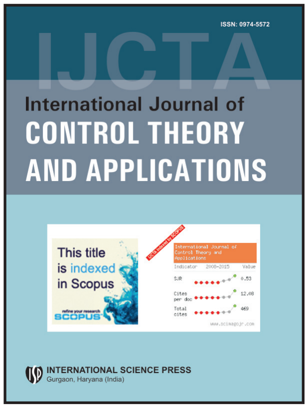

International Journal of Control Theory and Applications

ISSN : 0974-5572

Volume 10 • Number 12 • 2017

Seismic Evaluation of a RC Elevated Water Tank

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Abstract: Background/Objectives: A work on past seismic tremors uncovers that the disappointment of essential life saver prompts extreme damage even after the quake. Elevated water tanks are one such facility supportive in post tremor recuperation for providing drinking water and extinguishing fire.

Methods: In this study, a RC elevated rectangular tank of volume 900m^3 is subjected to seismic forces and dynamic analysis is carried out to assess the behaviour of the tank. This study includes hydrodynamic pressure generation, different fluid levels of the tank and the reaction of the tank with respective to the various level of filling conditions.

Findings: Analytical study using STAAD Pro and response spectra as per IS 1893 (Part II): 2002 were studied on an elevated fluid storage tank for various soil condition is analysed.

Improvement: This study will help to improve the design of elevated water tank for various soil condition under the seismic tremor to minimise the failure of structure.

Keywords: Hydrodynamic forces, Elevated tank, Sloshing, Spring mass, Base shear.

1. INTRODUCTION

Liquid storage tanks are inevitable in our day to day life whether it is water treatment or chemical industries. Elevated tanks are a type of liquid storage tank in which the liquid container is located at certain height above the ground by use of frame staging. The storage tanks are mainly adopted as facilities for water treatment, sewage treatment and treatment for industrial liquids. Elevated water tanks are a sort of liquid tanks, in order to provide the head of water required for water supply process, water tanks are introduced on a supporting tower, thereby instead of requiring substantial pumping, the gravity gives the necessary pressure.

The studies have provided a design procedure to enhance the distribution of the ductility demand based on the seismic responses of the elevated tanks. An elevated water tank is designed for the staging as well as the tank in an effective way to perform well during earthquakes. The mass distribution of the structure is taken as lumped mass based on Housner's dynamic behavior of the tanks are calculated. The impulsive mass is considered as reactive whereas the convective is considered as oscillatory. The load distribution pattern for frame staging is varied from that of the normal lateral load resisting frame.[1-6] The elevated tanks that are unsymmetrical are considered to be prone to torsional effects due to coincidence of centre of mass and centre of resistance. However there may be torsion generated from accidental eccentricities.[7] The response of the tanks which is affected by the quantity of fluid mass is also studied. The various dynamic forces acting on the walls of the tank with respect to the different filling levels of the tank is also studied. The tank is said to be completely impulsive when it is fully loaded. The lateral rigidity of the staging depends on its configuration with respect to the load at the top of the staging which incorporates the weight of the unfilled container, weight of the water in container. The staging is usually provided in regular configuration to reduce eccentricities. In certain cases, the pattern of staging is modified to provide additional stiffness by assigning braces to improve the performance of staging in an efficient and economical way.

However, the elevated water tanks when exposed to seismic forces are not only subjected to lateral loads and also another set of forces which are generated as hydrodynamic forces from the liquid inside the tank. Subsequently in this study, endeavor is made to investigate the performance qualities of a tank when subjected to seismic forces by nonlinear examination to decide the conduct of the structure and to avert failure of the tank amid tremor. In this investigation the example in which the forces are produced inside the tank and the reaction of the tank in correspondence with hydrodynamic forces are likewise considered.

2. ANALYTICAL STUDY OF ELEVATED TANK WITH FRAME STAGING

2.1. Description of Elevated Tank

A rectangular liquid storage tank of volume 900 m^3 is modelled. The effective dimensions of the tank is 16m × 12m × 5.3m with a freeboard level maximum upto 0.6 m with a maximum fluid (water) level of 4.7 m. The tank wall's thickness is computed as 0.3 m. The altitude of the staging is 20m above the natural ground level. The 0.15 m thick divider is used in the roof to encase the water tank. The slab in the base is 0.35 m thick. The beam of area 0.35m × 0.5m is used to support the tank on the staging. The tank consists of square shaped columns with a specification of 0.5 m. Figure 1 depicts the schematic plan and elevation of tank. The frame is modelled with a rigid link which signifies the centre of gravity of the elevated tank above staging. An arbitrary load of 10kN is applied to find the stiffness of the frame from the rigidity of frame in response to the load. The point of loading in frame used to analyse by STAAD Pro model is shown in Figure 2.

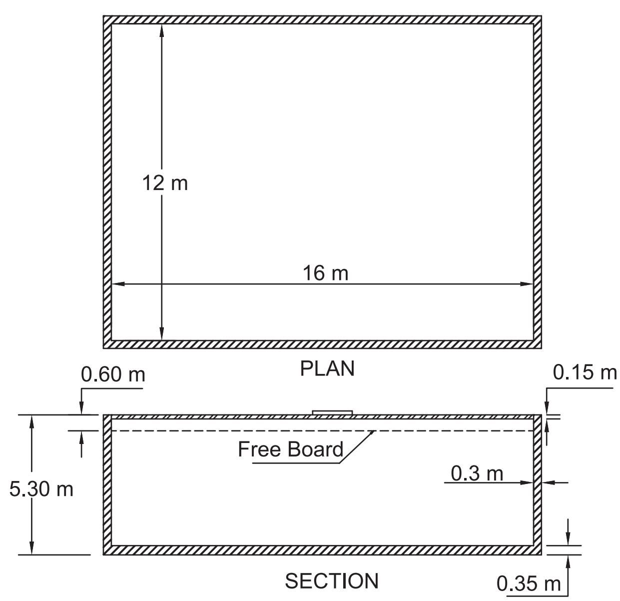

Figure 1: Typical layout of the tank

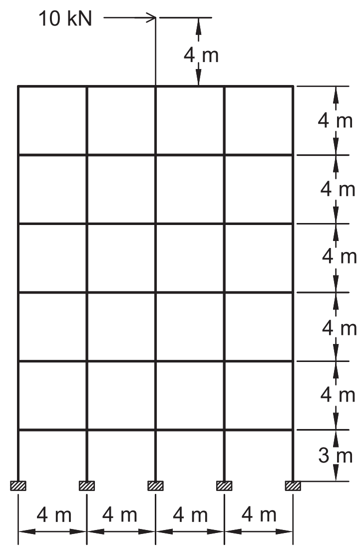

Figure 2: Loading of rigid link

2.2. Hydrodynamic Pressure Calculation

The liquid mass inside the tank is modelled as spring mass model which subdivides the liquid mass into two namely impulsive and convective. Impulsive mass is the mass of liquid which is set into motion as long as the earthquake lasts. Convective mass is the mass of liquid which is set into oscillation by the earthquake. The pressure generated within the tank is calculated as per IS 1893 (Part II): 2002 provisions. The typical hydrodynamic pressure distribution on tank wall and base slab is depicted in Figure 3.

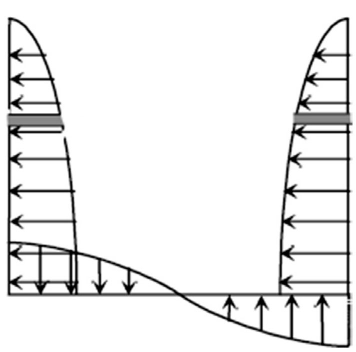

Figure 3: (a) Impulsive Pressure

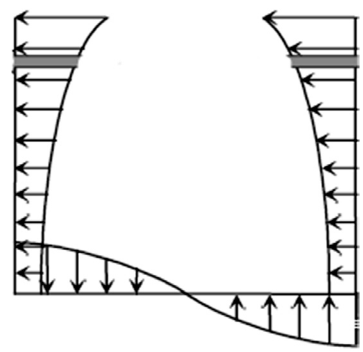

Figure 3: (b) Convective Pressure

Thus, the impulsive hydrodynamic pressure on wall of the tank (P_{iw}) is given by

$$P(y) = Q_{iw}(y)(A_h)i \times \rho \times g \times h$$

Where y is vertical distance of a point on tank wall, Q is the coefficient of impulsive pressure, h is the depth of water in tank, ρ stands for the density of water, acceleration due to gravity g and $(A_h)i$ is the design horizontal seismic coefficient for impulsive mode.

Similarly, the convective pressure on wall (P_{cw}) is computed using the coefficient of convective pressure (Q_{cw}) and L is the length of the tank within. This is given as,

$$P(y) = Q_{cw}(y)(A_h)c \times r \times g \times L$$

The Impulsive and Convective pressure obtained for the water tank used in the analysis with various soil condition is summarised in Table 1.The impulsive pressure and convective pressure of the soft soil is more than the hard soil for both the water filling levels.

Table 1
Variation of Impulsive and convective pressure in the water tank with various soil condition

Water filling level	*Soil type*	*Impulsive pressure kN/m²*	*Convective pressure kN/m²*	
			At top	*At bottom*
4.7 m	Hard	0.461903	0.56803	0.38819
	Medium	0.630387	0.7720	0.52764
	Soft	0.771392	0.94885	0.64844
2.7 m	Hard	0.274814	0.42087	0.36768
	Medium	0.374945	0.57239	0.50005
	Soft	0.459022	0.61416	0.70300

2.3. Analytical Study using STAAD Pro

An elevated tank model used in the analytical study was developed using STAAD Pro software to study the response of the structure. The result obtained from the analytical study is used to analyse the framed structure with the elevated water tank as shown in Figure 2 and model of the elevated water tank is shown in Figure 4.

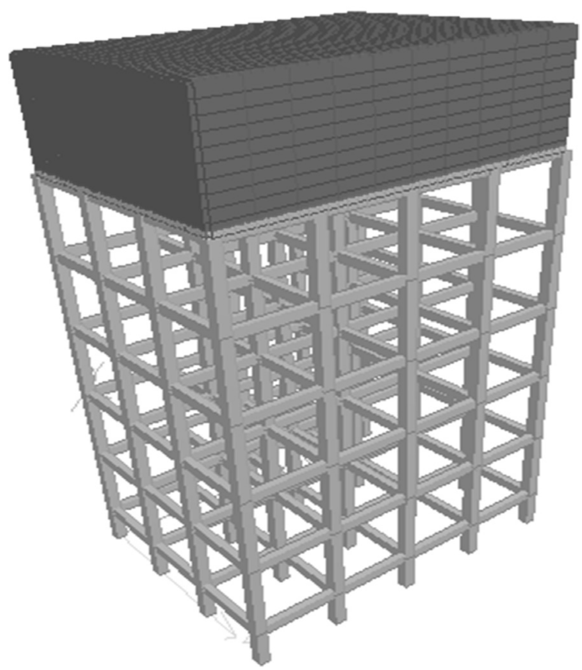

Figure 4: STAAD Pro model of an elevated tank

The elevated tank is designed as a fixed base with different soil types. Each soil type has its respective hydrodynamic effect on the tank. By the effective utilisation of STAAD Pro, the modelling of the tank along with the pictorial representation of hydrodynamic forces is shown in Figure 5.

Response spectra analysis is performed as per IS 1893 (Part-I):2002 provisions on the elevated rectangular tank. The displacement responses, effects of sloshing on the wall, base shear are compared in this study.

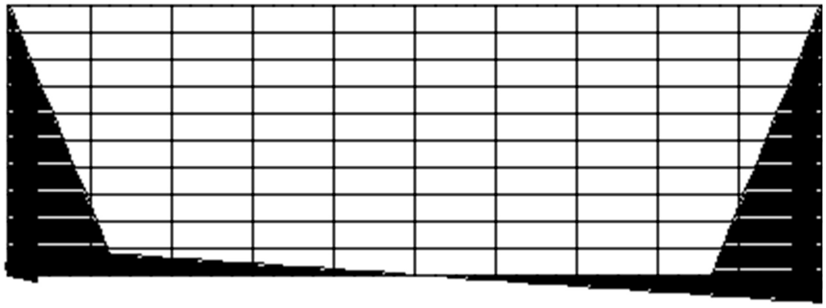

Figure 5: (a) Impulsive forces assignment on walls and base slab

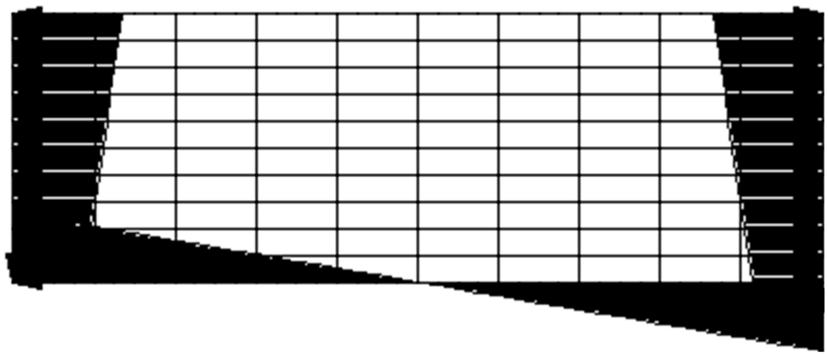

Figure 5: (b) Convective forces assignment on walls and base slab

3. RESULTS AND DISCUSSION

To verify and validate the response of the structure corresponding to analytical computations from the previous section, the results are sorted and contrasted. Different analyses were carried out by varying the soil types and water filling levels using STAAD Pro. The base shear in term of filling parameter is given in Table 2. The peak values of base shear occurs in tank under fully filled condition which is 4.7m excluding the freeboard (0.6m). Furthermore, the difference in base shear among filling condition reduces gradually from soft to hard and it is shown in Figure 6.

Table 2
Comparison of base shear for hard, medium and soft soil from analysis

Filling Parameter	*Soil type*	*Base shear(kN)*
4.7 m	Hard	920.80
	Medium	1254.10
	Soft	1357.59
2.7 m	Hard	918.69
	Medium	1249.54
	Soft	1350.63
0 m	Hard	918.40
	Medium	1247.42
	Soft	1350.17

The peak values of base shear occurs in the soft soil of the tank under fully filled, half-filled and empty condition.

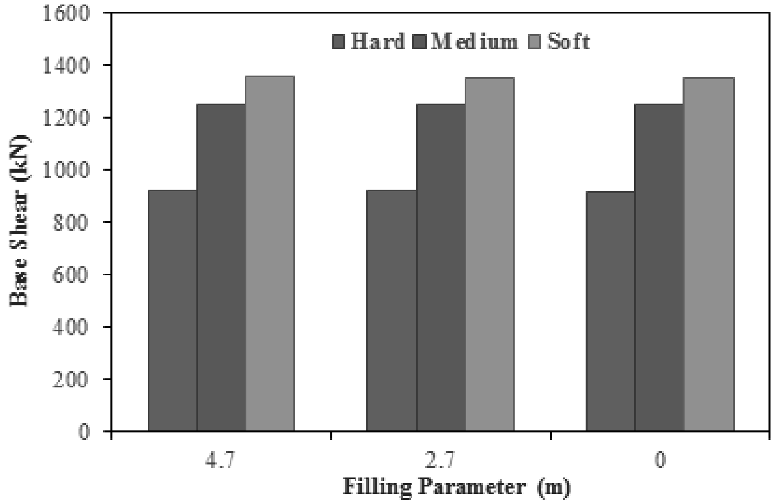

Figure 6: Comparison of base shear of hard, medium & soft soil for different water levels

A few analysis were made to depict the absence of hydrodynamic effects on the structure and the results of base shear for medium soil type is given in Table 3. The hydrodynamic forces have a broad impact on the base shear in fully filled condition in comparison to the half-filled water tank.

Table 3
Base shear comparison based on Hydrodynamic forces

Filling Parameter	*Excluding Hydrodynamic forces (kN)*	*Including Hydrodynamic forces (kN)*
2.7 m	1247	1249.54
4.7 m	1248.87	1254.10

Displacement occurring on floor of the tank and roof of the tank which also signifies the flexibility of the tank wall is given below in Table.4. The displacement of the floor and tank have changed along with changing soil conditions. The difference in displacement between floor and roof increases as the soil varies from hard to soft, resulting in maximum displacement in soft soil is depicted in Figure 7(a),7(b) and 7(c).

Table 4
Comparison of floor and roof displacement for hard, medium and soft soil

Filling Parameter	*Soil type*	*Tank floor displacement (mm)*	*Tank roof displacement (mm)*
4.7 m	Hard	30.351	30.760
	Medium	41.546	42.107
	Soft	45.070	45.679
2.7 m	Hard	29.870	30.265
	Medium	40.905	41.445
	Soft	44.332	44.917
0 m	Hard	29.581	29.973
	Medium	40.477	41.013
	Soft	43.956	44.538

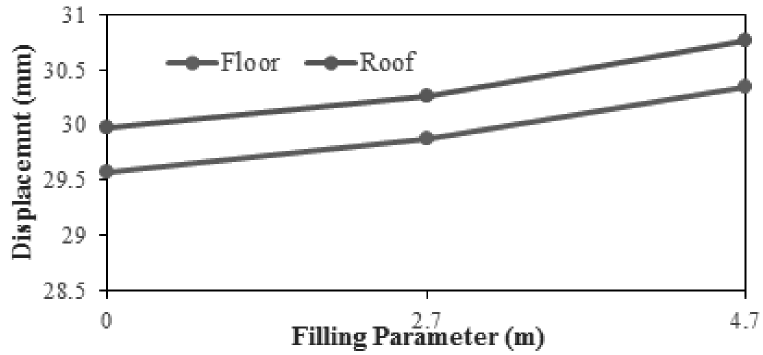

Figure 7: (a) Comparison of floor and roof displacement on hard soil

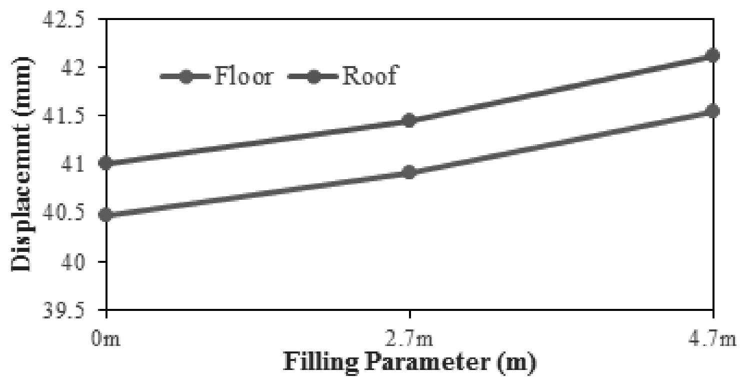

Figure 7: (b) Comparison of floor and roof displacement on medium soil

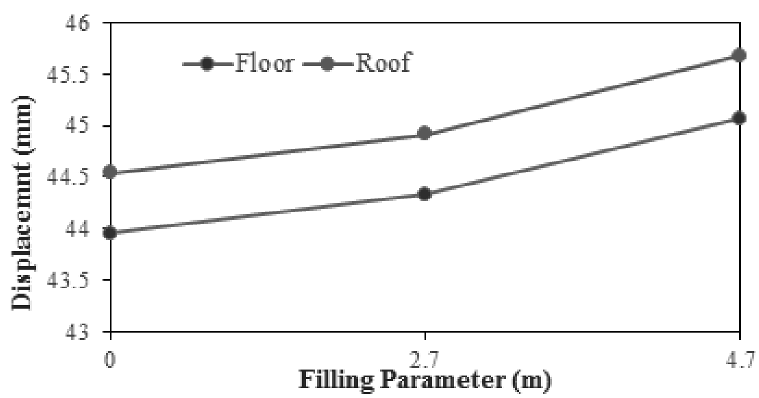

Figure 7: (c) Comparison of floor and roof displacement on soft soil.

The hydrodynamic forces generated from the accelerated liquid produce significant stresses on the tank walls is compared in Figure 8. The increase wall stresses vary with respect to liquid depth as this inspects the rigidity of the wall.

4. CONCLUSIONS

The analysis of the tank including the fluid structure interaction and its observed performance has been compared. The investigation in the initial phase involves in determining the hydrodynamic characteristics of the tank. A nonlinear analysis is carried out including the results computed from the hydrodynamic characteristics.

Based on the above discussed results following conclusions can be drawn:

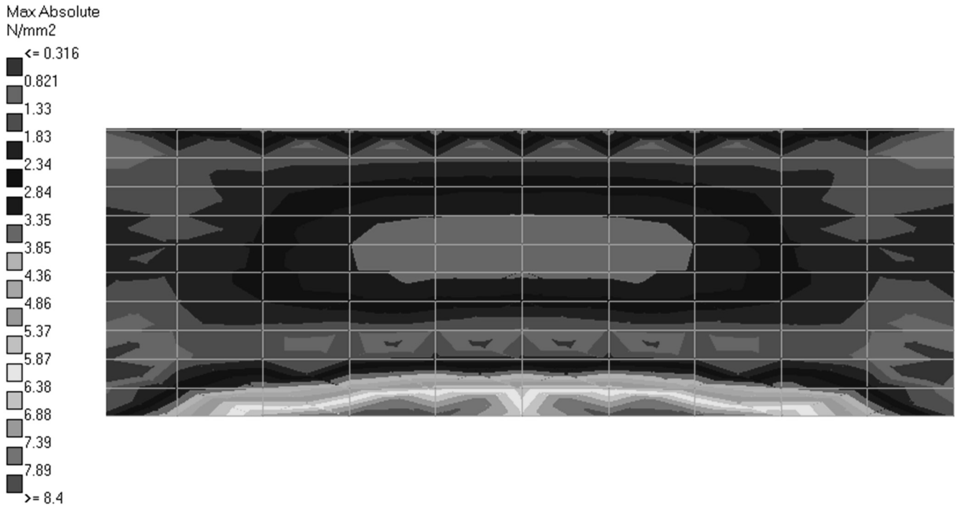

Figure 8: (a) Wall Stress excluding hydrodynamic forces for liquid filled upto 4.7m

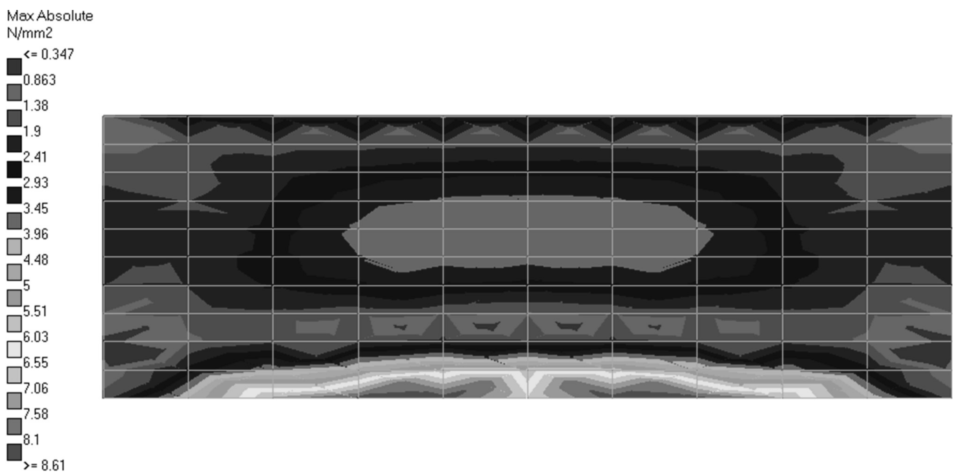

Figure 8: (b) Wall Stress including hydrodynamic forces for liquid filled upto 4.7m

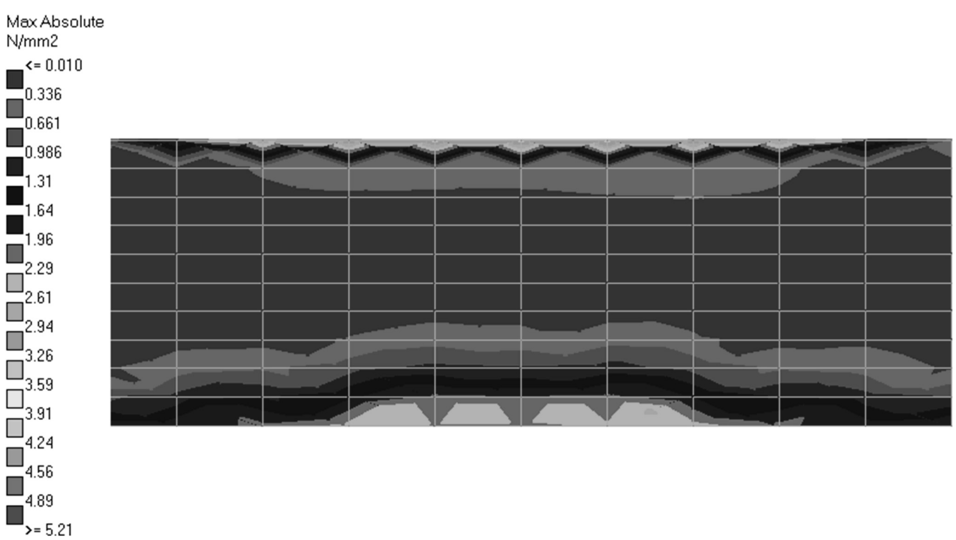

Figure 8: (c) Wall Stress excluding hydrodynamic forces for liquid filled upto 2.7m

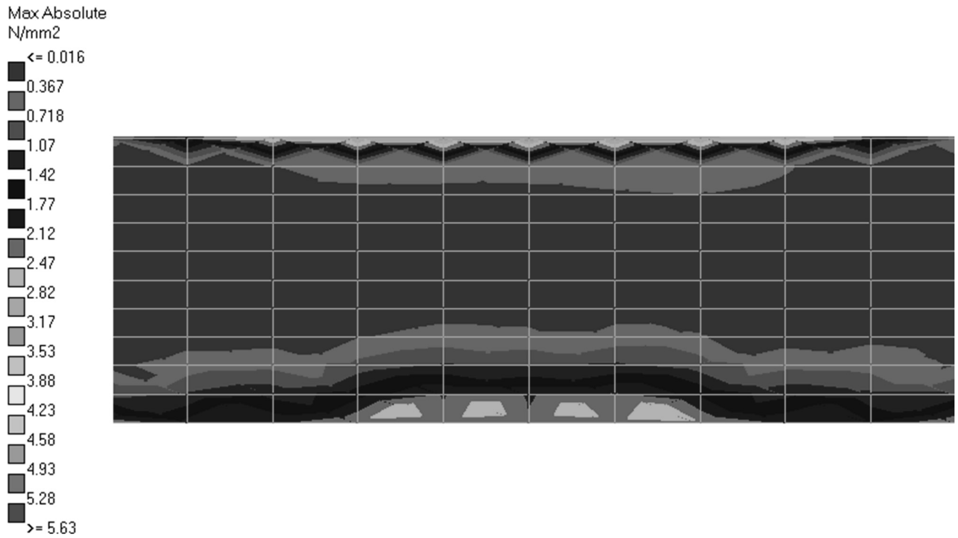

Figure 8: (d) Wall Stress including hydrodynamic forces for liquid filled upto 2.7m

1. The sloshing responses should be calculated as a part of seismic analysis of any liquid storage tank to validate the tank inclusive of hydrodynamic loads generated. This directly depends on the liquid depth, tank geometry and excitation of the tank.
2. Base shear is not conservative as we can predict from the results. Consequence of varying soil conditions and liquid depth has a major impact on determining the base shear.
3. The displacement responses generally increased as the soil gets softer. This also varies linearly with depth of the liquid inside.
4. The difference in displacement of the tank floor and roof proposes the need for designing the tank wall to provide required flexibility and integrity based on sloshing pressure.
5. Seismic design of RC elevated tanks based on the rough assumption that soil is rigid may lead to wrong assessment or lead to great threat as the characteristics of soil is critical in response of the structure.

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