EFFECT OF SLOSHING IN ELEVATED WATER TANK ON LEVELLED AND SLOPING GROUND

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Abstract - *Water tanks are very important for public utility and industrial structure which are considered as the main lifeline element. An elevated water tank is a large water storage container constructed for the purpose of holding water at a certain height to pressurize the water distribution system. Elevated tanks are supported on staging which consist of R.C.C. columns braced together, and walls subjected to water pressure from inside the tank. In water supply scheme, water tanks mainly account for 10% to 20% of the overall cost. The base is exposed to weight of water, weight of walls and weight of roof. The Main failures occurred in water tanks are shear failure in beam, bending-shear failure in beam, axial failure in columns and rupture in tank walls. The main damage of water tank is occurred due to sloshing effect. Sloshing is any motion of the free liquid surface inside its container caused due to any disturbance to partially filled container. A circular elevated water tank of same capacity and same staging heights are considered for this study. The modelling and analysis are carried out using ETABS software.*

Key Words: **Elevated water tank, Sloshing effect, Staging, ETABS, Free liquid surface**

1. INTRODUCTION

1.1 General

Water is life line for every kind of creature in the world. The water tank plays an essential role for public utility and other industrial structure having basic purpose to certain constant water supply from longer distance with sufficient static head to the desired location under the effect of gravitational force. They may be elevated, ground supported or underground tanks with different geometries depending on the nature and topography of land. The liquid storage tanks possess low ductility and energy absorbing capacity as compared to the conventional building. So seismic safety of liquid storage tank is of considerable importance. The water level in the tank effects the seismic performance of water tank. Water level in the tank has a important role in contributing base shear and base moment in case of water tank.

Earthquake damage to tanks can come in several forms. One of the phenomena at the free liquid surface is a sloshing effect of the upper portion of the liquid. Oscillation of the convective liquid in the storage tanks may result in negative effects such as deformations etc. During earthquakes, the water inside the tank undergoes sloshing motion. That sloshing motion depends the seismic performance of tank. Sloshing can be described as back and forth motions of the liquid in a partially filled tank. Slosh is a phenomenon occurred in a liquid container where liquid in a container moves irregularly with a splashing sound.

2. NUMERICAL INVESTIGATION

2.1 Tank Description

The study investigates the seismic behavior of circular elevated water tank on levelled and sloping ground and effect of sloshing on tank numerically. A circular elevated water tank of radius 5.6m with 6 column staging has been considered for this study, for understanding the seismic behavior of tank on levelled and sloping ground. The relevant dimensions taken for design of water tank are as follows.

Capacity - 500m^3

Diameter of tank – 11.2m

Height of tank – 5m + 0.5m(free board)

Height of Staging – 10m and 15m

The behaviour of tank has been analyzed for two staging heights of 10m and 15m with levelled and sloped ground condition. The analysis is carried out for medium soil condition with seismic zone of 0.36.

2.1 Material Properties

The grade of concrete is taken as M30 and grade of rebar is taken as Fe415.

2.2 Section Properties

The frame sections and area sections of water tank are to be defined in this section. The dimensions of frame section assigned are defined in the Table 1.

Table -1: Properties of frame sections of water tank

COMPONENT	SIZE (mm)
Ring Beam	200 X 400
Braces	250 X 500
Column	400 X 400

The dimensions of area section assigned are defined in the Table 2.

Table -2: Properties of area sections of water tank

COMPONENT	SIZE (mm)
Floor slab thickness	300
Roof slab thickness	200
Wall thickness	200
Gallery thickness	110

2.3 Loads Assigned

The loads considered while analysing this structure are Dead Load, Live Load, Earthquake Load and the load combinations defined are as follows: [4].

- 1.5(DL+LL)
- 1.5(DL+EQ)
- 1.2(DL+LL+EQ)
- 0.9DL + 1.5EQ

2.4 Modelling

The modelling of circular elevated water tank is carried out in ETABS software for levelled and sloping ground. The circular elevated water tank is modelled for 10m and 15m staging height in levelled and sloped ground for tank empty and tank full condition. And also the analysis is carried out for 5^0 sloping condition.

2.5 Water tank of 10m staging height

The tank is modelled by 10m staging height with 3 level of bracing by giving 2.5m spacing between the braces are shown in fig 1.

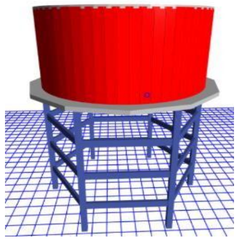


Fig -1: Tank model of 10m staging

2.6 Water tank of 15m staging height

The tank is modelled by 15m staging height with 4 level of bracing by giving 3m spacing between the braces are shown in fig 2.

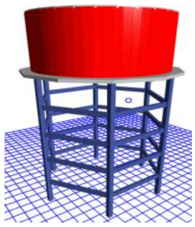
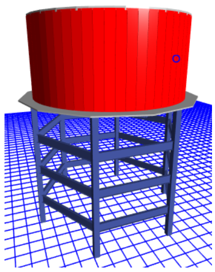


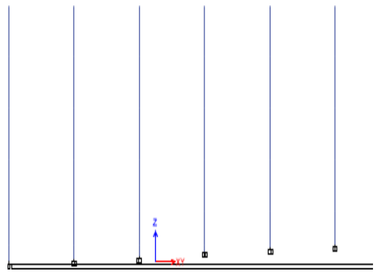
Fig -2: Tank model of 15m staging

2.7 Water tank of 10m staging height located on 5^0 sloping ground

The tank is modelled by 10m staging height with 3 level of bracing by giving 2.5m spacing located on 5^0 sloping ground is shown in fig 3(a). The elevation view of staging is shown in fig 3(b).



(a) Tank model

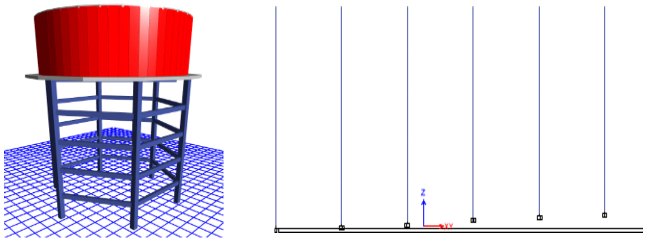


(b) Elevation view of staging

Fig -3: Tank model of 10m staging located on 5^0 sloping ground

2.8 Water tank of 15m staging height located on 5^0 sloping ground

The tank is modelled by 15m staging height with 4 level of bracing by giving 3m spacing between the braces and located on 5^0 sloping ground is shown in fig 4(a). The elevation view of staging is shown in fig 4(b).



(a) Tank model (b) Elevation view of staging

Fig -4: Tank model of 15m staging located on 5^0 sloping ground

3. RESULTS AND DISCUSSIONS

3.1 Water tank of 10m staging height

The tank is modelled and analyzed by giving the respective parameters illustrated above and the base shear and displacement values are found out. The base shear and displacement values found out are represented graphically are shown in chart 1 and chart 2.

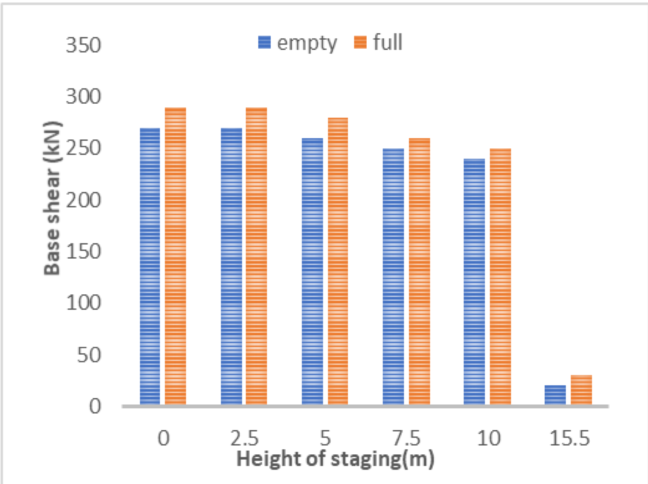


Chart-1: Height of tank vs Base shear (10m staging)

From the analysis it is found that the base shear is maximum at the bottom and minimum at the top shown in chart 1. The displacement value shows greater value at the top and zero value at the bottom shown in chart 2.

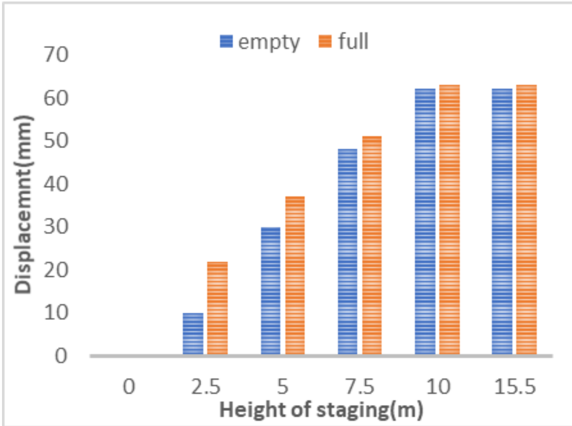
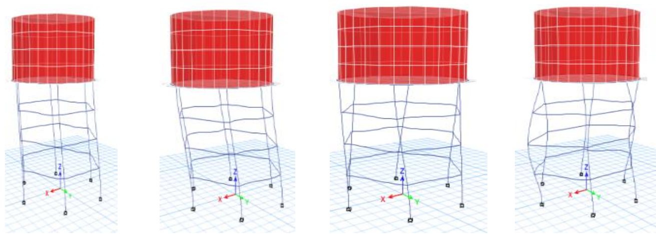
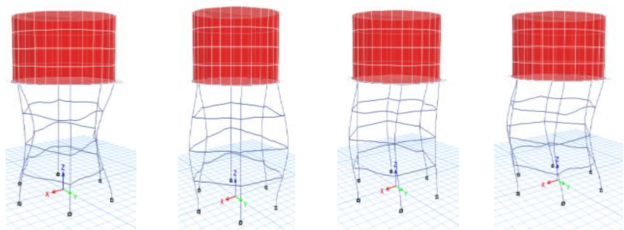


Chart -2: Height of tank vs Displacement (10m staging)

The first 8 mode shapes given from the analysis are shown in fig 5.



Mode 1 Mode 2 Mode 3 Mode 4



Mode 5 Mode 6 Mode 7 Mode 8

Fig -5: Different mode shapes of elevated water tank

3.2 Water tank of 15m staging height

The tank is modelled and analyzed by giving the respective parameters illustrated above and the base shear and displacement values are found out. The base shear and displacement values found out are represented graphically are shown in chart 3 and chart 4.

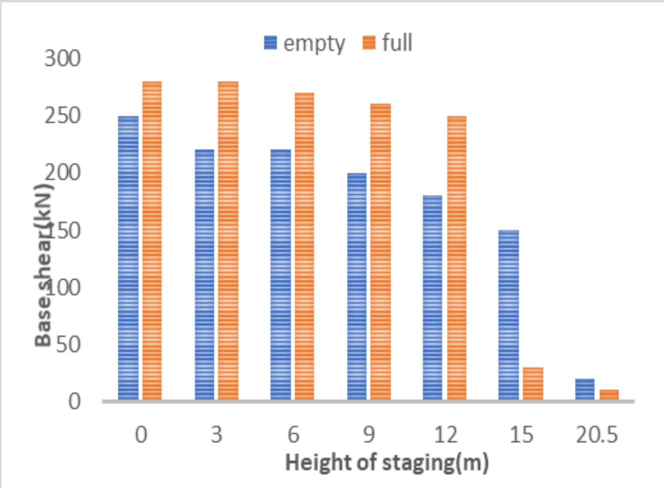


Chart-3: Height of tank vs Base shear (15m staging)

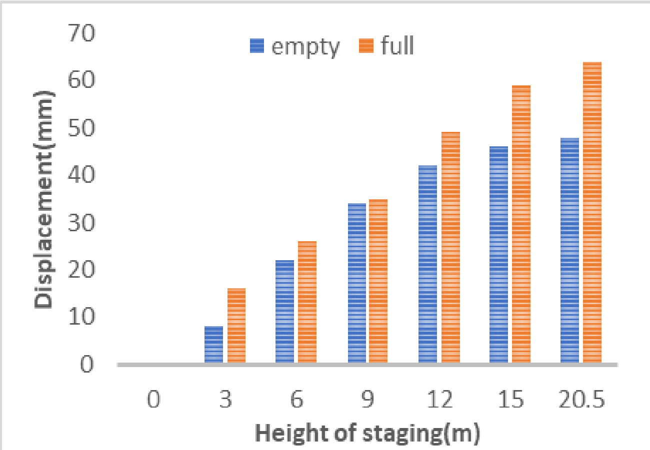
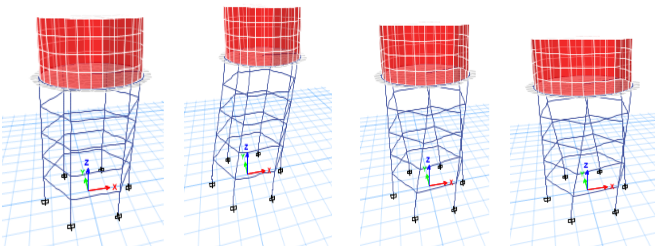


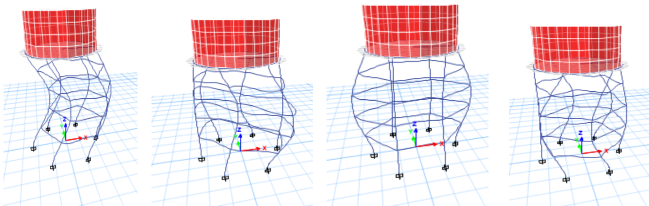
Chart -4: Height of tank vs Displacement (15m staging)

From the analysis it is found that the base shear is maximum at the bottom and minimum at the top shown in chart 3. The displacement value shows greater value at the top and zero value at the bottom shown in chart 4.

The different mode shapes given from the analysis of 15m staging water tank are shown in fig 6.



Mode 1 Mode 2 Mode 3 Mode 4



Mode 5 Mode 6 Mode 7 Mode 8

Fig -6: Different mode shapes of elevated water tank

3.3 Water tank of 10m staging height located on 5^0 sloping ground

The tank is modelled and analyzed by giving the respective parameters illustrated above and the base shear and displacement values are found out. The base shear and displacement values found out are represented graphically are shown in chart 5 and chart 6.

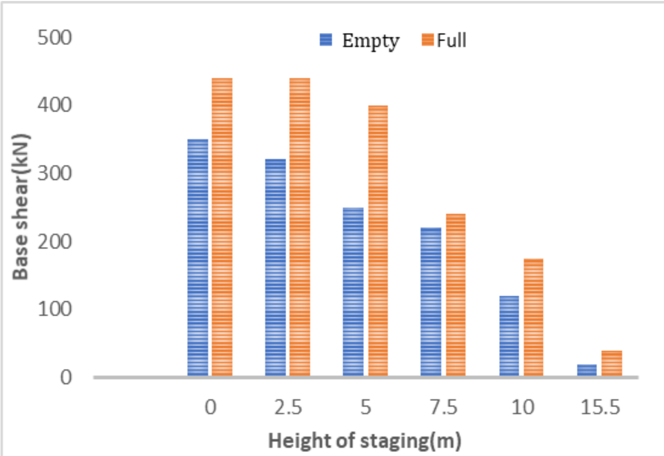


Chart-5: Height of tank vs Base shear (10m staging and 5^0 slope)

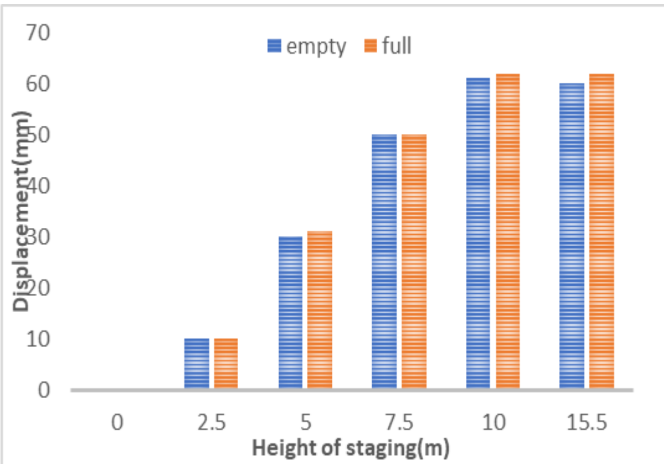
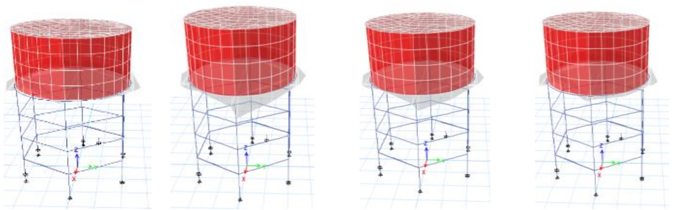


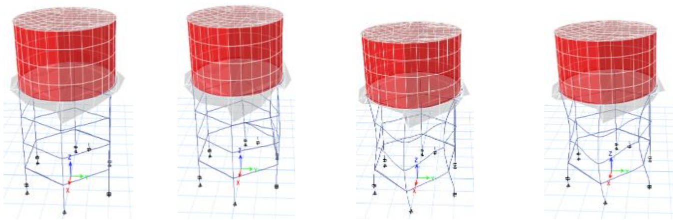
Chart -6: Height of tank vs Displacement (10m staging and 5^0 slope)

From the analysis it is found that the base shear is maximum at the bottom and minimum at the top is shown in chart 5. The displacement value shows greater value at the top and zero value at the bottom is shown in chart 6.

The different mode shapes given from the analysis of 15m staging water tank are shown in fig 7.



Mode 1 Mode 2 Mode 3 Mode 4



Mode 5 Mode 6 Mode 7 Mode 8

Fig -7: Different mode shapes of elevated water tank

3.4 Water tank of 15m staging height located on 5^0 sloping ground

The tank is modelled and analyzed by giving the respective parameters illustrated above and the base shear and displacement values are found out. The base shear and displacement values found out are represented graphically are shown in chart 7and chart 8.

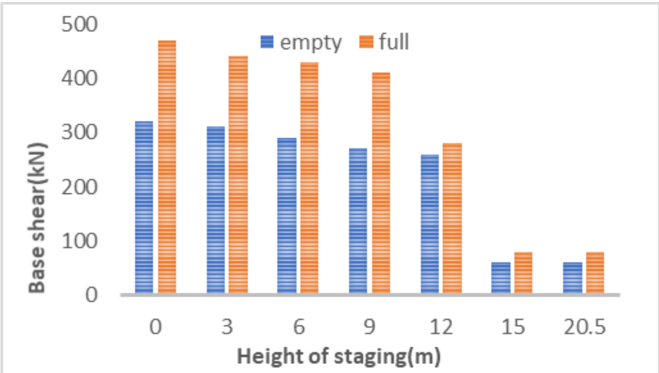


Chart-7: Height of tank vs Base shear (15m staging and 5^0 slope)

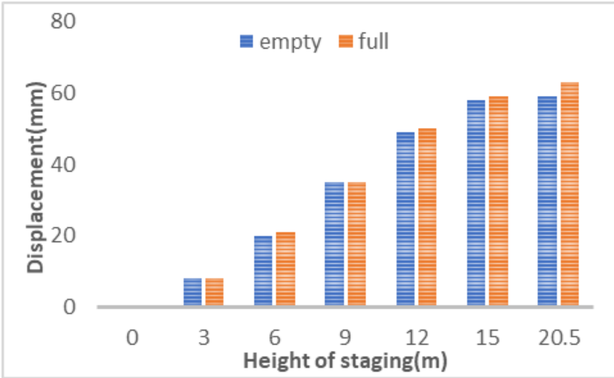
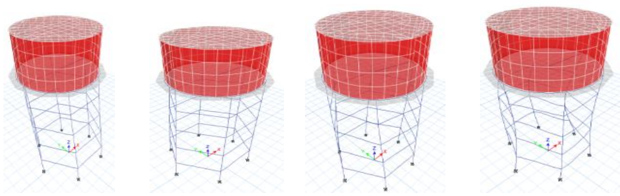


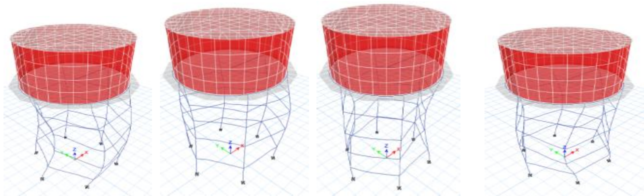
Chart -8: Height of tank vs Displacement (15m staging and 5^0 slope)

From the analysis it is found that the base shear is maximum at the bottom and minimum at the top is shown in chart 7. The displacement value shows greater value at the top and zero value at the bottom is shown in chart 8

The different mode shapes given from the analysis of 15m staging water tank are shown in fig 8.



Mode 1 Mode 2 Mode 3 Mode 4



Mode 5 Mode 6 Mode 7 Mode 8

Fig -8: Different mode shapes of elevated water tank

3.5 Sloshing Wave Height

Sloshing is defined as, any movement of the free fluid surface inside container, brought about by any aggravation to a halfway filled fluid holder. Earthquake excitation causes fluid sloshing inside the container creating additional forces on its walls and roof. During earthquake this effect changes the usual problem of elevated service reservoir from single D.O.F problem to dual D.O.F problem. The sloshing wave height for a circular water tank is calculated using the formula below.

Sloshing Wave Height,

$$d_{max} = (A_h)_c R (D/2)$$

Design seismic coefficient,

$$A_h = \frac{z I sa}{2 R g}$$

Where,

Z = 0.36 (Zone factor given in Table 2 of IS 1893: 2002)

I = 1.5 (Importance factor)

R = 2.5 (Response reduction factor)

Sa/g = 0.254 (Average response acceleration coefficient)

Design seismic coefficient, $A_h = 0.0275$

Sloshing Wave Height, $d_{max} = (A_h)_c R (D/2) = 0.385m$

The provided free board is 0.5m and is greater than the sloshing wave height. In case of sloshing wave height greater than provided free board, the free board should increase to a higher depth.

4. CONCLUSIONS

In this study mainly two staging heights of 10m and 15m for water tanks with same capacity are considered. The study is carried out for tank empty and tank full condition with tank located on levelled ground and 5^0 and 10^0 sloping grounds.

- Both Base shear and Displacement are higher for full tank condition than empty tank condition in both cases. Nearly 10% increase is given from the analysis.
- Displacement is maximum at top storey and base shear has the minimum value at top storey.
- Base shear increases with increase in staging height. The percentage increase of nearly 10% to 20% is noted from the analysis.
- Displacement slightly increases with increase in staging height.
- Base shear increases with increase in slope of the angle. The percentage increase varies from 3% to 5%.
- Displacement slightly decreases with increase in slope angle.

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