Impulsive and Convective Effect on Tanks Resting on Firm Ground

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Abstract— This study is an examination of an ideal reinforced concrete rectangular water tank resting on ground under the effect of earthquake (lateral) forces. A linear three-dimensional finite element analysis on Staad pro software have been used to analyse the tank response. The variable analysis parameters considered are the aspect ratio (tank height to length ratio) and tank water level, while the tank wall thickness is taken as a constant. Hydrodynamic forces exerted by liquid on tank wall shall be considered in the analysis in addition to hydrostatic forces. These hydrodynamic forces are calculated with the help of spring-mass model of tanks. When a tank containing liquid vibrates, the liquid exerts impulsive and convective hydrodynamic pressure on the tank wall and the tank base in addition to the hydrostatic pressure. In order to show the effect of hydro-dynamic pressure in the analysis, tank can be idealized by an equivalent spring-mass model, which includes the effect of tank wall-liquid interaction. The parameters of this model depend on geometry of the tank. In general, the results show that, there is a smooth increase in the moment and displacement of both hydrostatic and hydrodynamic analysis with a decrease in aspect ratio. The top displacement and moment for the hydrodynamic effects are greater than the hydrostatic results and it is observed that the maximum hydrodynamic moment is higher than the corresponding maximum hydrostatic moment. Likewise, the displacement obtained from hydrodynamic analysis is more than the corresponding hydrostatic value.

Key words: Hydrodynamic Effect, Convective and Impulsive, Rectangular Tanks, Finite Element Models, Staad-Pro

I. Introduction

Storage tanks are used for storing water, inflammable liquids toxic materials and other forms of liquids such as sewage water. Tanks constructed of reinforced concrete are most popular and widely used components in any major water distribution network for public utility and industrial facilities. Thus, it is evident that such tanks should be designed to withstand lateral loads in addition to vertical loads. However, due to lack of earthquake load consideration, damages of storage tanks in recent earthquakes have been observed and extensively studied by different researchers to render its vitality (Housner, 1963). Housner approaches first to evaluate the hydro-dynamic pressure distribution developed in fixed base tanks for a horizontal base excitation (Jaiswal and Jain, 2005a,b). In fact, prior to the advent of modern computers and the widespread of numerical methods in structural engineering, water storage tanks were analysed mathematically using closed form shell analysis solutions together with some relevant design curves. However, those approaches were conventionally limited to hydrostatic effects. Thus, using numerical methods for the rigorous evaluation of the dynamically induced stresses on the tank walls is found to be accurate approach as it involves the interaction between the lateral displacement of the tank and that of the fluid motion. This dynamic interaction due to lateral movement affects the strength and behaviour of the tank. Hence, there is a need to understand the behaviour of liquid retaining tanks and to consider the latest advances in the design so that they are not vulnerable under earthquake loads. In this study, behaviour of a typical ground supported tank under seismic load has been studied using the finite element model.

II. Modal Analysis of Water Tank

A. *Review of Reference Codes*

Some of the structural design codes that tackle fluid tank systems are the Indian Standard Codes IS 3370 Part1&2 IS 456-2000 IS 1893-Part-1&2 and IS 875-Part1&2. These codes address ground supported circular and rectangular concrete tanks having fixed or flexible bases. This condition is relevant to this study; the aim of which is to create an idealized model suitable for representing the vibrating fluid tank system by a proper spring-mass system which considerably simplifies the interaction. Proper seismic analysis accounts for the inertia forces of the accelerating structure as well as the inertia forces of the accelerating fluid which the tank contains.

B. *Spring - Mass Model*

Seismic analysis of liquid storage tank is a critical problem involving fluid-structure interaction. Based on several analytical, numerical and practical studies, a simple spring mass models of tank wall-liquid interaction have been developed to calculate hydrodynamic effects (Jaiswal and Jain, 2005a,b). If a tank containing liquid is subjected to lateral forces i.e. seismic ground movements, then tank wall and liquid undergoes horizontal acceleration. The liquid in the lower level of the tank behaves like a mass which is rigidly connected to tank wall surface. The impulsive mass of liquid, mi is rigidly connected to tank wall at height hi (or hi*). Similarly, convective mass, mc is connected to the tank wall at height hc (or hc*) by as spring of stiffness Kc. Representation of Spring Mass Model is Shown in figure-1 and Parameter for Sping Mass Model For Rectangular Tank is shown in fig-2 below.

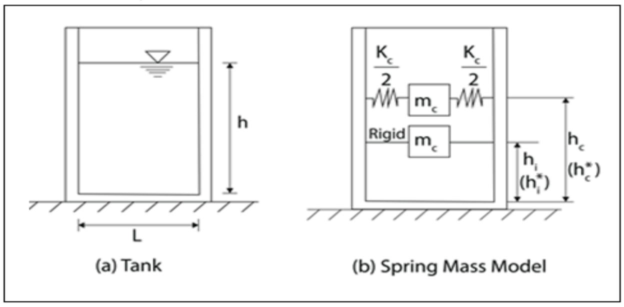

Fig. 1: Spring-Mass Model for Ground Supported Rectangular Tank

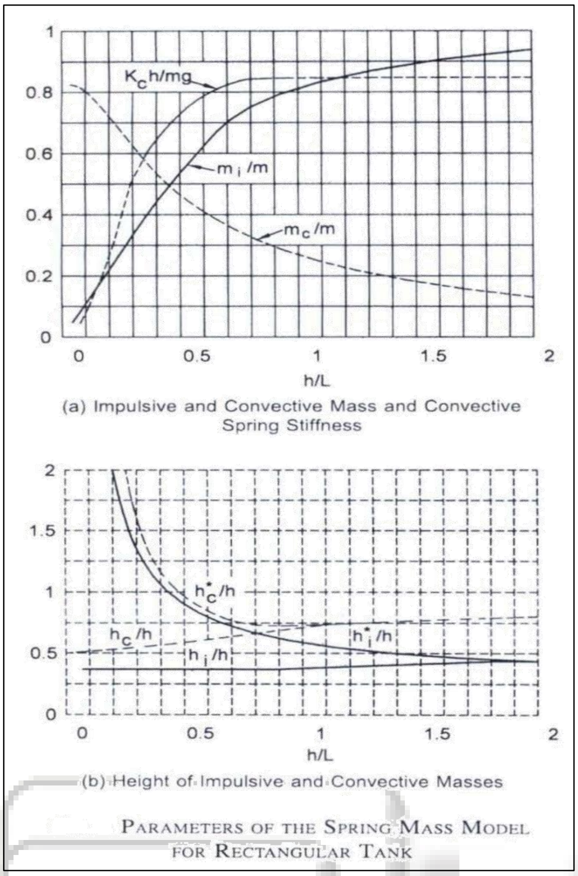

Fig. 2: Parameter for Spring Mass Model for Rectangular Tank

III. DESCRIPTION OF THE TANK STRUCTURE

The sewage tank (Treated Water) structure is analysed in the present study is a ground supported rectangular storage tanks with a volume of 150 m3. The geometries are selected taking into account the limitation of rectangular shaped tanks for containing higher volume due to lack of uniform stress distribution that leads to local failure. The contained liquid is assumed to be water with a density of 14 kN/m3. The planar dimensions of the tanks are 6.85m x 6.85m x 3.5m with a free board of 0.3 m and with a total height (h) of 3.5 m and the values of the aspect ratio(A) i.e. the ratio of the length to height of the tank (l/h), is used for analysis and comparison of results. The tank structure is idealized to be of 0.3m thickness reinforced concrete wall system with a concrete grade of M-30. A damping coefficient of 0.5% is used for the analysis.

IV. FEM MODELING AND DETAILED DYNAMIC ANALYSIS

The numerical analysis of the treated water storage rectangular tank structures is performed as per codal provisions and on the basis of detailed FE model implemented with the help of the available Finite Element analysis in Staad Pro software package. The wall thickness is approximated to be uniform thickness instead of tapered wall and the base slab thickness is also kept same for modelling.

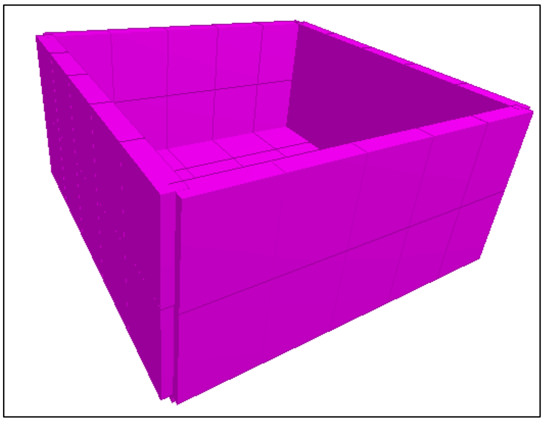

Fig. 3: 3D render view from Staad Pro

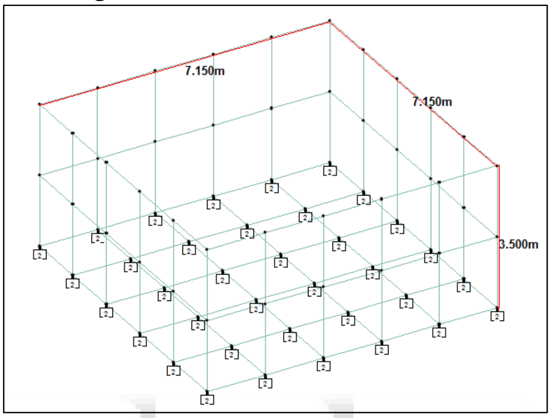

Fig. 4: Dimensional Model of Tank (Center to Center Dimension of Tank Wall)

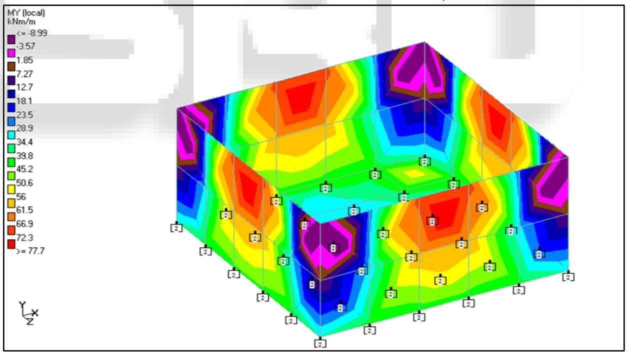

Fig. 5: Maximum Moments Results on Side Walls and Base Slab

Furthermore, the following assumptions are made to simplify the dynamic analysis procedure

1) The material of the tank is linearly elastic, isotropic and homogeneous;
2) The base is connected rigidly to the tank wall.

Impulsive and convective hydrodynamic pressure are calculated and by SRSS rule it is applied as equivalent linear distribution of pressure on wall and base of tank.

The maximum value of hydrodynamic pressure should be calculated by combining pressure due to horizontal and vertical excitation through square root of sum of squares (SRSS) rule, which can be given as:

$$P = \sqrt{(P_{iw}+P_{ww})^2+(P_{cw}^2+P_v^2}$$

V. RESULTS AND DISCUSSION

A hydrodynamic and hydrostatic analyses were carried out for ground rested sewage (Treated water) tank has been done.

As a result, maximum positive and negative moments are compared for following cases

1) When hydrostatic pressure is applied.
2) When Hydrostatic and Hydrodynamic Pressure together.

On the basis of above two cases we have compared the different design parameters like Moments, Shear and Membrane stresses as shown in following tables.

WALL-1 TO 4 RESULT CASE-1										
SUMMARY OF ANALYSIS RESULT FROM STAAD										
			Shear		Membrane			Bending Moment		
	Plate	L/C	SQX (local) N/mm2	SQY (local) N/mm2	SX (local) N/mm2	SY (local) N/mm2	SXY (local) N/mm2	Mx kNm/m	My kNm/m	Mxy kNm/m
Max Qx	5	32 (DL + LL	103.071	0	-224.057	-1815.019	0	-25.533	-32.346	0
Min Qx	10	33 (DL + LL	-117.04	-182.161	-158.192	192.534	261.538	17.163	-0.31	10.629
Max Qy	2	33 (DL + LL	-117.04	182.161	-158.192	192.534	-261.538	17.163	-0.31	-10.629
Min Qy	10	33 (DL + LL	-117.04	-182.161	-158.192	192.534	261.538	17.163	-0.31	10.629
Max Sx	9	5 TEMPER/	65.591	53.48	283.335	-886.401	253.678	-27.539	-34.105	-2.145
Min Sx	1	39 (DL + W	-104.742	104.755	-339.793	930.602	281.007	32.292	31.027	-5.395
Max Sy	5	33 (DL + LL	35.319	0	65.679	1984.839	0	42.001	52.404	0
Min Sy	5	5 TEMPER/	33.876	0	-144.868	-1899.929	0	-33.767	-42.375	0
Max Sxy	2	42 (DL + E(	81.055	-33.814	135.475	21.286	290.969	-20.962	-27.572	5.918
Min Sxy	10	43 (DL - EC	81.055	33.814	135.475	21.286	-290.969	-20.962	-27.572	-5.918
Max Mx	5	39 (DL + W	-67.821	-0.136	-31.354	1927.351	-1.048	51.406	48.956	-0.016
Min Mx	3	5 TEMPER/	35.536	5.493	-210.901	-1719.837	-201.554	-34.993	-41.349	4.191
Max My	6	33 (DL + LL	-44.301	0	83.336	-46.824	0	14.872	69.594	0
Min My	10	7 RL1	48.278	-88.39	139.554	211.605	-275.873	-23.845	-51.246	-2.32
Max Mxy	7	33 (DL + LL	17.491	-9.789	121.75	1810.743	-197.396	41.972	48.012	14.256
Min Mxy	3	33 (DL + LL	17.491	9.789	121.75	1810.743	197.396	41.972	48.012	-14.256

CASE 1: When only Hydrostatic pressure is applied

WALL-1 TO 4 RESULT CASE-2										
SUMMARY OF ANALYSIS RESULT FROM STAAD										
			Shear		Membrane			Bending Moment		
	Plate	L/C	SQX (local) N/mm2	SQY (local) N/mm2	SX (local) N/mm2	SY (local) N/mm2	SXY (local) N/mm2	Mx kNm/m	My kNm/m	Mxy kNm/m
Max Qx	5	32 (DL + LL	137.559	0	-220.474	-1786.613	0	-25.777	-29.652	0
Min Qx	10	33 (DL + LL	-129.918	-232.213	-157.201	262.585	260.399	16.044	-8.995	12.674
Max Qy	2	33 (DL + LL	-129.918	232.213	-157.201	262.585	-260.399	16.044	-8.995	-12.674
Min Qy	10	33 (DL + LL	-129.918	-232.213	-157.201	262.585	260.399	16.044	-8.995	12.674
Max Sx	9	5 TEMPER/	65.591	53.48	283.335	-886.401	253.678	-27.539	-34.105	-2.145
Min Sx	1	39 (DL + W	-104.742	104.755	-339.793	930.602	281.007	32.292	31.027	-5.395
Max Sy	5	33 (DL + LL	69.808	0	69.262	2013.244	0	41.757	55.098	0
Min Sy	5	5 TEMPER/	33.876	0	-144.868	-1899.929	0	-33.767	-42.375	0
Max Sxy	2	42 (DL + E(	81.055	-33.814	135.475	21.286	290.969	-20.962	-27.572	5.918
Min Sxy	10	43 (DL - EC	81.055	33.814	135.475	21.286	-290.969	-20.962	-27.572	-5.918
Max Mx	5	39 (DL + W	-67.821	-0.136	-31.354	1927.351	-1.048	51.406	48.956	-0.016
Min Mx	3	5 TEMPER/	35.536	5.493	-210.901	-1719.837	-201.554	-34.993	-41.349	4.191
Max My	6	33 (DL + LL	-50.099	0	82.57	19.035	0	17.177	77.726	0
Min My	10	7 RL1	35.4	-138.441	140.545	281.657	-277.013	-24.964	-59.931	-0.275
Max Mxy	7	33 (DL + LL	44.301	-10.218	119.056	1840.11	-190.649	41.994	49.789	17.401
Min Mxy	3	33 (DL + LL	44.301	10.218	119.056	1840.11	190.649	41.994	49.789	-17.401

CASE 2: When Hydrostatic and Hydrodynamic Pressure together

VI. CONCLUSION

This paper concludes the hydrostatic analysis and the hydrodynamic effect induced on ground supported sewage (Treated water) storage tank structures. It is observed from the above results that the dynamic effects are critical for the design point of view for such tank structures. In general, the outcomes show that, there is a smooth increase in the moment, shear and membrane stresses for hydrodynamic analysis by applying hydrodynamic pressure on the same tank. The maximum hydrodynamic moment is observed to be 10.5 % higher than the maximum hydrostatic moment. Similarly, the maximum shear is higher by 21.5 % obtained from hydrodynamic analysis than the corresponding hydrostatic result. Thus a due consideration of hydrodynamic effects must be given in the design of liquid storage tank structures in seismic prone areas.

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