Dynamic Behaviour of Elevated Concrete Water Tank with Alternate Impulsive Mass Configurations

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Abstract: - Analysis of hydrodynamic structure such as elevated concrete water tank is quite complicated when compared with other structures. As well as dynamic fluid-structure interaction (FSI) plays an important effects in this complexity for which research suggests solution by using different methods. This paper presents the dynamic behavior of elevated concrete water tank with alternative impulsive masses configurations. Six models were simulated to determine the effects of impulsive mass mode. Simulation of the models was carried out in three-dimensional finite element method via LUSAS FEA 14.1. An artificial ground motion compatible with a target response spectrum that developed by other researchers has been generated according to Gasparini and Vanmarcke procedure. The mass of impulsive mode has been obtained according to Errucode-8. The results of time for impulsive mode of free vibration and the response (time history) of node at highest level of the tank were then compared with added mass approach (Westergaard).

Key-Words: - Elevated concrete water tank, impulsive mass, artificial ground motion

1 Introduction

Design of new tanks and safety evaluation of existing tanks should be carried out with a high level of accuracy because the failure of such structures, particularly during an earthquake, may be disastrous. Hydrodynamic pressures on tanks under earthquake forces play an important role in the design of the tank.

In order to make sure that the water tank design is capable to withstand any earthquake loads like overturning moment and base shear, therefore the needs of detailed investigation of fluid structure interaction must be taken into account. The movement and response of the water towards the wall structure may create an effect to the fundamental frequency of elevated tank.

There are many techniques to handle the dynamic response of elevated concrete water tank. The analysis of elevated concrete water tank under dynamic load of fluid-structure interaction problems can be investigated by using different approaches such as added mass [12], Lagrangian [13], Eulerian [14], and Lagrangian Eulerian approach [3]. These analyses can be carried out in the finite element method (FEM) or by the analytical methods. Previous study has shown that using of analytical model could change the results of shear forces and bending moment at the base of water tank up to 10% compared with the FEM model [5], The added mass approach can be investigated by using some of conventional FEM software such as SAP 2000, STAAD Pro and LUSAS, whilst the other approaches of analyses needs special programs that include fluid elements such as ANSYS, ABAQUS ADINA, ALGOR and etc.

According to the added mass approach, when the tank containing liquid vibrates, the liquid in the lower region exerts as impulsive masses that are connected rigidly to the tank walls while the upper region of the liquid termed as convective mass that are connected to the tank wall by springs as shown in the figure 1,[8].

The difficulty is how to include the impulsive liquid's mass in the analysis of the natural frequency in the finite element model. One of the possible method is to analyse the model shapes by considering the inertia forces generated in the contained liquid as external force acting on the tank wall according to Westergaard's approach[12].

The objective of this paper is to suggest an alternative suitable modification, in order to simplify the Westergaard techniques and simultaneously will save the computational time and efforts.

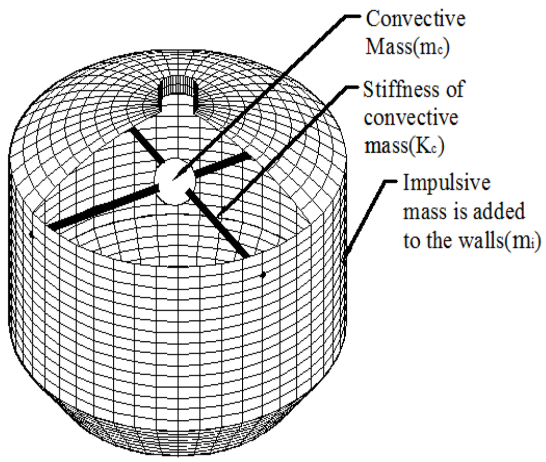

Fig.1 The finite element models for the structure–fluid system.

2 Modeling Techniques

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

$$M\ddot{u} + C\dot{u} + Ku = -M\ddot{u}_g \tag{1}$$

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

$$M^{*}\ddot{u} + C\dot{u} + Ku = -M^{*}\ddot{u}_g \tag{2}$$

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).

2.1 Generating Artificial Ground Motion

Selection of appropriate ground motions that compatible with design response spectrum in particular region could affect the results [1], thus in this paper the procedure developed by Gasparini and Vanmarcke [6] is adopted.

This procedure is based on the fact that any periodic function can be expanded into a series of sinusoidal waves [9].

$$x(t) = \sum_{i=1}^{n} A_i \sin(\omega_i t + \varphi_i) \tag{3}$$

In which A_i is the amplitude and ω_i is the phase angle of the i^{th} contributing sinusoidal. The amplitudes A_i are related to the (one side) spectral density function G (ω) in the following way:

$$A_i = \sqrt{2\int_o^{\omega_i} G(\omega_i).d\omega} \tag{4}$$

The relationship between spectral density function of ground motion and response spectrum can be expressed as flowing

$$G(\omega_i) \approx \frac{1}{\left(\dfrac{\pi}{4\zeta_s} - 1\right)} \left\{ \frac{\omega_i^2 (S_V)_{S.P}^2}{r_{S.P}^2} - \int_0^{\omega} G(\omega) d\omega \right\}^{1/2} \tag{5}$$

In which

$$\zeta_s = \frac{\xi}{1 - e^{-2\zeta\omega_n t}} \tag{6}$$

$$r_{s.p} = [2.\log\{2n[1 - \exp(-\delta_y(s)\sqrt{\pi.\log 2n}]\}]^{1/2} \tag{7}$$

$$\delta_y(s) = \left(\frac{4\zeta.t}{\pi}\right)^{1/2} \tag{8}$$

$$n = \frac{-\omega_n.t}{2\pi}.\frac{1}{\log 0.368} \tag{9}$$

Where S_V a spectral velocity, ξ is is a damping ratio, S is duration, and ω_n is a natural frequency.

The response spectrum in the equation (5) is obtained from seismic hazard analysis by other researchers [7]. The power of the motion produced by using equation (3) does not vary with time. To simulate the transient character of real earthquakes, the steady-state motions are multiplied by a deterministic envelope function I(t). The artificial motion X(t) becomes:

$$X(t) = a(t) = I(t)\sum_n A_n - \sin(\omega_n t + \phi_n) \tag{10}$$

There are three different envelope intensity functions available such as trapezoidal, exponential, and compound [6]. The procedure then artificially raises or lowers the generated peak acceleration to match exactly the target peak acceleration that has been computed by using seismic hazard analysis.

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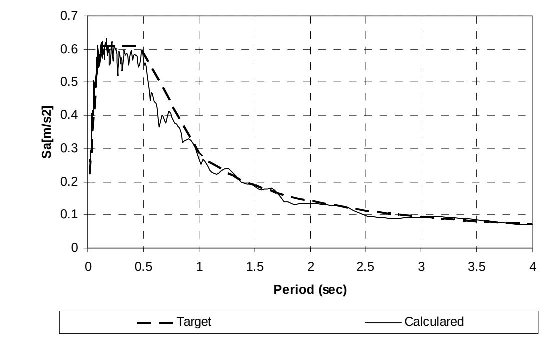
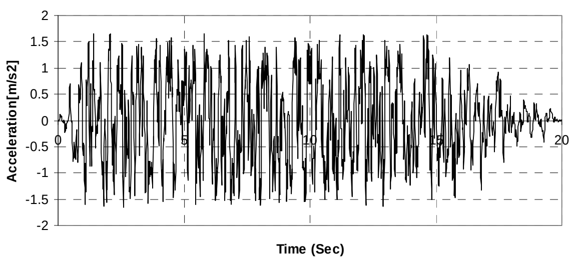


(a)



(b)

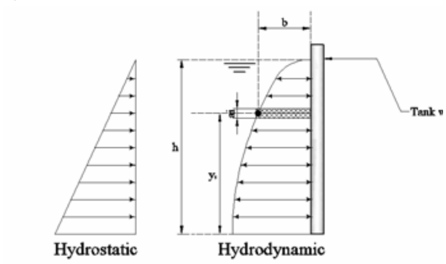
Fig 3 (a) target and calculated response spectrum, (b) artificial ground motion compatible with target response spectrum.

2.2 Westergaard Model

This method was originally developed for the dams but it can be applied to other hydraulic structure under earthquake loads i.e. tanks [3]. In this paper the impulsive mass has been obtained according to EC-8 technique and is added to the tanks walls according to Westergaard Approach Figure 2 using equation (3)

$$m_{ai} = [\frac{7}{8}\rho\sqrt{h(h-y_i)}]A_i \quad (11)$$

In which ρ is the mass density, H the depth of wall and $\ddot{u}_g$ the imposed ground acceleration.



(b)

(a)

Fig.2, (a) Westergaard Added Mass Concept,) Normal and Cartesian directions of curvilinear surfa

In the case of Intze tank where the walls having sloped and curved contact surface, the equation (1) should be compatible with the tank shape. This can be assumed and expressed by Westergaard's original parabolic shape. Even though the orientation of the pressure is normal to the face of the structure and its magnitude is proportional to the total normal acceleration at that point. In general, the orientation of pressures on a three-dimensional surface varies from point to point; and if 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 Kuo [10].

$$m_{ai} = \alpha_i A_i \lambda_i^T \lambda_i = \alpha_i A_i \begin{bmatrix} \lambda_x^2 & & sym \\ \lambda_Y \lambda_X & \lambda_y^2 & \\ \lambda_z \lambda_x & \lambda_z \lambda_y & \lambda_z^2 \end{bmatrix} \quad (12)$$

Where Ai = tributary area associated with node *i*

$\lambda_i = (\lambda_x, \lambda_y, \lambda_z)_i$ is the normal direction cosines as in Figure 3 (2)

α_i = Westergaard pressure coefficient given by

$$\alpha_i = \frac{7}{8}\rho_w\sqrt{h_i(h_i - y_i)}$$

2.3 Suggested Model

The suggested model is to distribute the impulsive mass, by different alternative configurations which are easier than Westergaard technique. The impulsive mass is considered to be acting at the level of gravity center of empty container tank walls, and distributed into 4, 8, 16, 24 and 48 masses, as shown in the figure 3. Whislt, in the model No 6 the mass is distributed equally along the walls

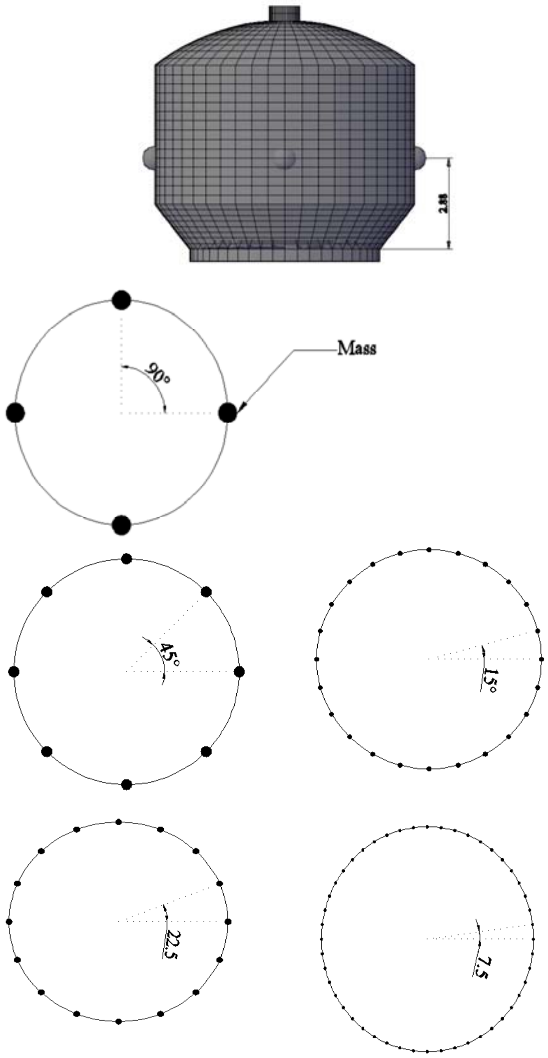


Fig.3 Alternative masses distribution

3 Case Study

3.1 Description of Existing Elevated Concrete Water Tank

The elevated concrete water tank has a capacity of 250 m^3 with the top of water level at about 21.8 m above ground. The tank is spherical in shape, 8.6 m in diameter and 7.85 m in height at its centre. The support consists of 6 vertical circular columns and the columns are connected by the circumferential beams at regular intervals, of 4,8,12 and 16 m as shown in Figure (4) and the density of concrete is 25 KN/m^3.

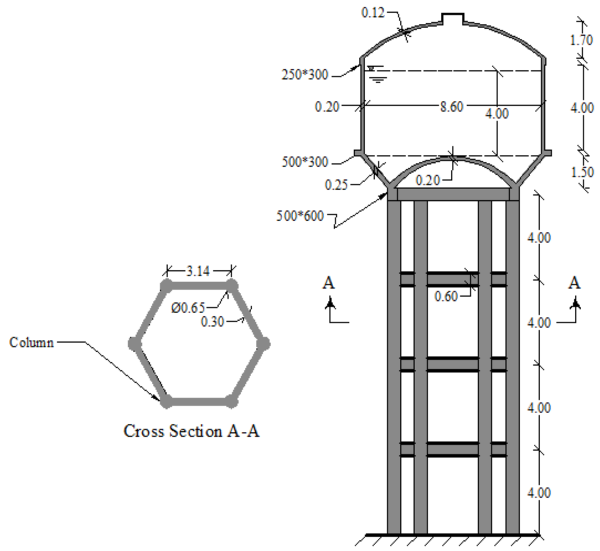
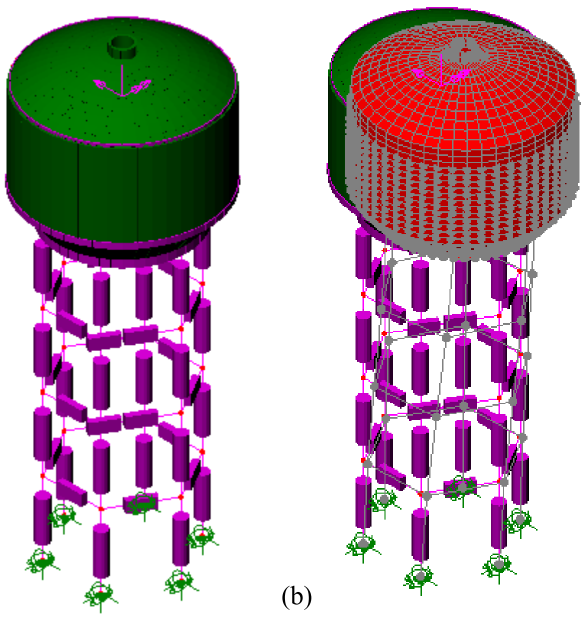


Fig.4 Details of tank geometry

3.2 Numerical Simulation of the tank

A finite element model is used to model the fluid-structure of the elevated water tank, based on the fixed base assumptions as shown in Figure5. Beams are modelled as frame elements (with six degrees-of-freedom per node) the walls container and slabs are modelled with quadrilateral shell elements (with four nodes and six degrees-of-freedom per node). The impulsive liquid masses are modelled as point's masses elements model which attached with tank wall (3-D non-structural mass). The dynamic analysis was carried out using the finite element structural analysis program, LUSAS FEA 14.1. All the chosen elements for the model mentioned above are available in LUSAS FEA 14.1[11].



(a) (b)

Fig.5 (a) Fixed Base 3D Finite element model of the fluid–structure system for the added mass.(b) shape for impulsive Mode

4 Results and Discussion

The results of impulsive mode (Ti) in Table 1 are almost same for the first 5 models; whilst for model 7 (Westergaard) the deviation is around 3%. Even though the computational effort in model 6 is more complicated than the first 5 models however the differences around 2% is acceptable. These results indicated that when the mass is distributed according to alternative mass distribution as in the first 5 models and model 6 configuration, there was clearly a good agreement of (Ti) when compared with that of Westergaard approach.

In the time histories analysis the response of node located at highest level of the tank are shown in Fig.6 to all cases. The results indicate that, the response of the node is not much affected by the alternative mass configurations.

Table 1 values of masses (Ton) and time for impulsive mode Ti (sec)

Model No	Mass	Ti
1	35.15	0.95
2	17.58	0.95
3	8.79	0.95
4	5.86	0.95
5	2.93	0.95
6	0.18	0.96
7	Westergaard	0.98

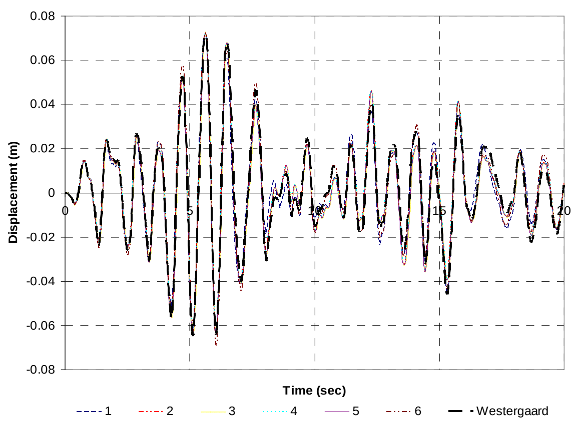


Fig 6 Variation of displacement time histories response as a function of time to the node located at highest level of the tank

5 Conclusion

The simulation investigation on the effects by using alternative adding impulsive mass of time for impulsive mode has been conducted through 3-D FEM. 6 models with alternative distributed masses were simulated to determine the impulsive mode time and compared with that of Westergaard approach (Model 7). Based on the results is showed that the effect of alternative mass distribution has a minor effect in the whole of dynamic response of elevated tank. These results also proved that for design purposes with added mass approach, the mass can be distributed by any pattern (model 1-5) instead of using the Westergaard method.

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