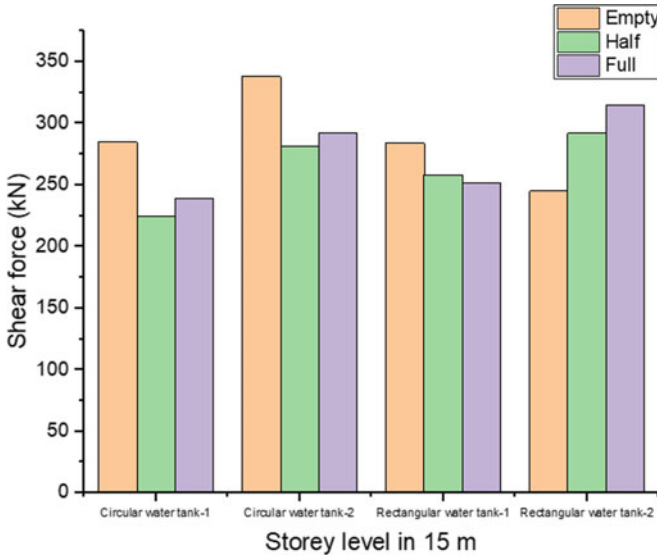2. Empty condition for Circular tank-2 has the largest shear force value.

Fig. 5 Shear force (kN) versus storey level

Table 9 Shear force (kN) Zone II in 15 m

Storey level in 15 m	Empty	Half	Full
Circular water tank-1	285	225	239
Circular water tank-2	338	281	292
Rectangular water tank-1	284	258	252
Rectangular water tank-2	245	292	315

3. Full condition for the Rectangular tank-2 has the next largest shear force value.
4. Half condition for Circular tank-1 has the lowest shear force value (Fig. 6 and Table 10).

Inferences

1. In all the cases, full condition shows more displacement and empty condition shows less displacement.
2. Circular tank > rectangular tank.
3. Circular tank-1 > Circular tank-2 > Rectangular tank-1 > Rectangular tank-2 (Fig. 7 and Table 11).

Inferences

1. In all the cases, empty condition shows more base shear but in Rectangular tank-2, full condition shows more value, and in Circular tank-2, half fill tank condition shows more value.
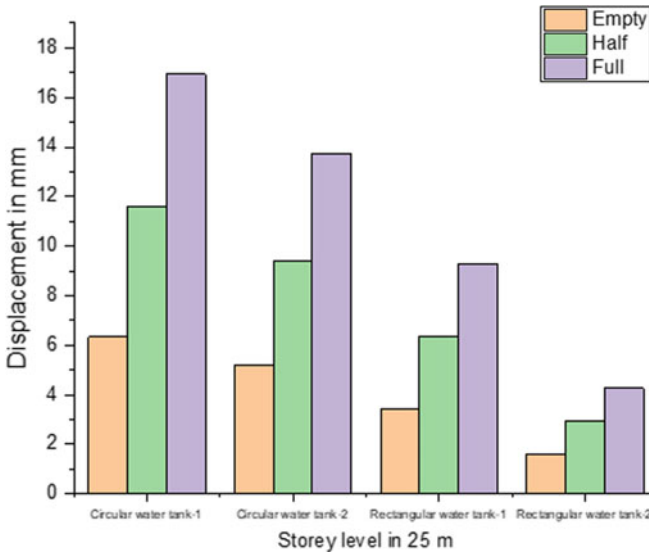2. Circular tank > rectangular tank.

Fig. 6 Displacement (mm) versus storey level

Table 10 Displacement (mm) Zone II in 25 m

Storey level in 25 m	Empty	Half	Full
Circular water tank-1	6.32	11.59	16.93
Circular water tank-2	5.16	9.42	13.74
Rectangular water tank-1	3.41	6.37	9.30
Rectangular water tank-2	1.61	2.92	4.25

3. Circular tank-2 and Rectangular tank-2 show more values since the wall thickness is more (Fig. 8 and Table 12).

Inferences

1. In general, empty condition is more, but in Circular tank-2 half fill condition and in Rectangular tank-2 full fill condition effect is more.
2. Circular tank is more effective than rectangular tank.
3. Rectangular tank-2 has more effect than Rectangular tank-1 since the wall thickness is more. Therefore, capacity > demand.

Zone III Different Storey level with 15 m staging

Inferences: Regarding Displacement

1. Circular tank-1 > Circular tank-2 > Rectangular tank-1 > Rectangular tank-2.
2. Full condition > half fill condition > empty condition for all the shapes.
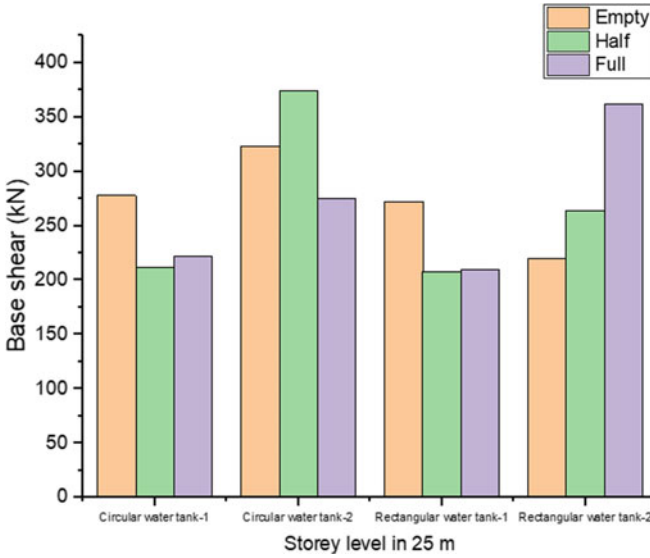3. 15 m Staging > 25 m staging.

Fig. 7 Base shear (kN) versus storey level

Table 11 Base shear (kN) Zone II in 25 m

Storey level in 25 m	Empty	Half	Full
Circular water tank-1	278	212	222
Circular water tank-2	323	374	275
Rectangular water tank-1	272	208	210
Rectangular water tank-2	220	264	362

Inferences: Regarding Base Shear

1. In general, empty is more than other cases, except in Rectangular tank-2 full condition since for Rectangular tank-2, wall thickness is 1890 mm which is greater than Rectangular tank-1 of 1665 mm.
2. Rectangular tank-2 and Circular tank-2 show more base shear since wall thickness is more.
3. 15 m staging > 25 m staging.

Inferences: Regarding Shear Force

1. All most all the cases are equal; however, a slight more in Rectangular tank-2 and a slight less in Circular tank-1 are observed.
2. In general, empty conditions show more value except Rectangular tank-2 full fill condition.
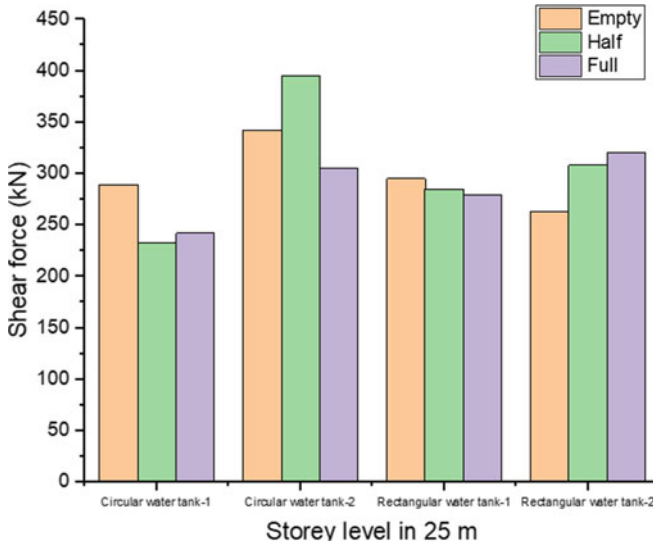3. 25 m staging < 25 m staging.

Fig. 8 Shear force (kN) versus storey level

Table 12 Shear force (kN) Zone II in 25 m	Storey level in 25 m	Empty	Half	Full
	Circular water tank-1	289	233	242
	Circular water tank-2	342	395	305
	Rectangular water tank-1	295	285	279
	Rectangular water tank-2	263	308	321

Zone III with 25 m staging

Inferences: Regarding Displacement

1. Circular tank-1 > Circular tank-2 > Rectangular tank-1 > Rectangular tank-2.
2. Circular tank > rectangular tank.
3. 15 m staging > 25 m staging.

Inferences: Regarding Base Shear

- Base shear is larger in Circular tank-2 half fill condition, and Rectangular tank-2 full fill condition is maximum since the wall thickness is more, i.e. 1890 mm.
- Circular tank-1, half fill condition and Rectangular tank-1, full fill condition have same values since they have same wall thickness 1665 mm which are less than Circular tank-2 and Rectangular tank-2.
- 25 m staging > 15 m staging.

Inferences: Regarding Shear Force

1. Circular tank-2 with half fill condition and Rectangular tank-2 with full condition show more values.
2. Circular tank-1 shows less value than all other cases.
3. 25 m staging > 15 m staging since distribution of base shear is more.

Zone IV Different Storey levels in m for 15 m staging

Inferences: Regarding Displacement

1. Circular tank-1 > Circular tank-2 > Rectangular tank-1 > Rectangular tank-2.
2. Full condition > half fill condition > empty condition.
3. Maximum 30 mm, minimum 3 mm.
4. 15 m staging < 2 m staging, i.e. 30 mm < 40 mm.

Inferences: Regarding Base Shear

1. Circular tank-2 and Rectangular tank-2 show more values, i.e. 320 KN and 350 KN, respectively.
2. Circular tank-2 with empty condition and Rectangular tank-2 with full condition shape influence more since thickness of wall is more, i.e. 1890 mm.
3. 15 m staging is almost equal to 25 m staging.
4. Maximum is 370 KN and minimum is 220 KN.

Inferences: Regarding Shear Force

1. Shear force is more in case of Rectangular tank-1 and Rectangular tank-2, which is about 325 KN to 330 KN even though maximum value exists in Circular tank-2 empty condition, i.e. 370 KN.
2. Circular tank-1 and Circular tank-2 show less values except empty condition of Circular tank-2, i.e. about 350 KN.
3. 25 m staging > 15 m staging since distribution of base shear is along the height.

Zone IV For 25 m staging

Inferences: Regarding Displacement

1. Circular tank-1 > Circular tank-2 > Rectangular tank-1 > Rectangular tank-2.
2. Full condition > half condition > empty condition 40 mm > 26 mm > 15 mm for circular tank.
3. 25 m staging displacement > 15 m staging displacement, i.e. 40 mm > 30 mm due to less stiffness.

Inferences: Regarding Base Shear

1. Circular tank-2 with half fill condition and Rectangular tank-2 with full condition show more base shear 350 KN and 400 KN, respectively.
2. Circular tank-1 and Rectangular tank-1 have almost same value, i.e. 275 KN in empty condition.

3. 25 m staging base shear is almost equal to 15 m staging base shear, i.e. 370 KN and 380 KN, respectively.

Inferences: Regarding Shear Force

1. Rectangular tank-2 and Rectangular tank-1 have about 340 KN to 350 KN, which are more than Circular tank-1 and Circular tank-2 except half fill condition in Circular tank-1 with 375 KN and empty condition in Circular tank-2 with 380 KN.
2. 25 m staging > 15 m staging, i.e. 380 KN > 370 KN.

Zone V Different Storey level for 15 m staging

Inferences: Regarding Displacement

1. Circular tank-1 > Circular tank-2 > Rectangular tank-1 > Rectangular tank-2.
2. Full condition > half fill condition > empty condition in each case.
3. Displacement of 25 m staging > 15 m staging, i.e. 60 mm > 45 mm.

Inferences: Regarding Base Shear

1. Circular tank-2 and Rectangular tank-2 show more values, i.e. 332 KN and 370 KN.
2. Circular tank-2 with empty condition and Rectangular tank-2 with full condition show more values because wall thickness is more, i.e. 1890 mm > 1665 mm.
3. Base shear for 25 m staging > 15 m staging, i.e. about 380 KN and 370 KN.

Inferences: Regarding Shear Force

1. Almost all are the same except Circular tank-1 with half fill condition having 375 KN and Circular tank-2 having 380 KN.
2. Rectangular tank has slightly more than that of the circular tank.
3. 25 m staging > 15 m staging, i.e. about 390 KN > 380 KN.

Zone V Different Storey level for 25 m staging

Inferences: Regarding Displacement

1. Circular tank-1 > Circular tank-2 > Rectangular tank-1 > Rectangular tank-2, i.e. 15 mm > 50 mm 32 mm > 18 mm.
2. Full Condition > half fill condition > empty condition.
3. 25 m staging > 15 m staging because of less stiffness.

Inferences: Regarding Base Shear

1. Circular tank-2 and Rectangular tank-2 are having maximum values. 375 KN and 360 KN values for Circular tank-2 in half fill condition and Rectangular tank-2 in full condition, respectively. Circular tank-1 and Rectangular tank-1 are less than Circular tank-2 and Rectangular tank-2.
2. Circular tank-2 dominates in empty condition.
3. Circular tank-1 and Rectangular tank-1 < Circular tank-2 and Rectangular tank-2.
4. 25 m staging > 15 m staging, i.e. 400 KN > 370 KN since the distribution of base shear is along the height.

Inferences: Regarding Shear Force

1. All are almost the same, except Circular tank-1 in half fill condition and Circular tank-2 in empty condition.
2. Rectangular tank-1 and Rectangular tank-2 are uniform. Circular tank-1 and Circular tank-2 are slightly more than rectangular tanks.
3. All the water fill conditions are almost the same.
4. 25 m staging is almost equal to 15 m staging, i.e. 375 K.

The maximum moments for circular tanks are lower than those for rectangular tanks. Increasing the height of the tanks' staging area for the same tank capacity increases the value of the moments. Due to the smaller effective area of a circular tank, it is less subjected to wind effects than a rectangular tank is. Due to the circular tank's lack of columns, this is more readily apparent than the rectangular tank.

5   Conclusion

Many good innovations and developments have been produced in various designs and forms for water tanks, which are highly significant for open utility and modern structure. The following are the results of the seismic analysis of the elevated water tank:

1. Because of the zone factor, response reduction factor, etc., the base shear of a full water tank and an empty water tank is both increased in seismic zones II–V.
2. Base shear in perfect working orders for the full tank is slightly higher than an empty tank because of the pressure difference or the absence of water.
3. Because of the zone factor, response reduction factor, etc., the displacement of a full water tank and an empty water tank is enhanced in seismic zones II–V.
4. When the tank is full, the wall of the tank has the maximum and smallest nodal deformations.
5. Comprehensive and empty water tanks are subjected to higher shear and bending moments due to the zone factor, response reduction factor, etc., in seismic analysis.
6. In a full tank, the shear force and bending moment are slightly larger than in an empty tank because of the lack of water or hydrostatic pressure.

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