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Effect of Shaft Height on Base Shear of Elevated Intze Water Tanks

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Abstract: **Overhead storage reservoirs such as elevated Intze tanks store water, petroleum products, and other liquids for effective distribution. In this study, four (10, 12,14, and 16) different heights of an elevated shaft in meters of Intze tank are assumed to carry a similar capacity of water. The diameter of the tank and height change simultaneously maintaining the same capacity in rising scenarios. The dynamic wind pressure analysis was carried out as per the American Institute stand ASCE-7, 2010 in which the impulse and convective pressure vary and are assumed hydrostatically on tank walls. The tank RCC analysis was also done in STAAD.Pro. V8i as per Indian standard IS:456 for reinforced concrete works. Variation in the base shear forces was observed for both tanks to increase from 289.94 kN to 362.98 kN for 10 m to 16 m shaft height.**

Keywords: **Intze Water Tank, Equivalent Static Load, DL-Dead load, LL- Live Load and WL – Wind Load.**

I. INTRODUCTION

Liquids obtained from stockpiled storage facilities save on fundamental logistics on sufficient supply for various uses of the intended liquid. Water as other chemicals is preferably stored in elevated water tanks for domestic use, agricultural supply, industrial use, and hazard mitigation measure such as firefighting [1]. Reinforced concrete overhead water tanks, steel staged overhead tanks and elevated staged plastic tanks have been used both in domestic, industrial, and municipal facilities for decades. The design of the stockpiled storage facility is guided by capacity, population, region terrain, seismic effects, and efficiency intended for the distribution as the main purpose.

Distribution being the key purpose for elevating storage tanks, does not necessarily serve the capacity purpose as compared to surface and subsurface tanks. Civil engineers over decades have worked towards beating constraints of capacity by varying staging shape and tank shape to achieve distribution aims such as sufficient and continuous flow, wider distribution, and many others.

The geographical location of Kenya does not put it vulnerable to intense natural disasters like earthquakes, cyclones, and hurricanes. Although the country is enjoying its geographical benefits, the future is unknown by reference to the existing fault lines along the Great Rift valley which expose the country to intense seismic disturbance. Among the natural calamities, wind serves as the leading cause and distributor of various storms such as cyclones that occur along coastal shores and Kenya borders the Indian Ocean. The general understanding drives civil engineers to design and analyze tall structures against overturning and seismic disturbances.

Elevated water tanks respond to natural forces and loadings like the tall structures despite the height since they consist of slender support systems and a lump of mass at the top. The loading nature makes the tank critical and more vulnerable to shear failure and overturning from lateral and axial forces as it assumes a single degree of freedom.

A. Classification of water tank

Water tanks are classified based on head and shape. According to the shape

- Spherical tanks
- Circular tanks
- Rectangular tanks
- Conical tanks and
- Intze water tanks

According to the head

- Underground tanks
- Ground or surface tanks
- Elevated tanks on staging.

In this classification, elevated tanks on staging are further categorized into staging types:

- Frame stage system and
- Shaft support system.

B. Types of the staging of elevated water tanks

The frame support system is quite common in staging overhead reservoirs. The frame consists of vertical columns and beams acting as braces thus a frame. The closure of the frame at the top is a circular ring beam joining the tank to the frame. The frame system bridges load from the tank to the foundation on the ground. The intended purpose of elevating a reservoir is to increase the distribution head hence the more head required the higher staging. The frame type support is regarded as superior over the shaft type on lateral resistance due to its large redundancy and higher capacity to absorb seismic energy[2].

In the shaft support system, a thin shell section supports the container carrying liquids on the top. The lateral resistance of the shaft is less compared to that of the staging frame thus not very common in use. The shaft can be masonry type or RCC type. It contains poor ductility and lacks redundancy of load path and toughness.

C. Type of analysis on elevated water tanks

There are two approaches to the dynamic response of water towers are based. Lateral loads resulting from winds, seismic energy, and sloshing effect require dynamic analysis. Through conventional methods, the dynamic response is converted to equivalent static loads.

In an equivalent static analysis of elevated water reservoirs seismic, sloshing and wind loads analysis is based on a single degree of freedom. The approach lumps the mass effect at the centre of gravity and both full and empty conditions can be analyzed. Over time the behavior of elevated tanks under full or empty conditions is realized as an unpredictable hence dynamic response is hard to define. The resultant energy from the sloshing of liquids and seismic disturbance should be considered apart from hydrostatic forces. Dynamic analysis has been simplified by assuming two mass models since proposed by Housner (1963) for the design and analysis of elevated water reservoirs[2]. In the two mass models, the top part of the tank experiences impulsive force while the lower part attached to the container surface is convective. When the container is not full, the seismic energy ground motion subject the entire system to horizontal acceleration. Although in this study, the focus is on obtaining base shear, an equivalent static analysis approach has been used[3].

D. Problem description

In this case, the study focuses on establishing the effect of varying the shaft height against constant shape capacity to the base shear. The result would project the instance of axial failure in the shaft and punching shear failure along the vertical plane. Lateral pressures will also produce numerous lateral shears along x and z planes from wind dynamic pressure where x and z are two orthogonal horizontal directions. Assuming wind pressure acts along the z-plane, the moments along the x plane are generated with positive and negative base shear in different supports as per position. The type of staging recommended is shaft support with a uniform diameter but the varying height from 10m, 12m, 14m, and 16m consecutively. The recommended intze tank dimensions remain unaltered with every shaft height change. Therefore, holding capacity constant and varying staging of the intze water tank, base shear forces are expected to affect the design soundness of the tank.

E. *Objective*

i) To establish the effect of varying intze elevated water tank shaft on-base shear forces.

II. LITERATURE REVIEW

Many scholars have presented the literature on reinforced concrete in technical papers for staging fluid towers. Distribution is the key interest in the required head for distribution of liquids as is fairly achievable by using gravity. Dynamic and static analyses are both subjected to framed and shaft supported towers establishing the liquid sloshing effect response. Some of them are listed below.

Vyankatesh and Varsha. [4]: The Gujarat earthquake on 26 January 2010 motivated this research on comparing the use of concrete shafts and reinforced concrete frames in elevating a water tank. Different support systems were considered in medium soil conditions and seismic zones II, III, IV and V. Besides, the results from the base moments and base shear were considered with different capacities. In the analysis, both convective and impulse pressure in different magnitudes were used. He established that the base shear for the concrete shaft support system is greater than that of the frame support system. The base moment is greater for tanks elevated with concrete shafts compared to framed supports posing a threat to high seismic intensity zones. Increasing the elevated tank capacity with a change in staging pattern reduced deflection of the support system. He concluded that the sloshing effect differs for tanks as capacity increases but is fairly the same for different supporting systems.

Pradnya V. Sambary, (2015)[5]: The paper on seismic analysis was triggered by the nature of seismic intensity distribution in India. A dynamic analysis was performed on a 50 m^3 by a response spectrum through frame staging on soft soil and hard rock. The hydrodynamic pressure, base shear and base moments were considered for an empty and full tank. In the study, lumped mass model and two-mass model methods were used for frame staged tanks in seismic zones III and V as per IS 1893-1984 and IS: 1893-2002 (part 2) codes. The two-mass model convective hydrodynamic pressure increased more realistic hence base shear and base moment were far greater compared to lumped mass idealization. He concluded that the shaft type staging should be avoided in future to minimize damage to elevated water tanks.

Devadanam *et. al*. (2015)[6]: A study on the effect of staging height on the seismic performance of reinforced concrete (RC) elevated circular water tank was carried out during the Bhuj and Lattur earthquake studies. The study findings hypothesis was that the RC frame has better seismic resistance compared to the shaft staging. The spring-mass model was used to assimilate the impulsive and hydrodynamic pressure from the liquid. About IS 1893:1984, IITK-GSMDA guidelines and SAP2000, observations indicated a base shear increase to a critical height. The base shear varied linearly with an increase in staging implying the seismic intensity factor is also linear. In addition, the properties of soil (soft to hard) affect the base shear linearly.

Anuja and Malika, (2019)[7]: The effect of tank height on the seismic performance of intze water retaining structures was conducted according to IS 1893: 2002 (part II). Parameters such as base shear, sloshing effect, time, and overturning effect by seismic forces were under study. The staging height with the intze capacity was considered. They observed that the base shear increased with an increase in tank height and also from half-empty to full capacity. Generally, the sloshing effect increased with an increase in tank height. They concluded by considering the half-full capacity in critical design during periods of seismic forces.

Hariteja N. *et. al*. (2016)[8]: A study on “seismic assessment of elevated circular water tank” was carried out in line with IS 1893: 2000 and through STAAD.Pro V8i. The limit state design approach was used considering both the live, dead, seismic and self-weight loads. The response spectrum analysis concluded that modal frequency increase with staging height. Concerning Rayleigh’s frequency, the frequency and deflection value was recorded to be almost the same in a common member.

Gurkalo, (2016)[9]: He conducted a study on using slit shaft reinforced concrete for the design of elevated water tank shafts. He investigated the effect of slit shaft from non-linear seismic forces through finite element analysis in SAP2000. The findings were recorded that converting the solid shaft to the slitting shaft increased ductility in the tank staging structure. Besides, increasing the width of slits increases ductility. The slit width significantly reduced the time response analysis in base shear and base moments. Although, increasing the slit with increased top of tank lateral displacement.

III. RESULTS AND DISCUSSION

The following results were obtained from modelling elevated Intze water tanks of different heights in shafts type support in STAAD-Pro V8i. Considering the same tank capacity and in the same location in Kenya.

The volume of the tank is assumed to be ($V = 0.585D^3 \; = 1000\,m^3$) according to Reynolds' assumption and obtained tank dimensions as in the table below[1].

TABLE 1: TANK DIMENSIONS

Serial No:	Size of Various Elements in mm	Tk 1	Tk 2	Tk 3	Tk 4
1	Diameter of the tank	12000	12000	12000	12000
2	Height of the tank	8000	8000	8000	8000
3	Height of water in the tank	7000	7000	7000	7000
4	Rise of the top dome	2000	2000	2000	2000
5	Thickness of top dome	120	120	120	120
6	Top ring beam	450 x 300	450 x 300	450 x 300	450 x 300
7	Cylindrical wall thickness	200	200	200	200
8	Bottom ring beam	500x400	500x400	500x400	500x400
9	Circular ring beam	450x300	450x300	450x300	450x300
10	Thickness of bottom dome	300	300	300	300
11	Height of conical dome	2000	2000	2000	2000
12	Rise of the bottom dome	1600	1600	1600	1600
13	Diameter of the shaft	8000	8000	8000	8000
14	Height of the shaft	10000	12000	14000	16000

Analysis of the tank using STAAD.Pro

Basing modelling on analytical calculations the elements in table 1 were modelled using STAAD.Pro V8i to determine the base shear and resulting overturning moments on both global axes. The location is urban, category 3, for wind pressure as per ASCE-7, 2010, with average wind pressure of 35m/s. Both the wind loads and the water load is perceived as hydrostatic with varying intensity on tank walls.

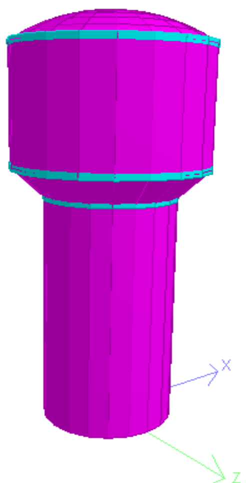

Fig. 1: Shaft Supported Elevated Intze Water Tank RCC Model In STAAD-Pro. V8i

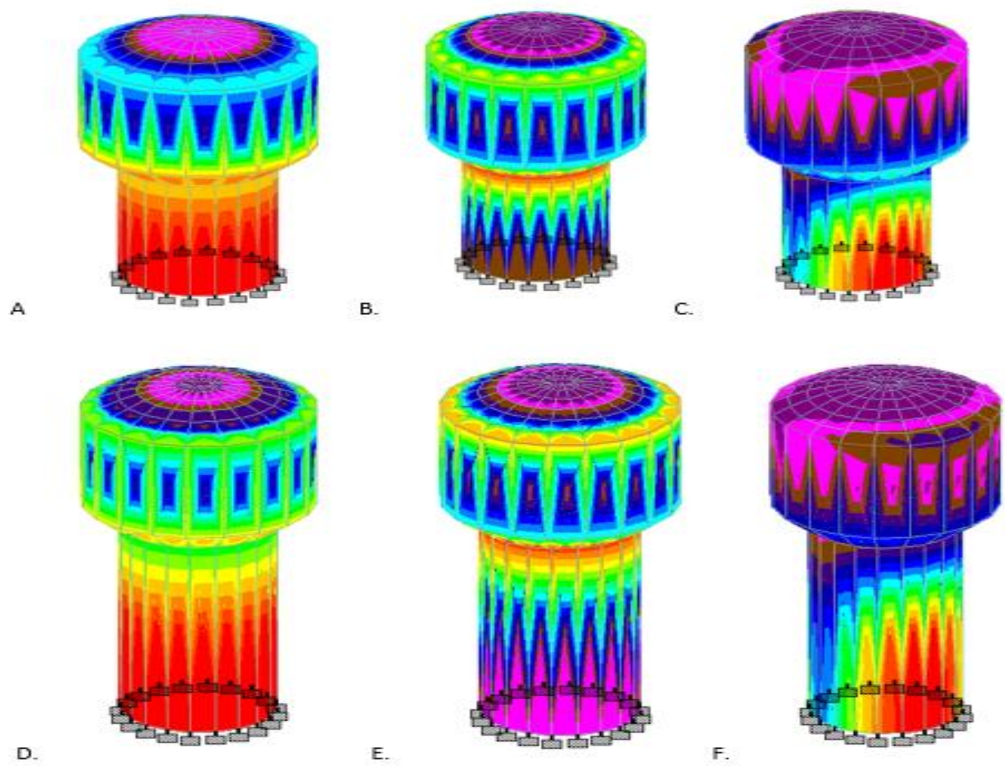

Fig. 2: A, B, C are 10m in height, and D, E, F are16m height shaft elevated intze water tank showing absolute stress distribution DL, LL, and WL.

The wind pressure on plane Z. on both tanks as per ASCE-7 (STAADPro.) intensity vs Height calculated from basic wind speed (Vz) of 35m/s obtained from the meteorological department of Kenya averaged for outskirts of Nairobi, Nanyuki town with minimal obstructions. The formula used as per the IS codes is in eq. 1.

$$Vz = Vb*k1*k2*k3 \qquad \text{Eqn. 1}$$

Where,

Vb = basic wind speed

Vz = design wind speed at a height in m/s (depends on risk level, terrain roughness, height, and size of the structure with local topography)

K1 = probability factor or (risk coefficient)

K2 = terrain height and structure size factor

K3 = topography factor

The height of the water tank is less than 30 m located in the outskirts of Nairobi city, Nanyuki town, and category three designed for 50 years. K1 = 1.0 (IS 875-1987 - part 3), K2 = 1 for slope is assumed less than 3° and k3 = 1.0 (category 3 class B) and Vb = 35.9 m/s

TABLE 2: WIND PRESSURE INTENSITY PER HEIGHT INTERVAL FOR A BASIC WIND SPEED OF 35M/S

Serial No:	Intensity (kN/m^2)	Height (m)
1	0.36554	0
2	0.36554	4.6
3	0.39685	6.1
4	0.42298	7.6
5	0.44560	9.1

6	0.46567	10.7
7	0.48377	12.2
8	0.50033	13.7
9	0.51562	15.2
10	0.52896	16.8
11	0.54319	18.3
12	0.55576	19.8
13	0.56765	21.3
14	0.57895	22.9
15	0.58973	24.4
16	0.60003	25.9
17	0.60991	27.4
18	0.61941	29.0
19	0.62855	30.1
20	0.63737	32
21	0.64590	33.5
22	0.65416	33.1

The base shear and base moment recorded were as in TABLE 3 below.

TABLE 3: FULL TANK BASE SHEAR AND MOMENT AS PER IS 1893 (PART II) 2002

Tank	Base Shear (kN)	Base Moment (kNm)
Tank 1	289.94	1068.7
Tank 2	310.20	1337.52
Tank 3	342.85	1607.48
Tank 4	362.98	1828.64

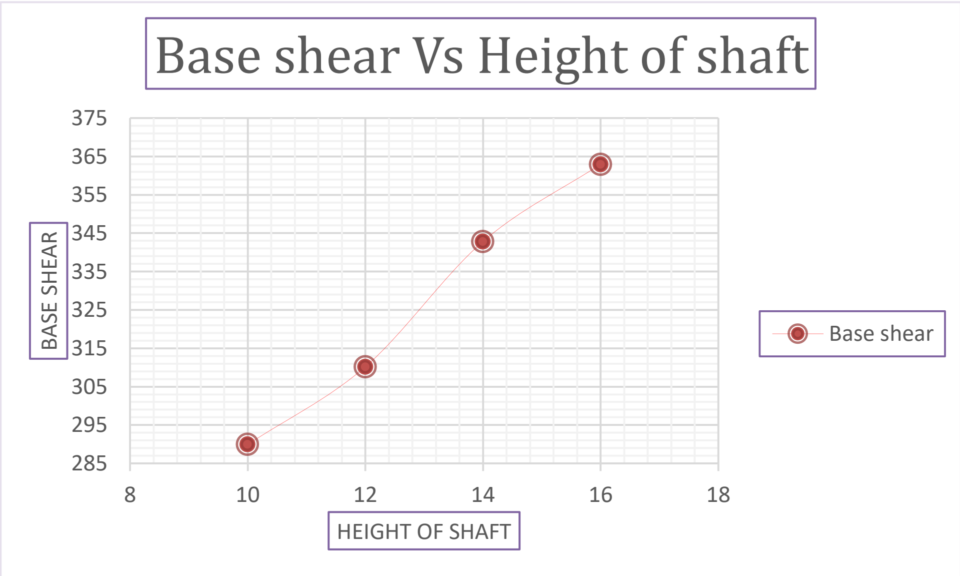

Fig. 3: Shows the effect of shaft height on the base shear

IV. CONCLUSION

The drawn conclusions from the study include,

i) Increasing staging of an elevated Intze Tank shaft results in a direct increase in base shear hence foundation design should change relatively.

ii) The change in base shear is non-linear despite the defined height interval increase in the shaft height.

iii) The equivalent static analysis does not provide clear distinctions of seismic, wind and hydrostatic pressure in analysis thus idealize on dynamic analysis.

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