Research Paper Engineering

# Analysis of Hybrid Staging Systems for Elevated Storage Reservoir

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**ABSTRACT**

Elevated water tanks are prominently in public view and visible from near as well as long distances. They often become landmarks on the landscape. It is therefore important that the shape and form of the container and the supporting structure must receive due attention from the point of aesthetics. Innovations in the shape and form should be encouraged when they improve the ambience and enhance the quality of the environment.The main aim of this study is to conceptualize innovative hybrid staging systems, considering seismic loading and to understand the behaviour of supporting system which is more effective under different response spectrum method with SAP 2000 software. Analysis follows the guideline for "Seismic Design of Liquid Storage Tanks" provided by the Gujarat State Disaster Management Authority and Preliminary Draft of IS: 11682 "Criteria for Design of RCC Staging for Overhead Water Tanks". In this Paper different supporting systems including innovative staging are considered for study.

**KEYWORDS** Elevated water tanks; Tank Staging; Fluid-structure interaction; Seismic Analysis; SAP2000.

## INTRODUCTION

Water is human basic needs for daily life. Sufficient water distribution depends on design of a water tank in certain area. An elevated water tank is a large water storage container constructed for the purpose of holding water supply at certain height to pressurization the water distribution system. Many new ideas and innovation has been made for the storage of water and other liquid materials in different forms and fashions. There are many different ways for the storage of liquid such as underground, ground supported, elevated etc. Liquid storage tanks are used extensively by municipalities and industries for storing water, inflammable liquids and other chemicals. Thus Water tanks are very important for public utility and for industrial structure.

Elevated water tanks consist of huge water mass at the top of a slender staging which are most critical consideration for the failure of the tank during earthquakes. Elevated water tanks are critical and strategic structures and damage of these structures during earthquakes may endanger drinking water supply, cause to fail in preventing large fires and substantial economical loss. Since, the elevated tanks are frequently used in seismic active regions also hence, seismic behaviour of them has to 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 also take more design forces.

The present study is an effort to identify the seismic behaviour of elevated water tank under Response Spectrum Method with consideration and modelling of impulsive and convective water masses inside the container for different Height wise, zone, soil type and types of staging using structural software SAP2000.

## MODEL PROVISIONS

A satisfactory spring mass analogue to characterize basic dynamics for two mass model of elevated tank was proposed by Housner (1963) after the chileane earthquake of 1960, which is more appropriate and is being commonly used in most of the international codes including GSDMA guideline. The pressure generated within the fluid due to the dynamic motion of the tank can be separated into impulsive and convective parts. When a tank containing liquid with a free surface is subjected to horizontal earthquake ground motion, tank wall and liquid are subjected to horizontal acceleration. The liquid in the lower region of tank behaves like a mass that is rigidly connected to tank wall, termed as impulsive liquid mass. Liquid mass in the upper region of tank undergoes sloshing motion, termed as convective liquid mass. For representing these two masses and in order to include the effect of their hydrodynamic pressure in analysis, two-mass model is adopted for elevated tanks.

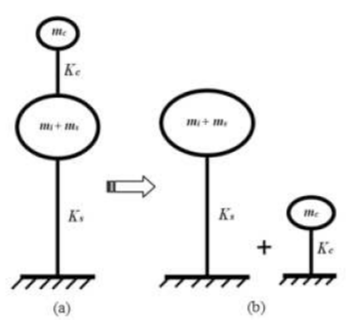


**Fig 1: Two mass model for elevated tank**

In spring mass model convective mass (mc) is attached to the tank wall by the spring having stiffness (Kc), whereas impulsive mass (mi) is rigidly attached to tank wall. For elevated tanks two-mass model is considered, which consists of two degrees of freedom system. Spring mass model can also be applied on elevated tanks, but two-mass model idealization is closer to reality. The two- mass model is shown in Fig. (1). where, mi, mc, Kc, hi, hc, hs, etc. are the parameters of spring mass model and charts as well as empirical formulae are given for finding their values. The parameters of this model depend on geometry of the tank and its flexibility. The two-mass model was first proposed by G. M. Housner (1963)and is being commonly used in most of the international codes. The response of the two-degree of freedom system can be obtained by elementary structural dynamics.

However, for most of elevated tanks it is observed that both the time periods are well separated. Hence, the two-mass idealization can be treated as two uncoupled single degree of freedom system as shown in Fig. 1(b). The stiffness (Ks) is lateral stiffness of staging. The mass (ms) is the structural mass and shall comprise of mass of tank container and one third mass of staging as staging will acts like a lateral spring. Mass of container comprises of roof slab, container wall, gallery if any, floor slab, floor beams, ring beam, circular girder, and domes if provided. Staging part of elevated water tanks follows the provisions given by Criteria for design of RCC staging for overhead water tanks (First revision of IS11682): Draft Code. This draft standard lays down criteria for analysis, design and construction of reinforced cement concrete staging of framed type with columns.

**FLUID-STRUCTURE INTERACTION**

The analysis of elevated tank under seismic load of Fluid-structure-interaction problems can be investigated by using different approaches such as added mass Westergaard or velocity potential, Lagrangian (Wilson and Khalvati), Eulerian (Zienkiewicz and Bettes), and Lagrangian Euclidian approach (Donea). These analyses can be carried out using FEM or by the analytical methods. The added mass approach as shown in Fig.(2) can be investigated by using some of conventional FEM software such as SAP2000, STAAD Pro and LUSAS. Whilst in the other approaches, the analysis needs special programs that include fluid elements in the elements library, such as ANSYS, ABAQUS ADINA, ALGOR and etc.

The general equation of motion for a system subjected to an earthquake excitation can be written as,

$$M\ddot{u} + C\dot{u} + Ku = -M\ddot{u}_g \qquad \text{……………..(1)}$$

In which M, C and K are mass, damping and stiffness matrices with $\ddot{u}$, $\dot{u}$ and u are the acceleration, velocity and displacement respectively, and is the ground acceleration. In the case of added mass approach the form of equation (1) become as below.

$$M^*\ddot{u} + C\dot{u} + Ku = -M^*\ddot{u}_g \qquad \text{……(2)}$$

In which M* is the new mass matrix after adding hydrodynamic mass to the structural mass, while the damping and stiffness matrices are same as in equation (1).

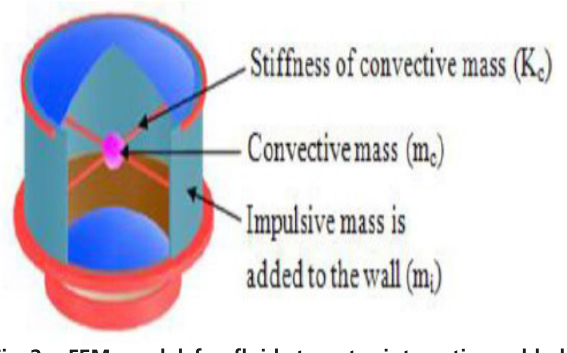


**Fig 2 : FEM model for fluid-strucutre-interaction added mass approach**

Westergaard Model's method was originally developed for the dams but it can be applied to other hydraulic structure, under earthquake loads i.e. tank. In this paper the impulsive mass has been obtained according to GSDMA guideline equations and is added to the tanks walls according to Westergaard Approach as shown in Figure (3) using equation (3).

Where, ρ is the mass density, h is the depth of water and Ai is the area of curvilinear surface.

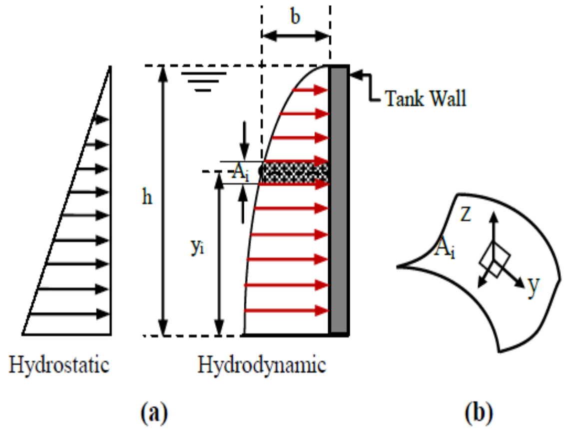


**Fig 3: (a) Westergaard added mass concept (b) Normal and Cartesian directions.**

$$m_{ai} = \left[\frac{7}{8}\rho\sqrt{h\left(h - y_i\right)}\right] A_i \qquad \text{………….(3)}$$

the case of Intze tank where the walls having sloped and curved contact surface, the equation (3) should be compatible with the tank shape by assuming the pressure is still expressed by Westergaard's original parabolic shape. But the fact that the orientation of the pressure is normal to the face of the structure and its magnitude is proportional to the total normal acceleration at the recognized point. In general, the orientation of pressures in a 3-D surface varies from point to point; and if it is expressed in Cartesian coordinate components, it would produce added-mass terms associated with all three orthogonal axes. Following this description the generalized Westergaard added mass at any point i on the face of a 3-D structure is expressed by the equation (4).

$$m_{ai} = a_i A_i \lambda_i^t \lambda_i = a_i A_i \begin{bmatrix} \lambda_x^2 & \lambda_y \lambda_x & \lambda_z \lambda_x \\ \lambda_y \lambda_x & \lambda_y^2 & \lambda_z \lambda_y \\ \lambda_z \lambda_x & \lambda_z \lambda_y & \lambda_z^2 \end{bmatrix} \qquad \text{………(4)}$$

Ai is the tributary area associated with node i, λi is the normal direction cosine(λ2y , λ2x , λ2z ) and ai is Westergaard pressure coefficient.

**STUDY PARAMETERS**

A reinforced elevated water tank with different supporting systems including innovative staging and different height of water tank, zones and soil types and their effect on seismic behavior of supporting systems considered for the present study. The study is carried out on an Intze shape water container of reinforced cement concrete. The storage capacity of water tank is 250 m3. A finite element model (FEM) is used to model the elevated tank system using SAP 2000.The staging heights considered for study are 12m, 16 m, 20 m with 4 m height of each panel. Grade of concrete and steel used are M20 and Fe415 respectively. Figure (4) shows the pictorial view of the sample of 18 models considered for study of

2,50,000 liter capacity reinforced cement concrete elevated water tank for staging pattern model (1). 5 different model Frame type, Shaft type, three innovative model of water tank modeling in Sap 2000 in Full condition. For each staging height two zone are considered and for each zone three soil types are considered. Similar models have been prepared for each suggested staging patterns model. Hence total ninety models are studied for 2,50,000 liter capacity reinforced cement concrete elevated water tank. The other relevant data used in the modeling is tabulated in table 1.

**Table 1: Dimension of Elevated Water Tank Components**

| Description | Data |
|---|---|
| Capacity of the tank (m3) | 250 |
| Unit weight of concrete (kN/m3) | 25 |
| Thickness of top Dome (m) | 0.200 |
| Rise of Top Dome (m) | 1.69 |
| Size of Top Ring Beam (m) | 0.250 x 0.300 |
| Diameter of tank (m) | 8.8 |
| Height of Cylindrical wall (m) | 4 |
| Thickness of Cylindrical wall (m) | 0.200 |
| Size of bottom Ring Beam (m) | 0.500 x 0.300 |
| Rise of Conical dome (m) | 1.5 |
| Thickness of Conical shell (m) | 0.250 |
| Rise of Bottom dome (m) | 1.41 |
| Thickness of Bottom dome shell (m) | 0.200 |
| Size of Circular Ring Beam (m) | 0.500 x 0.600 |
| Model 1 (Frame type) | |
| Number of Columns (circular) | 6 |
| Diameter of columns(m) | 0.650 |
| Size of bracings(m) | 0.300 x 0.600 |
| Distance between intermidiate bracing (m) | 3.14 |
| Model 2 ( Innovative model) | |
| Number of columns | 6 |
| Size of columns (m) | 1.65 x 0.200 |
| Beam(m) | 0.500 x 0.600 |
| Thickness of Plate form(m) | 0.200 |
| Model 3 (Curve shape Innovative model) | |
| Number of columns | 4 |
| Size of columns (m) | 2.645 x 0.200 |
| Description | Data |
| Beam(m) | 0.500 x 0.600 |
| Thickness of Plate form(m) | 0.200 |
| Model 4( Innovative model) | |
| Mid Shaft(m) | 6.28 |
| Corner shaft(m) | 2.22 |
| Beam(m) | 0.500 x 0.600 |
| Thickness of wall(m) | 0.200 |
| Thickness of Plate form(m) | 0.200 |
| Model 5 (Shaft type) | |
| Thickness of Shaft(m) | 0.150 |
| Staging Height(m) | 12, 16, 20 |
| Seismic Zone | IV, V |
| Soil type | Hard, Medium, Soft |
| Panel Height (m) | 4 |

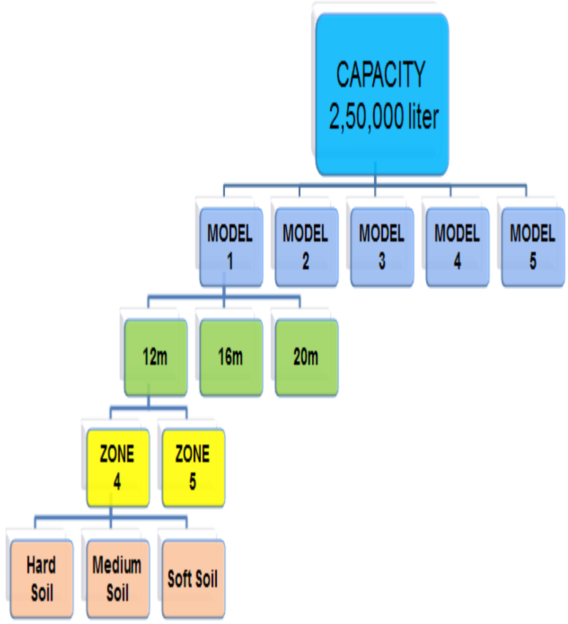


**Figure 4 : Models for Seismic Analysis**

In the present study different water tank supporting systems frame type, shaft type , innovative staging are shown in Fig (5).

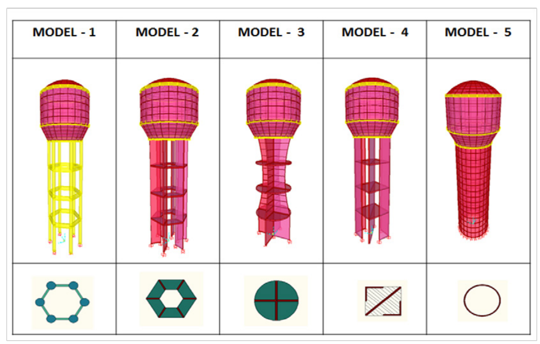


**Figure 5 : Water tank staging patterns models in SAP 2000**

## ANALYSIS RESULTS

Results for different important properties of this study are shown graphical form for base shear, overturning moment and top displacement by changing various parameters has been evaluated and compared for 90 water tanks.

**The obtained results are summarized as follows:**

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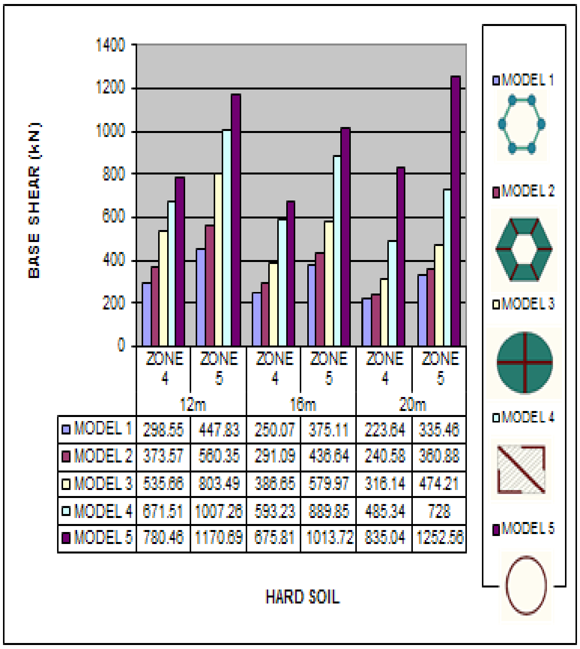
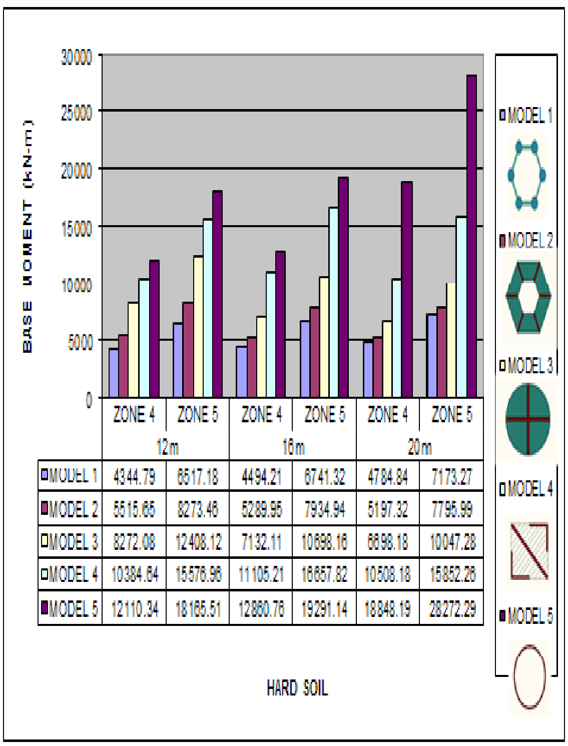


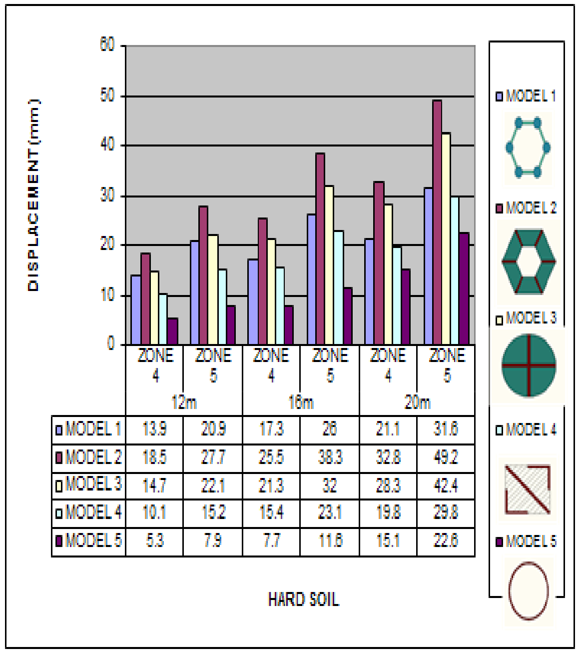

| | 12m ZONE 4 | 12m ZONE 5 | 16m ZONE 4 | 16m ZONE 5 | 20m ZONE 4 | 20m ZONE 5 |
|---|---|---|---|---|---|---|
| MODEL 1 | 298.55 | 447.83 | 250.07 | 375.11 | 223.64 | 335.46 |
| MODEL 2 | 373.57 | 560.35 | 291.09 | 436.64 | 240.58 | 360.88 |
| MODEL 3 | 535.66 | 803.49 | 386.65 | 579.97 | 316.14 | 474.21 |
| MODEL 4 | 671.51 | 1007.26 | 593.23 | 889.85 | 485.34 | 728 |
| MODEL 5 | 780.46 | 1170.69 | 675.81 | 1013.72 | 835.04 | 1252.56 |

**Fig 6 : Base Shear variation based on different staging patterns, height and Zone in Hard Soil**



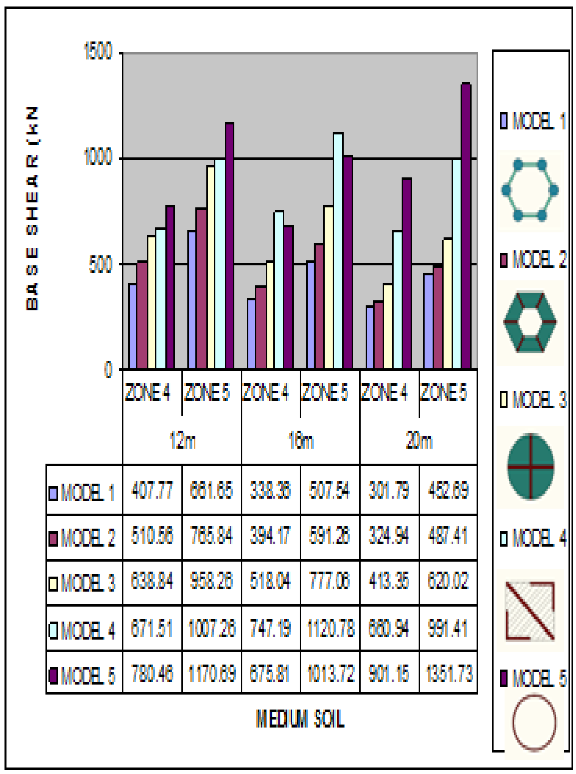

| | 12m ZONE 4 | 12m ZONE 5 | 16m ZONE 4 | 16m ZONE 5 | 20m ZONE 4 | 20m ZONE 5 |
|---|---|---|---|---|---|---|
| MODEL 1 | 4344.79 | 6517.18 | 4494.21 | 6741.32 | 4784.84 | 7173.27 |
| MODEL 2 | 5515.65 | 8273.46 | 5289.95 | 7934.94 | 5197.32 | 7795.99 |
| MODEL 3 | 8272.08 | 12408.12 | 7132.11 | 10698.16 | 6898.18 | 10047.28 |
| MODEL 4 | 10384.64 | 15576.96 | 11105.21 | 16657.82 | 10508.18 | 15852.26 |
| MODEL 5 | 12110.34 | 18165.51 | 12860.76 | 19291.14 | 18848.19 | 28272.29 |

**Fig 7: Base Moment variation Based on different staging patterns, height and Zone in Hard Soil**



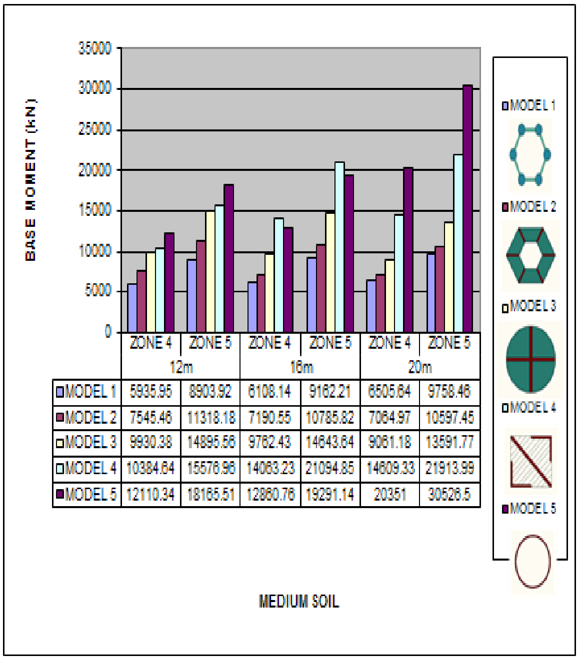

| | 12m ZONE 4 | 12m ZONE 5 | 16m ZONE 4 | 16m ZONE 5 | 20m ZONE 4 | 20m ZONE 5 |
|---|---|---|---|---|---|---|
| MODEL 1 | 13.9 | 20.9 | 17.3 | 26 | 21.1 | 31.6 |
| MODEL 2 | 18.5 | 27.7 | 25.5 | 38.3 | 32.8 | 49.2 |
| MODEL 3 | 14.7 | 22.1 | 21.3 | 32 | 28.3 | 42.4 |
| MODEL 4 | 10.1 | 15.2 | 15.4 | 23.1 | 19.8 | 29.8 |
| MODEL 5 | 5.3 | 7.9 | 7.7 | 11.6 | 15.1 | 22.6 |

**Fig 8 : Displacement variation based on different staging patterns, height and Zone in Hard Soil**



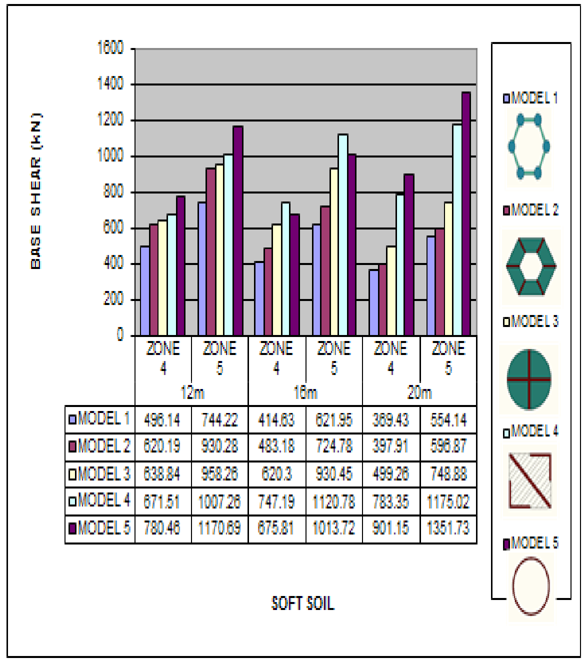

| | 12m ZONE 4 | 12m ZONE 5 | 16m ZONE 4 | 16m ZONE 5 | 20m ZONE 4 | 20m ZONE 5 |
|---|---|---|---|---|---|---|
| MODEL 1 | 407.77 | 661.65 | 338.36 | 507.54 | 301.79 | 452.69 |
| MODEL 2 | 510.56 | 765.84 | 394.17 | 591.26 | 324.94 | 487.41 |
| MODEL 3 | 638.84 | 958.26 | 518.04 | 777.06 | 413.36 | 620.02 |
| MODEL 4 | 671.51 | 1007.26 | 747.19 | 1120.78 | 660.94 | 991.41 |
| MODEL 5 | 780.46 | 1170.69 | 675.81 | 1013.72 | 901.15 | 1351.73 |

**Fig 9 : Base Shear variation based on different staging patterns, height and Zone in Medium Soil**



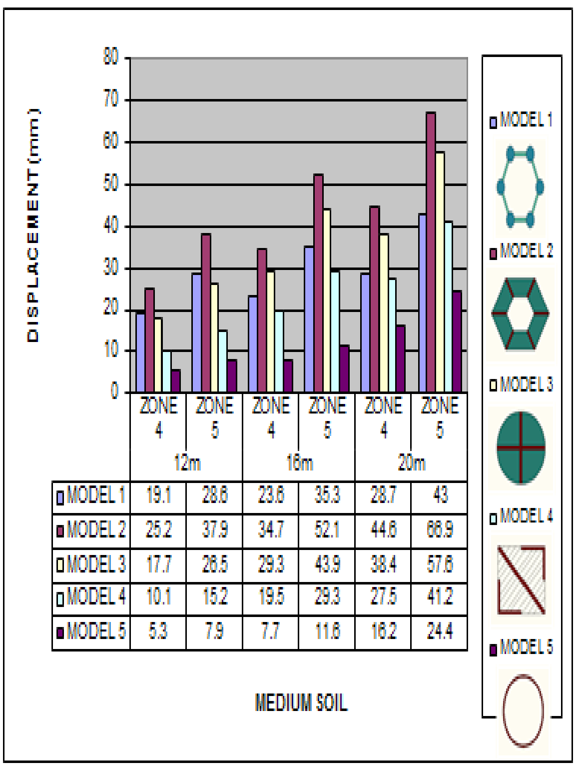

| | ZONE 4 (12m) | ZONE 5 (12m) | ZONE 4 (16m) | ZONE 5 (16m) | ZONE 4 (20m) | ZONE 5 (20m) |
|---|---|---|---|---|---|---|
| MODEL 1 | 5935.95 | 8903.92 | 6108.14 | 9162.21 | 6505.64 | 9758.46 |
| MODEL 2 | 7545.46 | 11318.18 | 7190.55 | 10785.82 | 7064.97 | 10597.45 |
| MODEL 3 | 9930.38 | 14895.56 | 9762.43 | 14643.64 | 9061.18 | 13591.77 |
| MODEL 4 | 10384.64 | 15576.96 | 14063.23 | 21094.85 | 14609.33 | 21913.99 |
| MODEL 5 | 12110.34 | 18165.51 | 12860.76 | 19291.14 | 20351 | 30526.5 |

**Fig 10 : Base Moment variation based on different staging patterns, height and Zone in Medium Soil**



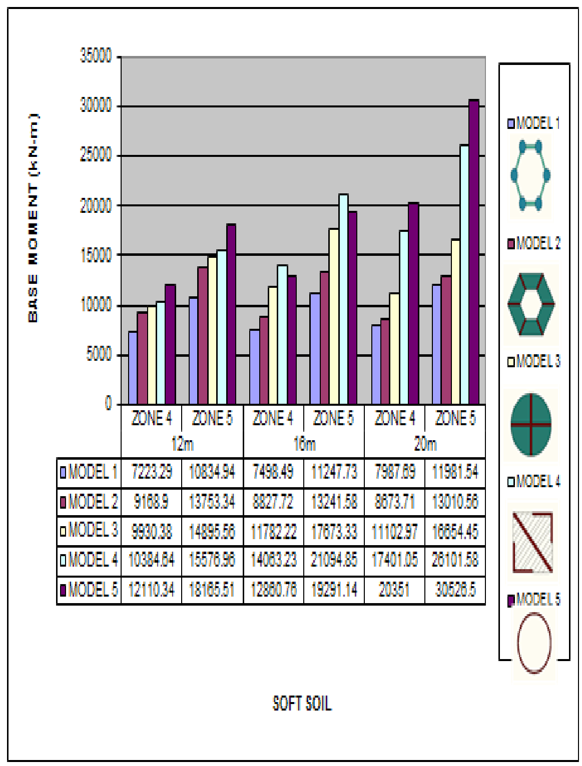

| | ZONE 4 (12m) | ZONE 5 (12m) | ZONE 4 (16m) | ZONE 5 (16m) | ZONE 4 (20m) | ZONE 5 (20m) |
|---|---|---|---|---|---|---|
| MODEL 1 | 496.14 | 744.22 | 414.63 | 621.95 | 369.43 | 554.14 |
| MODEL 2 | 620.19 | 930.28 | 483.18 | 724.78 | 397.91 | 596.87 |
| MODEL 3 | 638.84 | 958.26 | 620.3 | 930.45 | 499.26 | 748.88 |
| MODEL 4 | 671.51 | 1007.26 | 747.19 | 1120.78 | 783.35 | 1175.02 |
| MODEL 5 | 780.46 | 1170.69 | 675.81 | 1013.72 | 901.15 | 1351.73 |

**Fig 12 : Base Shear variation based on different staging patterns height wise and Zone in Soft Soil**




| | ZONE 4 (12m) | ZONE 5 (12m) | ZONE 4 (16m) | ZONE 5 (16m) | ZONE 4 (20m) | ZONE 5 (20m) |
|---|---|---|---|---|---|---|
| MODEL 1 | 19.1 | 28.6 | 23.6 | 35.3 | 28.7 | 43 |
| MODEL 2 | 25.2 | 37.9 | 34.7 | 52.1 | 44.6 | 66.9 |
| MODEL 3 | 17.7 | 26.5 | 29.3 | 43.9 | 38.4 | 57.6 |
| MODEL 4 | 10.1 | 15.2 | 19.5 | 29.3 | 27.5 | 41.2 |
| MODEL 5 | 5.3 | 7.9 | 7.7 | 11.6 | 16.2 | 24.4 |

**Fig 11 : Displacement variation based on different staging patterns, height and Zone in Medium Soil**




| | ZONE 4 (12m) | ZONE 5 (12m) | ZONE 4 (16m) | ZONE 5 (16m) | ZONE 4 (20m) | ZONE 5 (20m) |
|---|---|---|---|---|---|---|
| MODEL 1 | 7223.29 | 10834.94 | 7498.49 | 11247.73 | 7987.69 | 11981.54 |
| MODEL 2 | 9168.9 | 13753.34 | 8827.72 | 13241.58 | 8673.71 | 13010.56 |
| MODEL 3 | 9930.38 | 14895.56 | 11782.22 | 17673.33 | 11102.97 | 16654.45 |
| MODEL 4 | 10384.64 | 15576.96 | 14063.23 | 21094.85 | 17401.05 | 26101.58 |
| MODEL 5 | 12110.34 | 18165.51 | 12860.76 | 19291.14 | 20351 | 30526.5 |

**Fig 13 : Base Moment variation based on different staging patterns, height and Zone in Soft Soil**

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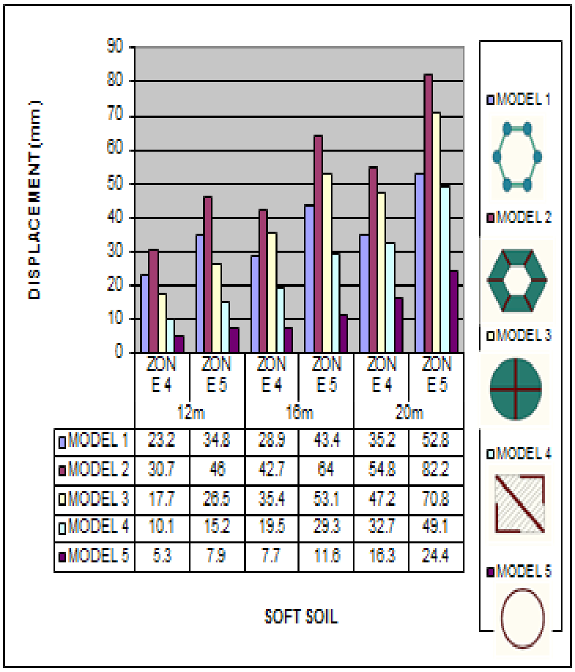


| | ZONE 4 (12m) | ZONE 5 (12m) | ZONE 4 (16m) | ZONE 5 (16m) | ZONE 4 (20m) | ZONE 5 (20m) |
|---|---|---|---|---|---|---|
| MODEL 1 | 23.2 | 34.8 | 28.9 | 43.4 | 35.2 | 52.8 |
| MODEL 2 | 30.7 | 46 | 42.7 | 64 | 54.8 | 82.2 |
| MODEL 3 | 17.7 | 26.5 | 35.4 | 53.1 | 47.2 | 70.8 |
| MODEL 4 | 10.1 | 15.2 | 19.5 | 29.3 | 32.7 | 49.1 |
| MODEL 5 | 5.3 | 7.9 | 7.7 | 11.6 | 16.3 | 24.4 |

**Fig 14 : Displacement variation based on different staging patterns, height and Zone in Soft Soil**

## CONCLUSIONS

(a) Base shear increases from seismic zone IV to V for different types of staging patterns about 50%.

(b) Base shear increases from soil type I to III for different types of staging patterns. Base shear for hard soil is about 35% to 37% less than that of medium soil, about 65% to 67% less than that of soft soil. Base shear for medium soil is about 20% to 23% less than that of soft soil.

(c) Base shear of Hybrid staging patterns are between column brace type and shaft type staging systems.

(d) Base moment is increases from seismic zone IV to V for different types of staging patterns about 50%.

(e) Base moment increases from soil type I to III for different types of staging patterns. Base moment for hard soil is about 35% to 37% less than that of medium soil, about 65% to 67% less than that of soft soil. Base shear for medium soil is about 20% to 23% less than that of soft soil.

(f) Base Moment of Hybrid staging patterns are between column brace type and shaft type staging systems

(g) Displacement is increases from seismic zone IV to V about 50%.

(h) Displacement is increases from soil type I to III. Displacement for hard soil is about 35% to 37% less than that of medium soil, about 65% to 67% less than that of soft soil. Base shear for medium soil is about 20% to 23% less than that of soft soil.

Present study will be useful to civil engineers to understand the Seismic behaviour of elevated water tank for various staging systems and also to get the feel of effect of height, zones, soil types on base shear, base moment and displacement.

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