Analytical Study of Elevated Service Reservoir with Water Baffles Under Seismic Loading

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Abstract. Around the world earthquakes occur often causing some serious damages to property and life. Earthquakes weaken the structure and cause it to fail suddenly. Elevated Water tanks are such structures which have heavier masses suspended at a height supported on slender staging. When earthquake is induced in the tanks, it generates wave sloshing, the motion of the water induced due to seismic excitation. This sloshing of the water inside the tank will move in relative direction the seismic excitation causing structural instability. The water inside the tank will also act as tuned liquid mass damper and absorbs most of the energy created during seismic excitation. In this paper we have analysed various arrangement of baffle walls inside the tank in order to determine the stresses and displacements induced by the sloshing motion of the water tank. The water inside the tank will also act as tuned liquid mass damper where it will reduce the energy generated due to seismic excitation. During sloshing motion, there is an increase in lateral pressure applied over the tank walls which has adverse effect on the displacement of the system. The displacement of the system increases due to sloshing activity. By providing baffle walls we can reduce this displacement induced due to sloshing and thereby reduce the stresses generated on the supporting structure. From this analytical work the latter said was very evident.

1. Introduction

In this modern world the buildings are growing taller day by day and becoming leaner as well. So, there is probability for the structure prone to vibrations causing discomfort, failure and damages of the structure. The tuned liquid damper is a passive energy absorption method in which the energy will be used to act as a damper to the structure. Tuned liquid damper is effective in resisting the lateral movement and acceleration in buildings. The external forces act more on the taller and slimmer buildings compared to those of low-rise constructions. So, the buildings are affected by external forces like earthquake and winds.

Sloshing is the movement of the liquid in a free surface of a structure or a container. It is important factor that has to be considered in various areas such as fuel tanks, cargo in ships and other containers where there will be large volume of water where sloshing forces can be significant when it is subjected to lateral deflections. Damping is the structures ability that dissipates some portion of the energy which is released in a dynamic loading and it is the important parameter in limiting the response of the structure.

The vibration of the structure caused by the sloshing motion dissipates a portion of the energy during the dynamic loading and it increases the equivalent damping force of the structure. Modi and Munshi (1998) investigated on liquid sloshing damper for the efficient vibration control and found out...
that there is significant energy dissipation of about 60% by the addition of an obstacle in the path of the moving liquid. The response of the structure in SDOF can be reduced upto 30% when the mass ratio of the structure is 4% and depth ratio (ratio of water depth to tank length) is 0.15% is explained by Pradipta Banerji (2004). By the provision of the sharp-edged baffle the turbulence flow in the liquid is reduced thus reducing the sloshing effect in the tank is studied by Panigrahy, Saha and Maity (2009). Jitaditya Mondal et al (2014) carried out a work on Tuned Liquid Damper saying when the structure was excited at the resonance frequency of the structure, there is a reduction of vibration of about 80% (i.e., 22 to 4) output/input ratio with the help of TLD. With the provision of the baffle in the tank there is 20-30% reduction in motion of the liquid which in turn increases the damping values of the structure upto 8 times foe single baffle and 10 times for double baffled tanks were studied by Naghdali Hosseinzadeh and Hamid Tayakolian (2014). When there is an increase in the mass ratio to the total weight of the structure then there is a significant improvement in the response reduction due to vibration in the structure during any seismic events. When the mass ratio is 0.5% to 3%, the structural response is significantly improved by the TLD and beyond 3% the effectiveness of the TLD is very minimal which is found out by Ali Ashasi-Sorkhabin et al (2014). Most of the past works has been carried out on liquid storage tanks with reduced sloshing effect by the provision of baffle walls and it is found out that the sloshing is greatly reduced because of the energy is being absorbed by the baffle walls which improves the lateral movement of the structure during seismic. This investigation is extended to study the sloshing behaviour in the structure using ABAQUS software so that the baffle walls using liquid can be used as a damper effectively in buildings. The vertical sloshing effect in the tank is also restrained by providing adequate methods which will make the structure more rigid during earthquake. The seismic analysis and design procedure for various elements and for various conditions such as short column effect, varying heights of columns, seismic excitation and damping were studied from literatures by Pradeep.S.(2014-2019)

2. Structural Modelling

The modelling and analysis of the structure is done by using the (FEM) software ABAQUS. It is a software application used for modelling, assembling, meshing, job and visualizing the finite element result. ABAQUS provides the flexible and complete solution to understand the behaviour of the complex system, and can be used to refine concepts for new designs and can be used to understand the behaviour of the newer materials.

2.1 Model Details

- Grade of concrete: M25
- Grade of steel: Fe415
- Size of longitudinal reinforcement: 8 mm
- Size of transverse reinforcement: 6 mm
- Size of confining reinforcements (stirrups and ties): 6 mm
- Size of each bay 800 mm × 800 mm. Height of bay: 1000 mm
- Size of column: 100 mm × 100 mm. Height of column: 1000 mm
- Size of beam: 100 mm × 100 mm. Length of beam: 800 mm
- Size of slab: 1000 mm × 1000 mm. Depth of slab: 50 mm
- Size of the tank: 800 mm × 800 mm. Height of the tank: 500 mm

2.2 Model Description

The various models used for the analysis of slosh tank with various baffle arrangements are Empty Tank as shown in figure 1, Tank with water, Tank with two vertical baffle walls as shown in figure 3, Tank with 4 vertical Baffle Walls as shown in figure 4, Tank with four vertical baffle and a horizontal baffle as shown in figure 5, Tank with fully covered Baffle as shown in figure 6, Tank with fully covered baffle and a horizontal baffle as shown in figure 7. The water levels were kept at Empty Condition as well as at 50% tank capacity.
Figure 1. Model of Slosh tank.
Figure 1 represents the RCC slosh tank with no inner baffle walls.

Figure 2. Model of Reinforcement inside RCC structure.
Figure 3. Model of slosh tank with 2 vertical baffles.

Figure 4. Model of slosh tank with 4 vertical baffles.

Figure 5. Model of slosh tank with 4 vertical baffles 1 horizontal baffle.
The RCC structure with slosh tank is provided with 4 vertical baffle walls and also a horizontal baffle to a depth of 30 mm and the width assumed as 100 mm and at a height of 375 mm from the bottom of the tank.

![Figure 6. Model of slosh tank with full baffle.](image)

The tank is provided with full baffle arrangement and it also has a circular hole (Dia-6mm) for the water moment inside the tank so the water will have connection to the adjacent area in the tank.

![Figure 7. Model of slosh tank with full baffle and horizontal baffle.](image)

2.3 Meshing the Model
The model was meshed as Hex Elements with geometry-based mesh type. The mesh size used was 30mm X 30 mm Hex elements. The entire modelled was seeded first and then the instances were meshed. The reinforcements were meshed at 25mm Sweep elements as they are circular in profile.
Figure 8. Meshing of Reinforcements.

Figure 9. Meshed of Reinforcements.
2.4 Boundary Conditions and Loading
The base of the model was given fixed boundary condition. The displacement along X and Y directions were restrained. The displacement along Z direction was paired with the El Centro NS loading data along with Gravity loading. The tank walls were subjected to a sloshing velocity of 3m/s^2.

3. Analytical Results
The analysis was carried out using dynamic explicit analysis for the El Centro Loading and the stresses at beam column and the maximum displacements were extracted.

3.1. Stresses
Stress is created in the member when the is subjected to dynamic load. Stress in that the points in the beam column joints and the failure of the joints can be seen due to the stress in the structure. The stress
in the structure due to the empty tank is $112.6 \text{ N/mm}^2$ is lesser than the stress of slosh empty water tank ($185.6 \text{ N/mm}^2$)

Figure 12. Stress Contour for RCC slosh tank.

Figure 13. Stress Contour for slosh tank with 4 vertical baffles.
The stresses at each beam column joints and tank walls were plotted with XY plotter in the abaqus software. The maximum stresses of each model were taken and given in tabular format as shown in Table 1.

Table 1. Maximum Stresses of various models.

| Tank Model                                      | Maximum Stress, N/mm² |
|------------------------------------------------|-----------------------|
| Empty Tank                                      | 112.6                 |
| Tank 50% water                                  | 185.6                 |
| Tank with 2 vertical baffles                    | 165.8                 |
| Tank with 4 vertical baffles                    | 123.9                 |
| Tank with 4 vertical baffles and 1 horizontal baffle | 127.4                 |
| Tank with full baffles                          | 131.08                |
| Tank with full baffles with horizontal baffle   | 133.5                 |

Figure 14. Stress Contour for slosh tank with full baffles.
3.2 Displacement

The maximum displacement of the structure is found out for the sloshing effect in the water tank in the structure. Due to the sloshing effect there is a maximum deflection in the structure with the addition of the baffle there is a reduction in the deflection of the structure. The deflection values are obtained for every baffle arrangement for corresponding load. The maximum deflection for maximum load is recorded and the values are plotted in graph as shown in figure 16.

Table 2. Maximum Displacement of various models.

| Tank Model                                  | Maximum Displacement, mm |
|---------------------------------------------|--------------------------|
| Empty Tank                                  | 0.0087                   |
| Tank 50% water                              | 0.010                    |
| Tank with 2 vertical baffles                | 0.007                    |
| Tank with 4 vertical baffles                | 0.0043                   |
| Tank with 4 vertical baffles and 1 horizontal baffle| 0.004                   |
| Tank with full baffles                      | 0.004                    |
| Tank with full baffles with horizontal baffle| 0.005                    |

Figure 15. Graphical representation of maximum stresses.
4. Discussions and Conclusions

The analytical results are obtained from dynamic explicit analysis for El Centro Loading condition are tabulated and the displacement and the stresses were found and the following conclusions are made based on the result

- The displacement of the structure with 4 vertical baffle, 4 verticals with 1 horizontal baffle and full baffle system are less compared to other sloshing tank arrangements and the stiffness of the structure increases due to the addition of the baffles.
- The 4 vertical baffle arrangement is much efficient in the energy dissipation of the RC structure and it is also economical.
- The structure displacement is reduced to 60% in the case of tank with 4 vertical baffle wall and RCVBH and also RCVF walls.
- The stress in the structure is maximum with the slosh water tank and the displacement is also more in the tank without baffle compared to the baffle condition.
- The stress in the structure is more with the slosh water tank (185.6 N/mm²) and with the arrangement of the baffles to the RCC structure the stress is reduced considerably by 30%.

So, it is concluded that the placement of baffle walls inside the water tank will increase the seismic performance of the building by damping the energy created during sloshing excitation. The full baffle wall arrangement path gave a reasonable energy dissipation and thus reduced the lateral displacement of the entire system.

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