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Effect of Bracing system on Seismic Behavior of Rectangular Elevated RC Water Tank

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Abstract -*Fluid-structure interaction is one of the most perplexing phenomenon in dynamic analysis of elevated water tank. In order to have a better understanding of the seismic behavior of such structures, elevated water tank should be idealized as spring mass system. The Spring Mass system considers the hydrodynamic forces applied by liquid on tank wall in addition to hydrostatic forces. This paper presents the study of seismic analysis of elevated water tanks by modelling total mass as convective mass and impulsive mass as per IS CODE: 1893 (part 2) and IITK-GSDMA guidelines, using SAP2000.The study focuses on the effect of different steel bracing system at empty tank condition and full tank condition of a rectangular elevated RC water tank by using Response Spectrum Analysis.*

Key Words: Spring Mass system, Convective Mass, Impulsive mass, Rectangular Elevated RC tank, SAP2000, Response Spectrum Analysis

1. INTRODUCTION

Elevated water tanks are substantial structures based on their serviceability performance during and after strong earthquakes [1].Hence, design of new tanks and safety evaluation of existing tanks should be carried out at most accuracy because the failure of such structures, particularly during an earthquake, may be disastrous and could lead to substantial economic loss. Elevated Water tank consist of a configuration highly vulnerable to earthquake forces due to the large mass concentrated over slender supporting structures. Since, the elevated tanks are frequently used in seismic active regions hence, seismic behavior of these structures should be investigated properly[2].Past experiences shows that ,most of the failure or collapse of elevated water tank is mainly due to the lack of knowledge of supporting system and dynamic effect of water. It is observed that analysis of elevated water tank is not similar to the analysis of typical building, due to the dynamic effect of water. When liquid containing tank is subjected to horizontal seismic acceleration, sloshing waves are generated which exerts hydrodynamic forces on wall as well on the base of water tank. In order to include the hydrodynamic forces in dynamic analysis, as per IS 1893(part2), the elevated water tank should be idealized as spring mass system [3].

1.2 Spring Mass Model for Seismic Analysis

Most elevated tanks are never completely filled with liquid. Hence a two-mass idealization of the tank is more appropriate as compared to a one- mass idealization, which was used in IS 1893: 1984. Two mass model for elevated tank was proposed by Housner (1963b) and is being commonly used in most of the international codes [4].

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. Thus, total liquid mass gets divided into two parts, i.e., impulsive mass and convective mass [4]. In spring mass model of tank-liquid system, these two liquid masses are to be suitably represented as shown in Fig-1.

Structural mass m_s, includes mass of container and one-third mass of staging. Mass of container comprises of mass of roof slab, container wall, gallery, floor slab, and floor beams. Staging acts like a lateral spring and one-third mass of staging is considered based on classical result on effect of spring mass on natural frequency of single degree of freedom system. Most elevated tanks are never completely filled with liquid. Hence a two-mass idealization of the tank shown in Fig-1 (c) is more appropriate as compared to a one mass idealization, which was used in IS 1893: 1984. 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 periods are well separated. Hence, the system may be considered as two uncoupled single degree of freedom systems as shown in Fig-1 (d). This method will be satisfactory for design purpose, if the ratio of the period of the two uncoupled systems exceeds 2.5. If impulsive and convective time periods are not well separated, then coupled 2-DOF system will have to be solved using elementary structural dynamics. There are two cases for seismic analysis namely tank empty condition and tank full condition. For tank empty condition, tank will be considered as single degree of freedom system and empty tank will not have convective mode of vibration whereas tank full condition is considered as two degree of freedom system [5].

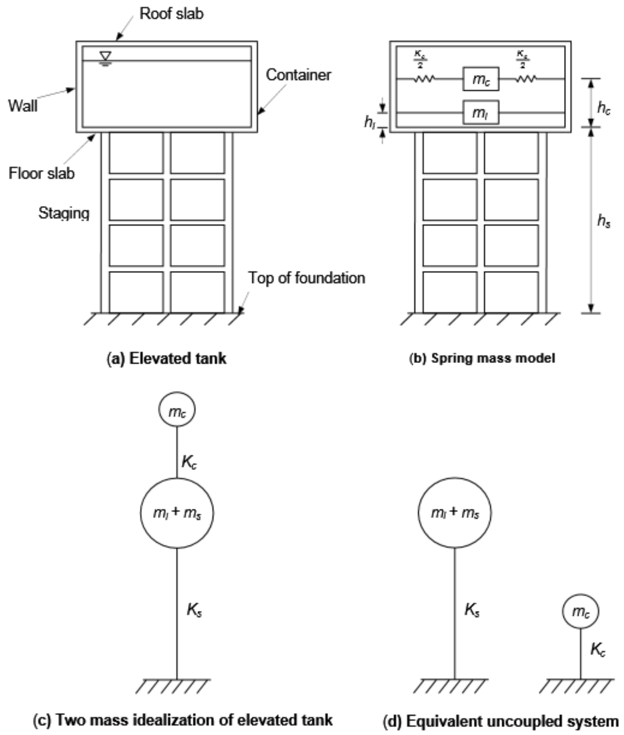


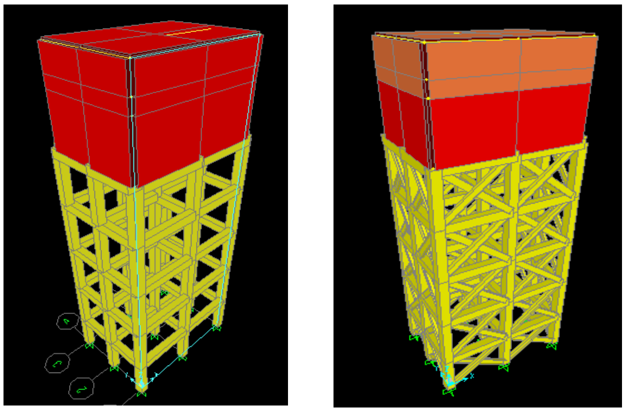
Fig-1: Two mass idealization

2. DESCRIPTION OF RECTANGULAR ELEVATED RC WATER TANK

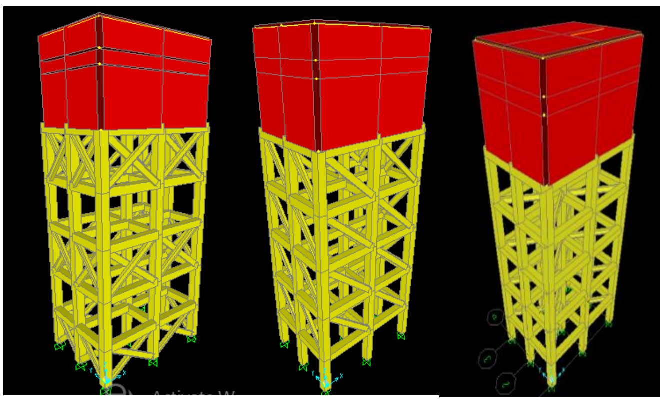
For study of the effect of bracing system on elevated rectangular elevated RC water tank, the different bracing system opted are X braces, Alternate X braces, Diagonal braces and Radial braces in comparison to elevated tank without braces. The analysis is carried out on reinforced cement concrete rectangular water tanks having a capacity of 100m^3 with a staging height of 12m. Considering 2.5m as intermediate height. Hard soil of seismic zone V is taken into consideration.

Table -1: Details of Rectangular Elevated RC Water Tank

Capacity	100m3
Size of tank	6m x 4.2m
Depth of water in container	3.7m
Free board	0.3m
Roof slab	0.2m
Wall thickness	0.2m
Floor slab	0.3m
Floor beam	0.3m x 0.7m
Bracing	0.35m x0.45m
Columns	9No.- 0.4m x 0.4m
Steel bracing	ISLB 300



(a) Without braces (b) X braces



(c) Alternate X braces (d) Diagonal braces (e) Radial Braces

Fig-2: Different Bracing System

2.1. Finite Element modelling of fluid-structure interaction

The area elements such as wall, roof slab and floor slab of the structure were modelled with shell elements, while that of structural elements of the supporting frame were beam elements. In order to incorporate the dynamic behavior of the fluid in the FEM model tanks, two concentrated masses were considered. The first mass is impulsive component of fluid which is calculated as per IS 1893 (part 2) , rigidly linked to the wall by constraining movement and rotation in x, y, z direction. The second mass is convective component of fluid and it is connected by a system of springs to the tank walls; the axial stiffness of the springs is calibrated to formulate the first convective mode. The spring mass parameters calibrated during preliminary design is shown in Table 2. The impulsive mass part has been modelled as a concentrated mass, placed at a height hi from the bottom of tank. This mass is connected through a system of "link" elements to the vertical walls. The convective mass, placed at height hc, is linked to the walls through a system of springs to reproduce the same stiffness in plane as accurately as possible. The stiffness of each spring has been calibrated in order to have stiffness in the direction equal to kc/2.

Table -2: Details of Rectangular Elevated RC Water Tank

Height of convective mass, h_c	2.96m
Height of impulsive mass, h_i	2.405m
Spring stiffness of convective mode, k_c	128.25kN/m
Total mass of liquid in tank, m	1,02,752.3 kg
Convective mass, m_c	36,990.828 kg
Impulsive mass, m_i	67,816.518 kg
Mass of structure, m_s	1,08,233.3422 kg

3. RESULTS AND DISCUSSION

Table -3: Time period of Rectangular Elevated Water tank in Empty and Full condition

Bracing system	Time period Empty condition (sec)	Time period Full condition	
		Convective Time period (sec)	Impulsive Time period(sec)
Without braces	0.649s	2.490s	0.963s
X braces	0.379s	2.490s	0.385s
Alternate X braces	0.443s	2.490s	0.521s
`Diagonal braces	0.380s	2.490s	0.447s
Radial braces	0.882s	2.490s	0.762s

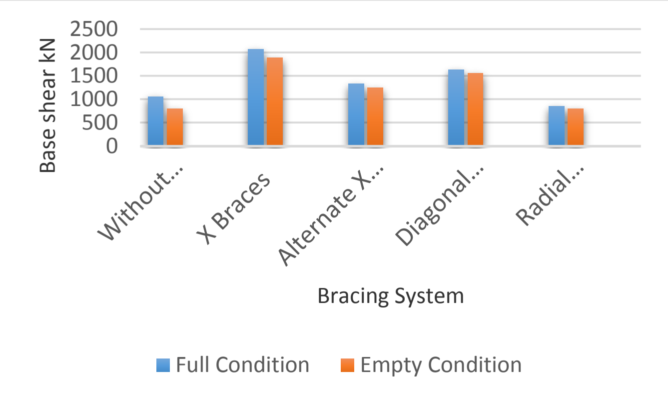


Chart-1: Base shear of Rectangular Elevated RC Water Tank

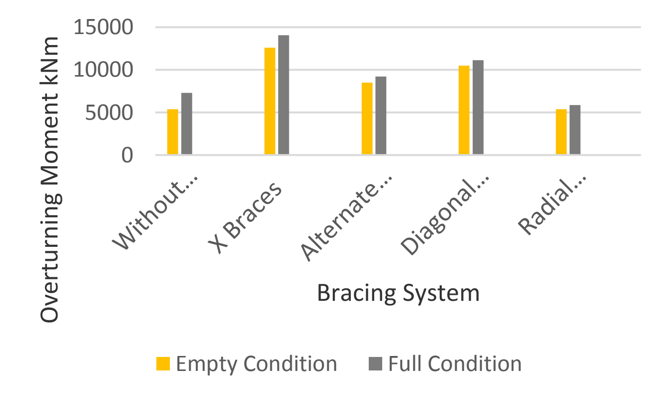


Chart-2: Overturning moment of Rectangular Elevated RC Water Tank

Chart 1and chart 2 shows the base shear and overturning moment of different bracing system using dynamic static analysis-Response Spectrum Analysis.

3. INFERENCES

- Time period decreases with bracing system compared to that of without braces as the earthquake forces are counteracted by the ductility of the structure. Hence the time period decreases with the implementation of braces.
- The time period varies in tank empty condition and tank full condition, this may be due to the sloshing effect. Hence the design of rectangular elevated tank should be considered in tank full condition.
- Base shear increases by 75.88% and base moment increases by 71.77% in empty condition with the initiation of bracing system.
- Base shear increases by 55.56% and overturning moment by 54.335 % in tank full condition with the initiation of bracing system.
- Comparing without braced water tank to X braced water tank, base shear increases by 150.13% in empty

condition while base shear increases by 95.55% in full condition.

- Comparing X braced tank to without braced tank, base moment increases by 134.023% in empty condition and increases by 92.127 % in full condition.
- In comparison to different bracing system, X bracing provides least time period showing that it provides considerable stiffness to the structure compared to other types of bracing.
- Radial bracing doesn't seems to provide any significant influence to the structure .The base shear and base moment approximately decreases by 0.4% in comparison to without braces.

4. CONCLUSION

- The dynamic analysis of rectangular elevated RC water tank should comprise of hydrodynamic effect, hence the elevated water tank should be taken analyzed as two mass spring model.
- The base shear and overturning moment in full condition is more than base shear and overturning moment in empty condition. Hence forth, elevated rectangular water tank should be designed for full condition.
- With the introduction of braces, the time period considerably decreases .This indicates that the structure gets stiffer with braces compared to without braced structure.
- The time period in empty condition and full condition seems to vary drastically, this is due to the sloshing effect of water. In full condition, the first time period is taken as convective time period while the second time period signifies impulsive time period.
- The convective time period remains constant throughout different bracing system. This implies that the convective mode doesn't depend on staging and eventually depends on the size of the rectangular tank.
- Among different bracing system, X bracing provides less time period and more base shear as well as overturning moment followed by diagonal braces.
- Radial bracing didn't show any significant change as compared to other bracing system. This may due to usage of steel bracing inside of RC braces.
- The base shear and overturning moment of the Rectangular Elevated Water tank increases due to the weight of the bracing system.

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