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Dynamic Analysis of Elevated RCC Circular Liquid Storage Tank

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Abstract- It is well recognized that liquid tanks possess low ductility and energy absorbing capacity as compared to the conventional buildings. Seismic safety of liquid storage tanks is of considerable importance. As known from very upsetting experiences, elevated water tanks were heavily damages or collapsed during earthquake Due to the fluid-structure interactions, the seismic behaviour of elevated tanks has the characteristics of complex phenomena. Water storage tanks should remain functional in the post earthquake period to ensure potable water supply to earthquake affected regions. The main aim of this study is to analyze the Elevated Circular RCC Liquid Storage Tank by using Response spectrum method (IS 1893 method).

1. 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 behavior 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.

2. LITERATURE REVIEW

Earthquakes represent an external hazard for industrial plants and may trigger accidents, i.e. fire and explosions resulting in injury to people and to near field equipments or constructions, if structural failures result in release of hazardous material. Quantitative Risk Analysis (QRA) [1] provides a guide for analysis of industrial risk; such an assessment may include the seismic threat if ground motion related malfunctioning (i.e. failure) rates are available for components [2]. From the structural perspective, steel tanks for oil storage are standardized structures both in terms of design and construction [3], [4], [5]. Review of international standards for the construction points out that design evolved slowly; therefore, a large number of post-earthquake damage observations [6] are available and empirical vulnerability functions have been developed [7]. Liquid containing structures (LCS) as part of environmental engineering facilities are primarily used for water and sewage treatment plants and other industrial wastes. Normally, they are constructed of reinforced concrete in the form of rectangular or circular configurations. Currently there are few codes and standards available for seismic design of LCS in North America. In almost all of codes and standards, the Housner's model (Housner, 1963) has been adopted for dynamic analysis of LCS. The hydrodynamic pressures induced by earthquakes are separated into two parts of impulsive and convective components which are approximated by the lumped added masses. The added mass in terms of impulsive pressure is assumed rigidly connected to the tank wall and the added mass in terms of convective pressure is assumed connected to the tank wall using flexible springs to simulate the effect of sloshing motion. In this model, the boundary condition in the calculation of hydrodynamic pressures is treated as rigid. Although the Housner's model has been applied in the seismic design of LCS in the past, recent studies show that due to the assumption of the lumped added mass and the rigid tank wall, this method leads to overly conservative results. Chen and Kianoush (2005) developed a procedure referred to as the sequential method for computing hydrodynamic pressures based on a two-dimensional model for rectangular tanks in

which the effect of flexibility of tank wall was taken into consideration. Later Kianoush et al. (2006) and Ghaemian et al. (2005) applied the staggered method to solve the coupled liquid storage tank problems in three-dimensional space. Compared to the Housner's model, these results show that in most cases the lumped mass approach overestimates the base shear and base moment significantly. Chen and Kinaoush (2007) proposed a generalized single degree of freedom (SDF) system for dynamic analysis of LCS. The consistent mass approach and the effect of flexibility of tank wall on hydrodynamic pressures were considered. The prescribed vibration shape functions representing the mode shapes for the cantilever wall boundary condition were validated.

Dynamic analysis of liquid storage tanks

Problem description

A RCC circular water tank of 50 m^3 capacities having following properties is selected for this study.

Internal diameter = 4.65 m

Height of circular water tank = 3.3 m (including freeboard of 0.3 m)

Lowest water level = 12 m above ground level

Density of concrete = 25 kN/m^3

Grade of concrete = M20

Grade of steel = Fe 415

It is supported on RC staging consisting of 4 columns of 450 mm dia with horizontal bracings of 300 x 450 mm at four levels. Staging conforms to ductile detailing as per IS13920. Staging columns have isolated rectangular footings at a depth of 2m from ground level. Tank is located on soft soil in seismic zone II.

Solution

Tank must be analysed for tank full and empty conditions.

Preliminary Data

Details of sizes of various components and geometry are shown in Table 1.1

Component	*Size (mm)*
Roof Slab	120 thick
Wall	200 thick
Floor Slab	200 thick
Gallery	110 thick
Floor Beams	250 x 600
Braces	300 x 450
Columns	450 dia

Table 1.1 Sizes of various components

Component	*Calculations*	*Weight (kN)*
Roof Slab	[π x (5.05)2 x (0.12 x 25)]/ 4	60.1
Wall	π x 4.85 x 0.20 x 3.30 x 25	251.4
Floor Slab	[π x (5.05)2 x 0.20 x 25] / 4	100.2
Floor Beam	π x 4.85 x 0.25 x (0.60 – 0.20) x 25	38.1
Gallery	[π x ((7.05)2 – (5.05)2) x (0.110 x 25)]/ 4	52.3
Columns	[π x (0.45)2 x 11.7 x 4 x 25] / 4	186.1
Braces	3.43 x 0.30 x 0.45 x 4 x 4 x25	185.2
Water	[π x 4.652 x 3.0 x 9.81] / 4	499.8

Table 1.2 Weight of various components

From Table 4.2,

Weight of staging = 186.1 + 185.2 = 371.3 kN.

Weight of empty container = 60.1 + 251.4 + 100.2 + 38.1 + 52.3 = 502.1 kN.

Hence, weight of container + one third weight of staging = 502.1 + 371.3 / 3 = 626 kN.

Time Period

Time period of impulsive mode,

$$T_i = 2\pi\sqrt{\frac{m_i + m_s}{K_s}}$$

$$= 2\pi\sqrt{\frac{33{,}116 + 63{,}799}{60{,}60{,}000}} = 0.80\,sec.$$

Time period of convective mode,

$$T_c = C_c\sqrt{\frac{D}{g}}$$

For h / D = 0.65, Cc = 3.28.

Thus

$$T_c = 3.28\sqrt{\frac{4.65}{9.81}} = 2.26 \text{ sec.}$$

Design Horizontal Seismic Coefficient

Design horizontal seismic coefficient for impulsive mode,

$$(A_h)_i = \frac{Z}{2}\frac{I}{R}\left(\frac{S_a}{g}\right)_i$$

Where,

Z = 0.1 (IS 1893(Part 1): Table 2; Zone II)

I = 1.5 (Table 1)

Since staging has special moment resisting frames (SMRF), R is taken as 2.5 (Table 2)

Here, Ti = 0.80 sec, Site has soft soil,

Damping = 5%, (Section 4.4)

Hence, $(Sa/g)\ i$ = 2.09 (IS 1893(Part 1): Figure 2)

$$(A_h)_i = \frac{0.1}{2} \times \frac{1.5}{2.5} \times 2.09 = 0.06.$$

Design horizontal seismic coefficient for convective mode,

$$(A_h)_c = \frac{Z}{2}\frac{I}{R}\left(\frac{S_a}{g}\right)_c$$

Where,

Z = 0.1 (IS 1893(Part 1): Table 2; Zone II)

I = 1.5 (Table 1)

R = 2.5

For convective mode, value of R is taken same as that for impulsive mode as per Section 4.5.1.

Here, Tc = 2.26 sec, Site has soft soil,

Damping = 0.5%, (Section 4.4)

Hence, $(Sa/g)c$ = 1.75 x 0.74 = 1.3 (IS 1893(Part 1): Figure 2)
Multiplying factor of 1.75 is used to obtain *Sa /g* values for 0.5% damping from that for 5% damping.

$$(A_h)_c = \frac{0.1}{2} \times \frac{1.5}{2.5} \times 1.3 = 0.04$$

Base Shear

Base shear at the bottom of staging, in impulsive mode,

$$V_i = (A_h)_i\,(m_i + m_s)\,g$$

= 0.06 x (33,116 + 63,799) x 9.81 = 59.9 kN.
Similarly, base shear in convective mode,

$$V_c = (A_h)_c\, m_c\, g$$

0.04 x 17,832 x 9.81 = 7.0 kN.
Total base shear at the bottom of staging,

$$V = \sqrt{V_i^2 + V_c^2}$$
$$= \sqrt{(59.9)^2 + (7.0)^2}$$
$$= 60 \text{ kN.}$$

Total lateral base shear is about 5 % of total seismic weight (1,126 kN). It may be noted that this tank is located in seismic zone II.

Base Moment

Overturning moment at the base of staging, in impulsive mode,

$$M_i^* = (A_h)_i\,[\, m_i\,(\, h_i^* + h_s\,) + m_s\, h_{cg}\,]\, g$$

= 0.06 x [33.116 x (1.92 + 14) + (63.799 x 15.18)] x9.81 = 924 kNm.
Similarly, overturning moment in convective mode,

$$M_c^* = (A_h)_c\, m_c\, (h_c^* + h_s)\, g$$

= 0.04 x 17,832 x (2.19 +14) x 9.81
= 113 kN-m.
Total overturning moment at the base of staging,

$$M^* = \sqrt{M_i^{*2} + M_c^{*2}}$$

= 931 kN-m.
Since total base shear (60 kN) and base moment (931 kN-m) in tank full condition are more than that total base shear (50 kN) and base moment (760 kN-m) in tank empty condition, design will be governed by tank full condition.

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