Seismic Investigation of RC Elevated Water Tank for Different Types of Staging Patterns

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Abstract

As known from past upsetting experiences, adequately designed elevated water tanks were heavily damaged or collapsed during earthquakes. This might be due to the lack of knowledge regarding the behaviour of supporting system of the tank; and also due to improper geometrical selection of staging patterns. For certain proportions of the tank and the structure, the sloshing of the water during earthquake may one of the dominant factor. In this paper, the seismic behavioural effect of elevated circular water tank is studied for constant capacity and constant number of columns; for various types of staging arrangement in plan, and variation in number of stages in elevation by using finite element method based software SAP2000. Two mass idealizations suggested by Gujarat State Disaster Management Authority (GSDMA) guideline are considered here. Total nine combinations were analysed using Response Spectrum Method (RSM) and results are presented. Radial arrangement with six staging levels is found to be best for ten numbers of columns.

Keywords: Elevated water tank, Response spectrum analysis, SAP 2000, Two mass model.

I. 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 pressurise the water distribution system. There are different ways for the storage of liquid such as underground, ground supported and elevated. 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.

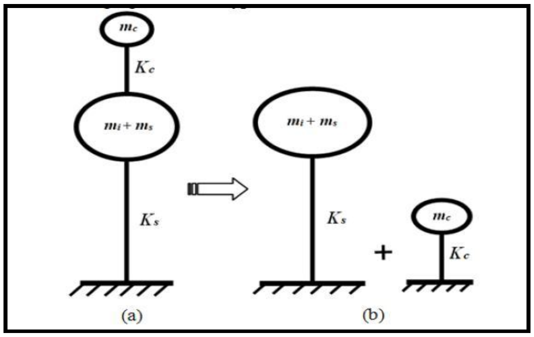
Elevated water tanks consist of huge water mass at the top of a slender staging which is most critical consideration for the failure of the tank during earthquakes. Elevated water tanks are critical and strategic structures; damage of these structures during earthquakes may endanger drinking water supply, cause to fail in preventing large fires and may cause substantial economical loss. Due to the lack of knowledge of supporting system some of the water tank were collapsed or heavily damaged. So there is need to focus on seismic safety of lifeline structure with respect to alternate supporting system which are safe during earthquake.

The present work is an effort to study the structural responses of Elevated water tank using Response spectrum Method (RSM); considering different staging arrangements and staging levels, using structural software SAP2000. For modelling two mass model is considered.

II. MODEL PROVISIONS

Most elevated tanks are never completely filled with liquid. Hence two mass idealization of the tank is more appropriate as compared to one mass idealization, which was used in IS 1893:1984. Two mass model proposed by Housner (1963) and is being now commonly used in most of the international codes including draft code 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 and induces impulsive hydrodynamic pressure on tank wall. 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 the base. Thus total liquid mass gets divided into two parts, i.e., impulsive mass and convective mass.

For elevated tanks, impulsive and convective parameters with circular container are available in Figure 2; page 17 of IITK GSDMA Guidelines. The two degree of freedom system shown in Figure 1 (a) can be treated as two uncoupled single degree of freedom systems shown in Figure 1 (b). Latter represents the impulsive plus structural mass behaving as an inverted pendulum with lateral stiffness equal to that of the staging, k_s and the other representing convective mass with k_c.



a) Two mass idealization

b) Equivalent uncoupled system

Fig. 1: Two mass idealization for elevated tank

Structural mass m_s, includes mass of container and one third mass of staging. Mass of container comprises of roof slab, container wall, gallery (if any), floor slab and floor beams. The response of the two-degree of freedom system can be obtained by elementary structural dynamics. However, for most elevated tanks it is observed that the two time periods are well separated. Hence, the two mass idealizations can be treated as two uncoupled single degree of freedom systems. For circular tanks, maximum hydrodynamic force per unit circumferential length at ϕ = 0, for convective and impulsive mode, is given by

$$q_i = \frac{(A_h)_i \times m_i}{\pi D/2}.g.H \quad = \frac{(A_h)_c.m_c}{D/2}.g.h$$

where,

q_i = Impulsive hydrodynamic force per unit length of wall

q_c = Convective hydrodynamic force per unit length of wall

$(A_h)_i$ = Design horizontal seismic coefficient for impulsive mode

$(A_h)_c$ = Design horizontal seismic coefficient for convective mode

m_i = Impulsive mass of liquid

m_c = Convective mass of liquid

g = Acceleration due to gravity

D = Inner diameter of circular tank

III. FLUID-STRUCTURE INTERACTION

During lateral base excitation seismic ground causes hydrodynamic pressure on the tank 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 using different approaches such as added mass Westergaard approach, Lagrangian approach (Wilson and Khalvati), Eulerian approach (Zienkiewicz and Bettes), or the Eulerian-Lagrangian approach (Donea). The simplest method is added mass approach and can be investigated by using some of conventional Finite Element Method software such as SAP2000, STAAD Pro and LUSAS.

IV. PROBLEM DESCRIPTION

The frame type is the most commonly used staging in practice. The main components of frame type of staging are columns and braces. In frame staging, columns are arranged on the periphery and it is connected internally by bracing at various levels. The staging is acting like a bridge between container and foundation for the transfer of loads acting on the tank. In elevated water tanks, head requirement for distribution of water is satisfied by adjusting the height of the staging portion. A reinforced elevated circular water tank having different staging arrangements and staging levels has been considered for the present study. Total nine combinations were studied for tank full and empty condition. The storage capacity of water tank is 500 m^3 considering ten number of columns. Finite element model of tank is modelled in SAP2000. In the present study three types of arrangements have been considered i.e. normal, radial and cross as shown in Figure 2.

TABLE 1(A):
PROBLEM DATA

Capacity of tank	500 m^3
Staging height	16 m
Unit weight of concrete	25 kN/m^3
Grade of steel	Fe415
Grade of concrete	M25
Zone	III
Type of soil	Medium soil
Staging levels	Four, Five, Six
Number of columns	Ten

TABLE 1(B):
SIZES OF VARIOUS COMPONENTS OF WATER TANK

Roof slab	320 mm
Wall	350 mm
Floor slab	350 mm
Floor Beams	400 x 750mm
Braces	300 x 500
Ten columns	350 dia.
Inner Diameter	9.50 m
Outer Diameter	10.20 m
Height	7.15 m
Freeboard	0.30 m

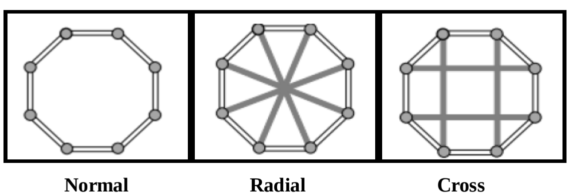


Fig. 2: Different types of staging arrangements

Data interpretation through Graphs:

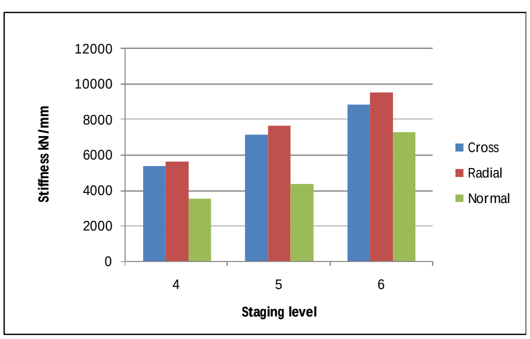


Fig. 3: Stiffness variation for different staging arrangements

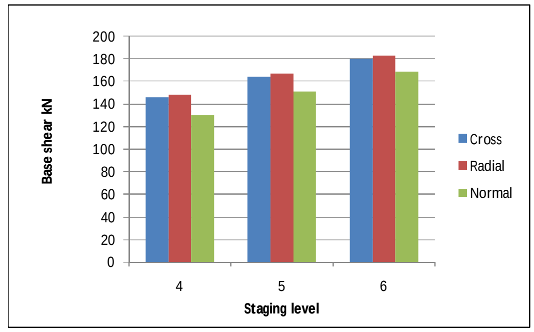


Fig. 4: Base Shear Variation for tank full condition

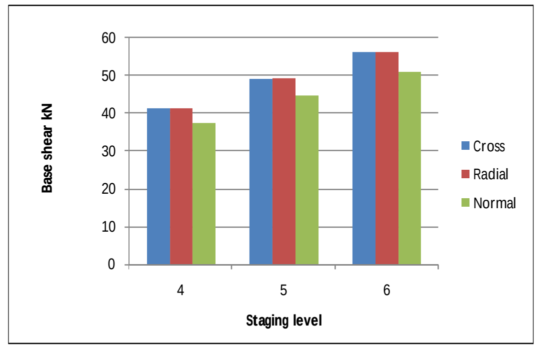


Fig. 5: Base shear Variation for tank empty condition

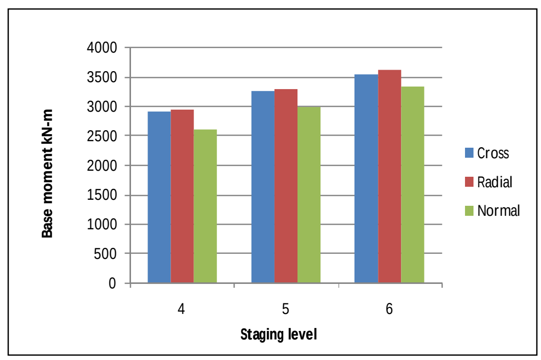


Fig. 6: Base moment variation for tank full condition

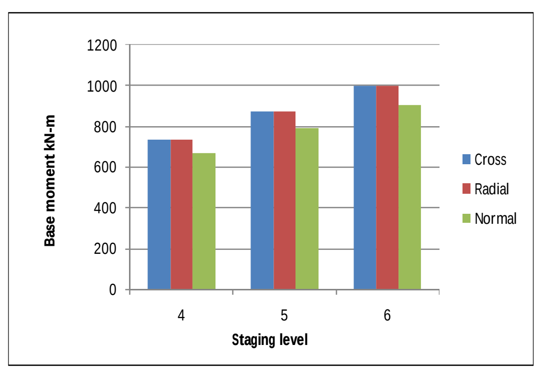


Fig. 7: Base moment variation for tank empty condition

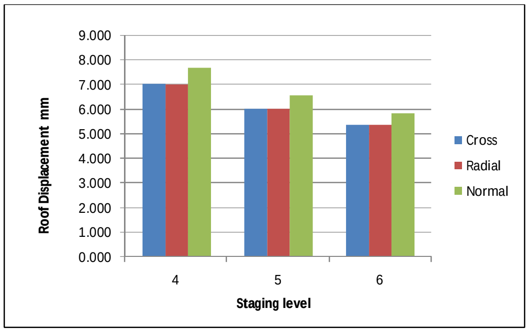


Figure 8: Roof Displacement variation for tank full condition

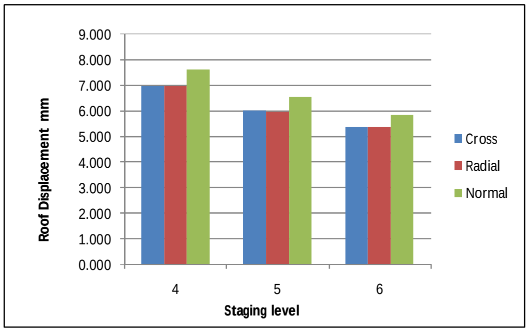


Figure 9: Roof Displacement variation for tank empty condition

V. OBSERVATIONS

(i) As staging levels increases, the deflection decreases and stiffness increases.

(ii) Normal type of arrangement has more deflection than cross having least in radial and stiffness vice versa.

(iii) For tank full and empty conditions, as staging levels increases; Base shear with Base moment increases with decrease in Roof displacement.

(iv) For tank full and empty conditions, Base shear and Base moment is more for radial arrangement then cross and followed by normal type of arrangement.

(v) Tank Empty condition has less Base shear and Base moment compared to Full tank condition. Vice versa for the Roof displacement.

(vi) Roof displacements of all models are within permissible limits as per IS 1893 (PartI): 2002.

VI. CONCLUSIONS

(i) Radial arrangement with six staging levels is best suited for ten number of columns followed by cross and normal.

(ii) Full tank condition shows critical response than empty tank conditions. But we can't neglect empty tank condition.

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