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Economical Aspects 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. 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 compare cost for conceptualize innovative hybrid staging systems of ESR, considering seismic loading and analyzed with SAP2000. Economical aspects are studied for different innovative water tanks staging systems with reference to conventional frame type and shaft type staging of ESR. The present rate of steel and concrete are taken in to consideration for study. Analysis follows the guideline for "Seismic Design of Liquid Storage Tanks" provided by the Gujarat State Disaster Management Authority and Indian Standard and IS: 11682 "Criteria for design of RCC staging for over head water tanks".*

KEYWORDS : Elevated water tanks; Tank Staging; Two mass model; Fluid-structure interaction; Cost Analysis; SAP2000.

I. INTRODUCTION

Water is essential to humans and other 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 draft code for liquid retaining structures is one of the outcomes of the project. The present study is an effort to identify the cost calculation of innovative staging systems of ESR and compared with frame type and shaft type staging systems of ESR. The present rate of steel and concrete are used. The designs of steels are derived considering load combinations as per IS: 1893 (Part-I) by using structural software SAP2000.

II. MODEL PROVISIONS

Two mass model for elevated tank was proposed by Housner (1963) which is more appropriate and is being commonly used in most of the international codes including Draft code for IS 1893 (Part-II). 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. This mass is termed as impulsive liquid mass which accelerates along with the wall and induces impulsive hydrodynamic pressure on tank wall and similarly on base Liquid mass in the upper region of tank undergoes sloshing motion. This mass is termed as convective liquid mass and it exerts convective hydrodynamic pressure on tank wall and base. For representing these two masses and in order to include the effect of their hydrodynamic pressure in analysis, spring mass model is adopted for ground-supported tanks and two-mass model for elevated tanks.

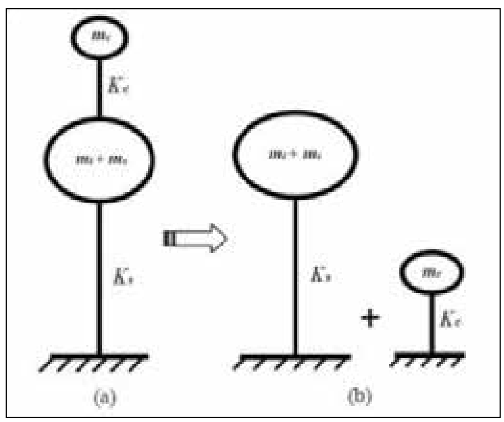

Fig 1: Two mass model for elevated tank

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.

III. FLUID-STRUCTURE INTERACTION

During lateral base excitation seismic ground acceleration causes hydrodynamic pressure on the tank wall which depends on the geometry of tank, height of liquid, properties of liquid and fluid-tank interaction. Proper estimation of hydrodynamic pressure requires a rigorous fluid-structure interaction analysis. In the mechanical analogue of tank-liquid system, the liquid is divided in two parts as, impulsive liquid and convective liquid. The impulsive liquid moves along with the tank wall, as it is rigidly connected and the convective and sloshing liquid moves relative to tank wall as it under goes sloshing motion. This mechanical model is quantified in terms of impulsive mass, convective mass, and flexibility of convective liquid. Housner (1963) developed the expressions for these parameters of mechanical analogue for circular and rectangular tanks. Fluid–structure interaction problems can be investigated by various approaches such as added mass approach (Westergaard, 1931; Barton and Parker, 1987), the Eulerian approach (Zienkiewicz and Bettes, 1978), the Lagrangian approach (Wilson and Khalvati, 1983; Olson and Bathe, 1983) or the Eulerian–Lagrangian approach (Donea et al., 1982). The simplest method of these is the added mass approach as shown in Figure 2, can be investigated using some of conventional FEM software such as SAP2000, STAAD Pro and LUSAS. The general equation of motion for a system subjected to an earthquake excitation can be written as,

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

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.

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

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).

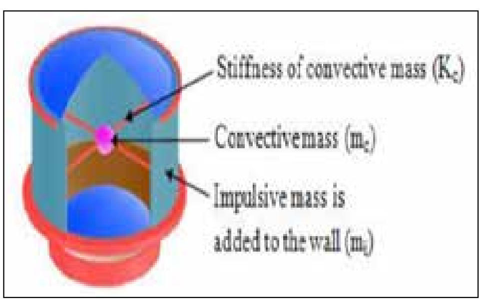

Fig 2: FEM model for fluid structure interaction added mass approach

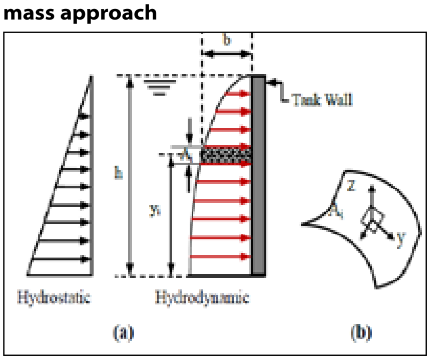

Fig 3: (a) Westergaard added mass concept (b) Normal and Cartesian directions.

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

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.

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

IV. PROBLEM DESCRIPTION

A reinforced elevated water tank with different supporting systems including innovative staging 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.Grade of concrete and steel used are M20 and Fe415. The cost calculation of innovative staging systems are calculated and compared with frame type and shaft type staging. The present rate of steel and concrete are used. The designs of steels are derived by using structural software SAP2000. 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 intermediate 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
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)	16
Seismic Zone	IV
Soil codition	Medium type
Panel Height (m)	4

In the present study different water tank supporting systems frame type, shaft type, innovative staging are shown in Fig (4).

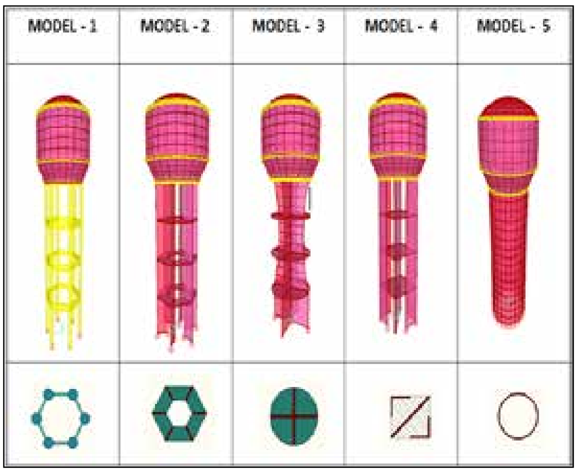

Figure 4: Different Water Tank Staging Patterns Models in SAP2000

V. ESTIMATION OF QUANTITIES

After the analysis and design of a structure quantity analysis is to be performed. Quantity analysis is basically a practical aspect. This analysis gives the overall material consumed in the construction of a structure. The economy of a structure depends upon the quantity of material used in a structure. Structures are designed keeping in mind economy and safety. Quantity analysis includes not only the structural material i.e. concrete and steel but also other materials like cement mortar, epoxy paint, etc including labor.

For this problem only structural quantities i.e. concrete in m3 and steel in kg (without labor), have been worked out. The material used in each component is calculated in the program while designing.

The general formula for finding the concrete and steel quantity is

$Q_c = W_m D_m L_m$
$Q_s = A_b L_b \rho_s$

Where, Q_c = Quantity of concrete (m3)
W_m = Width of member (m)
D_m = Depth of member (m)
L_m = Length of member (m)
Q_s = Quantity of steel (kg)
A_b = Area of bar (m2)
L_b = Length of bar (m)
ρ_s = Density of bar (=7850 kg/m3)

VI. COST ESTIMATION

This is the final step to be done before completion of any design project. The cost of the structure is worked out. The cost of entire project involves structure cost, transportation cost, instrumentation cost, real estate cost, management cost, depreciation cost in case of heavy machineries, overhead project cost in case of delay etc. Here, discussion has been limited to structure cost only. The structural cost also involves cost of many items e.g. cost of excavation, scaffolding, piping, plastering, painting, etc. The cost of different grade of concrete is also different.

Depending upon the quantity analysis, the cost for concrete and steel has been worked out in the program. That is total cost of concrete and steel used in the tank is found out. The rate of concrete per m3 and steel per kg is known. These rates will be multiplied by the total quantity of concrete and steel and by adding their cost; total cost of tank has been obtained. For finding the cost per litre of tank, the total cost obtained has been divided by the capacity of the tank. The cost obtained is exclusively of the concrete and steel, no other materials are taken into consideration. Cost of concrete is 4500 per m^3 and cost of steel is 56 per kg has been taken. Cost estimation of Intze tank for capacity 250 m3 and for 16m height staging has been carried out.

The observation is, the cost per liter of tank is more for lesser capacity. If the different components of the tank are constructed with different grade of concrete i.e. top dome may be in M20, ring beams and other components in M25, foundation in M30, etc then the cost of concrete for each component should be worked out accordingly and then there summation would give the entire cost. The cost is worked by using the program, the present rates of concrete and steel is applying as an input.

VII. RESULTS

In the present study different staging systems including innovative hybrid staging systems are study. The cost of innovative staging systems are calculated and compared with cost of frame type and shaft type water tank. The present rate of steel and concrete are taken in to consideration for study. Analyses of different innovative hybrid staging systems of ESR are to be given by using FE software SAP2000.

Table 2. Cost Calculations For Different Staging Systems Including Innovative Hybrid Staging Systems Of Esr.

Water Tank Staging Types	Volume (m3)		Cost (Rs.)		Total Cost (Rs.)
	Steel	Concrete	Steel	Concrete	
Frame Type staging - model 1	1.438	104.45	6,32,464	4,70,043	11,02,507
Innovative Type staging-mode 2	1.52	111.65	6,71,160	5,02,425	11,73,585
Curve Type Innovative staging-model 3	1.81	118.61	7,95,984	5,33,745	13,29,729
Innovative Type staging-model 4	2.21	129.68	9,74,064	5,83,560	15,57,624
Shaft Type staging-model 5	1.85	109.47	8,13,344	4,92,615	13,05,959

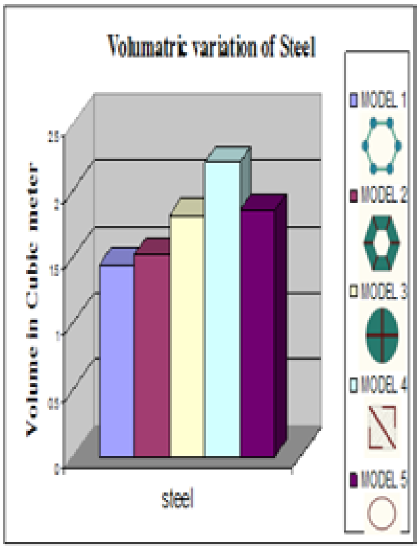

Figure 5: Volumetric Comparison of Steel for different Staging Systems including innovative hybrid staging systems of ESR.

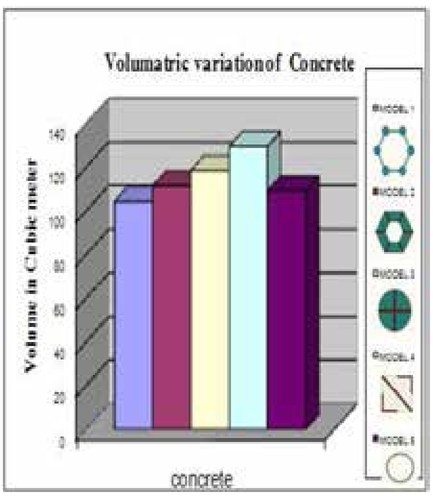

Figure 6: Volumetric Comparison of Concrete for different Staging Systems including innovative hybrid staging systems of ESR.

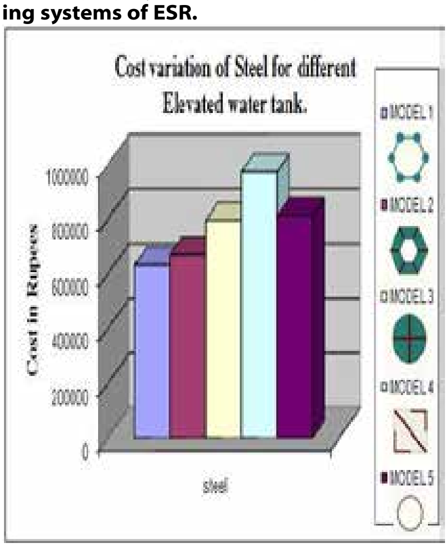

Figure 7: Cost Comparison of Steel for different Staging Systems including innovative hybrid staging systems of ESR (cost is in Rupees).

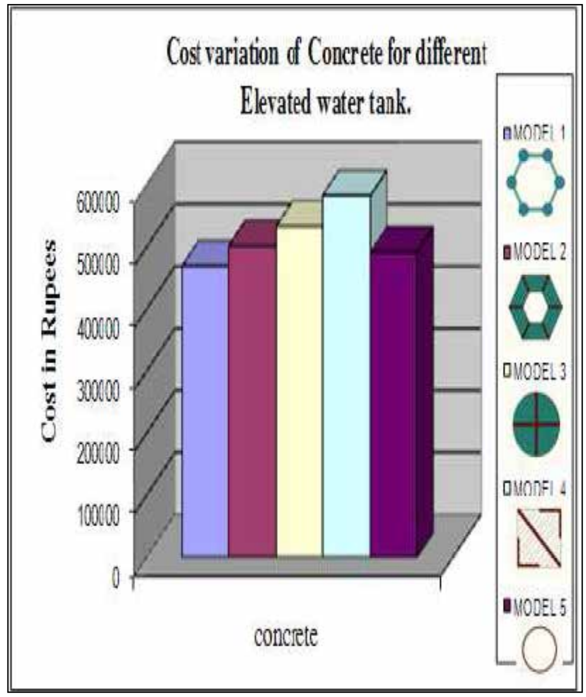

Figure 8: Cost Comparison of Concrete for different Staging Systems including innovative hybrid staging systems of ESR (cost is in Rupees).

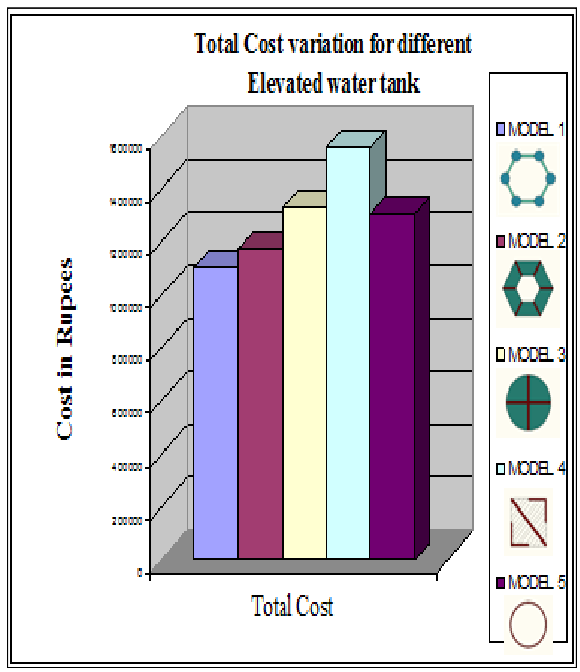

Figure 9: Total Cost Comparison for different Staging Systems including innovative hybrid staging systems of ESR (cost is in Rupees).

VIII. CONCLUSIONS

The obtained results are summarized as follows:-

a) Graph of total cost revels that total cost of the innovative type water tank staging system of model 2 is nearly equal to frame type water tank model 1.

b) In case the total cost, innovative type water tank staging system of model 3 is nearly value to shaft type water tank model 5.

c) Total cost of innovative models of water tank staging systems are nearly of shaft type staging and frame type; but the cost of innovative water tank staging systems of model 4 is considerably higher. However the some extra cost of model 4 but innovative elevated water tanks are prominently aesthetics visible from near as well as from long distances in public view. The innovative supporting structure must receive due attention from the point of aesthetics..

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