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Seismic Response and Optimization of Multidecked Water Tank with Variation in H/D Ratio

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Abstract: ***The main aim of this study is to understand the behavior of multidecked elevated circular water tank for different staging height under different loading conditions and strengthening the conventional type of staging, to give better performance during earthquake. Normal type of bracing system applied to the staging of elevated circular water tank for earthquake zone IV of India. Analysis is carried out using SAP2000 v15. Twenty models are used for calculating base shear and nodal displacements for H/D ratios 0.3, 0.4, 0.5, 0.6. Variation in staging height is 12m, 16m, 24m and 28 m at 4m each. In the analysis response spectrum method has been used for seismic analysis of structures for software. Sloshing forces and base shear was calculated from IITK guideline. Hydrodynamic pressure for impulsive and convective mode was calculated.***

Keywords: Circular water tank, Convective Hydrostatic and Impulsive Hydro static pressure, IITK guideline, sloshing forces.

1. Introduction

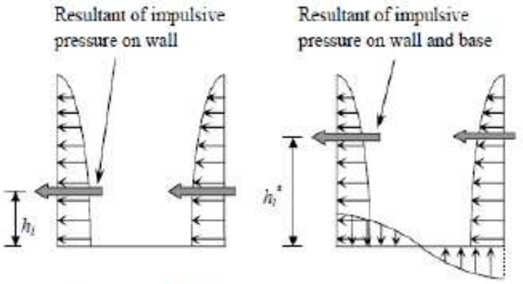
Water is human basic needs for daily life. Sufficient water distribution depends on design of a water tank in certain area. An elevated water tank is a large water storage container constructed for the purpose of holding water supply at certain height to pressurization the water distribution system. 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. The walls of these tanks are subjected to pressure and the base is subjected to weight of water and pressure of soil. From design point of view the tanks may be classified as per their shape rectangular tanks, Circular tanks, intze type tanks, spherical tanks conical bottom tanks and suspended bottom tanks .The liquid storage tanks are particularly subjected to the risk of damage due to earthquake-induced vibrations. A large number of overhead water tanks damaged during past earthquake.

1.1 Spring Mass Model for Elevated Tank

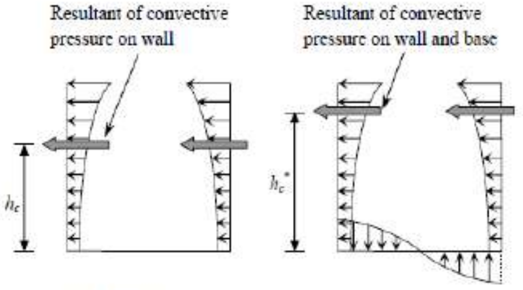
When a tank containing liquid with a free surface is subjected to horizontal earthquake ground motion, tank wall and liquid are subjected to horizontal acceleration. The liquid in the lower region of tank behaves like a mass that is rigidly connected to tank wall. This mass is termed as impulsive liquid 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 hydrodynamic pressure on tank wall and base. Thus, total liquid mass gets divided into two parts, i.e., impulsive mass and convective mass. In spring mass model of tank-liquid system, these two liquid masses are to be suitably represented. A qualitative description of impulsive and convective hydrodynamic pressure distribution on tank wall and base is given in Figure.

2. Methodology

To study the seismic performance of elevated circular water tank for seismic zones IV of India for various heights of staging 12m,16m, 20 m, 24m and 28m for 200000 liter capacity of elevated water tanks for H/D ratios 0.3,0.4,0.5,0.6. Total twenty models are made for analysis of elevated water tank. Seismic analysis is done by response spectrum method. To study the Indian standard codes guidelines for the analysis of such tanks, study the suitability of normal types of bracing considering tanks for different H/D ratios and different heights of staging for a constant capacity of the circular and rectangular water tank. To study the seismic analysis of water tank by using response spectrum method using FEM Software SAP2000v15. Water tank is modeled and analyzed for sloshing forces as per IIT KANPUR Guideline for different Indian Seismic zones. Validation of software result with IIT KANPUR Guideline. Comparison of base shear and maximum displacement/nodal displacement of container will do.



(a) Impulsive pressure on wall (b) Impulsive pressure on wall and base



(c) Convective pressure on wall (d) Convective pressure on wall and base

Figure 1: Qualitative description of hydrodynamic pressure distribution on tank wall and base

2.1 Design Horizontal Seismic Coefficient

Design horizontal seismic coefficient, Ah shall be obtained by the following expression,

Ah=Z/2xI/R x Sa/g

Where,

Z = Zone factor given in IS 1893 (Part 1): 2002,
I = Importance factor for social structure 1.5 as IITK guideline
R = Response reduction factor 1.8 for OMRF as per IITK guideline
Sa/g = Average response acceleration Coefficient,

Design horizontal seismic coefficient, Ah will be calculated separately for impulsive (Ah)i, and convective (Ah)c modes.

For hard soil sites

Sa /g = 2.5 for T < 0.4
= 1.0/T for T ≥ 0.4

For medium soil sites

Sa /g = 2.5 for T < 0.55
= 1.36/T for T ≥ 0.55

For soft soil sites

Sa /g = 2.5 for T < 0.67
= 1.67/T for T ≥ 0.67
Time period of impulsive mode,
Ti in seconds is given by,
Ti=2PÖ mi+ms/k
Where,
ms = mass of container and one-third mass of staging
K = lateral stiffness of staging.

Lateral stiffness of the staging is the horizontal force required to be applied at the center of gravity of the tank to cause a corresponding unit horizontal displacement Time period of convective mode**.**

Tc = Cc √(D/g)
Where,
Cc = Coefficient of time period for convective mode
D = Inner diameter of tank.
Base shear in impulsive mode, just above the base of staging (i.e. at the top of footing of staging) is given by
Vi = (Ah)i (mi + ms)
Base shear in convective mode is given by
Vc= (Ah)c mc g
Where,
ms = Mass of container and one-third mass of staging.

Total base shear V, can be obtained by combining the base shear in impulsive and convective mode through Square root of Sum of Squares (SRSS) rule and is given

as follows,
V = Vi +Vc

2.2 Load Combinations

Working combinations are considered for proper result interpretation.
Tank empty: self-weight of structure + earthquake loads as per response spectra method.
Tank full: Self weight of structure + Earthquake loads as per response spectra method + sloshing force.
Method of analysis: Response spectra As per IS1893-1984 & IITKGSDMA guidelines, by using Sap 2000-v15Hydro static pressure at base of wall.
Impulsive Hydro static pressure at base of wall at
y=0
Pi(Y) = Q (Y)x Ahi x 9810 x cos Φ
Convective Hydrostatic pressure at base of wall
y=0
Qcw = 0.5625xcoshs(3.674xY/D)/cosh(3.674xh/D)
Convective Hydro static pressure at base of wall
Pi(Y)= Qcwx Ahc x 9810x D(1-(1/3)cos2 Φ)cosΦ
at y=h
Pcw(Y)= Qcwx Ahc x 9810x D(1-(1/3)cos2 Φ)cosΦ

3. Problem Statement

The tank has been modeled as 3D Space frame model with six degree of freedom at each node using SAP 2000 software for stimulation of behavior under gravity and seismic loading. The isometric 3D view and elevation of the tank model is shown as figure. The support condition is considered as fully fixed.

Table 1: Dimension Details of circular water tank

Type of Water Tank - Elevated Circular				
Staging height	12M,16M,20M,24M,28M			
H/D Ratio	0.3	0.4	0.5	0.6
Diameter of container	10.15	9.17	8.18	8.205
Height of container	3.3	3.9	4.3	5.1
wall thickness	0.15	0.17	0.18	0.205
base slab thickness	0.3	0.3	0.3	0.3
Rng beam Depth	0.75	0.75	0.75	0.75
Rng beam width	0.35	0.35	0.35	0.35
CG of Container	2.00	2.31	2.51	2.92
Dia of Staging C/C	10.3	9.34	8.36	8.41
No of staging	4	4	4	4
Each staging height =	3	3	3	3
No of columns =	10	10	10	10
dia of each column	0.5	0.5	0.5	0.5
bracing beam Depth	0.3	0.3	0.3	0.3
Width	0.5	0.5	0.5	0.5

Table 2: Loads on SAP2000, staging ht. 12m

Type of Water Tank - Elevated Circular				
Staging Height	**12M**			
H/D Ratio	0.3	0.4	0.5	0.6
1) Sloshing Forces				
1-(a) Impulsive =kN	22.21	29.4	34.88	45.0
1-(b) Convective =kN	7.19	9.53	10.92	15.3
Water pressure on base slab				
2) WL = 9.81xH kN/m2	32.37	38.2	42.18	50.0

Table 3: Loads on SAP2000, staging ht. 16m

Type of Water Tank - Elevated Circular				
Staging Height	**16M**			
H/D Ratio	0.3	0.4	0.5	0.6
1) Sloshing Forces				
1-(a) Impulsive =kN	17.36	23.1	27.75	35.5
1-(b) Convective =kN	7.19	9.53	10.92	15.3
Water pressure on base slab				
2) WL = 9.81xH kN/m2	32.37	38.2	42.18	50.0

Table 4: Loads on SAP2000, staging ht. 20m

Type of Water Tank - Elevated Circular				
Staging Height	**20M**			
H/D Ratio	0.3	0.4	0.5	0.6
1) Sloshing Forces				
1-(a) Impulsive =kN	14.56	19.4	23.52	29.8
1-(b) Convective =kN	7.19	9.53	10.92	15.3
Water pressure on base slab				
2) WL = 9.81xH kN/m2	32.37	38.2	42.18	50.0

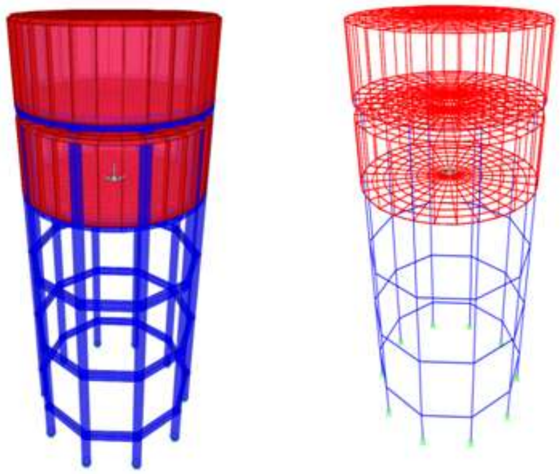


Figure 2: 3D View of multistage circular water tank

Table 5: Loads on SAP2000, staging ht. 24m

Type of Water Tank - Elevated Circular				
Staging Height	**24M**			
H/D Ratio	0.3	0.4	0.5	0.6
1) Sloshing Forces				
1-(a) Impulsive =kN	12.67	16.93	20.62	25.97
1-(b) Convective =kN	7.19	9.53	10.92	15.36
Water pressure on base slab				
2) WL = 9.81xH kN/m2	32.37	38.26	42.18	50.03

Table 6: Loads on SAP2000, staging ht. 28m

Type of Water Tank - Elevated Circular				
Staging Height	**28M**			
H/D Ratio	0.3	0.4	0.5	0.6
1) Sloshing Forces				
1-(a) Impulsive =kN	11.29	15.0	18.4	23.0
1-(b) Convective =kN	7.19	9.53	10.9	15.3
Water pressure on base slab				
2) WL = 9.81xH kN/m2	32.37	38.2	42.1	50.0

4. Analysis and Results

Table 7: Base Shear

H/D	**0.3**	**0.4**	**0.5**	**0.6**
Staging height	KN	KN	KN	KN
12m	1246.6	1243.434	1234.357	1229.212
16m	1038.84	1036.124	1031.21	1019.621
20m	919.131	886.317	878.357	865.155
24m	839.71	835.47	809.045	800.901
28m	782.096	746.899	741.786	737.452

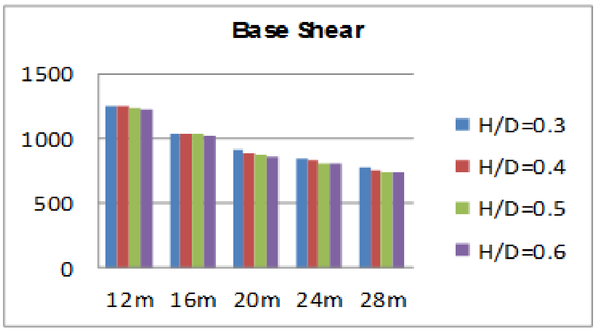


Figure 3: Base shear in kN

Table 8: Joint Displacement U1 - TANK EMPTY CONDITION

H/D	0.3	0.4	0.5	0.6
Staging height	m	m	m	m
12m	0.03665	0.039337	0.040224	0.0442
16m	0.04709	0.047549	0.050145	0.05173
20m	0.05858	0.061307	0.062769	0.06313
24m	0.06889	0.071795	0.073382	0.07397
28m	0.07933	0.082292	0.083915	0.08491

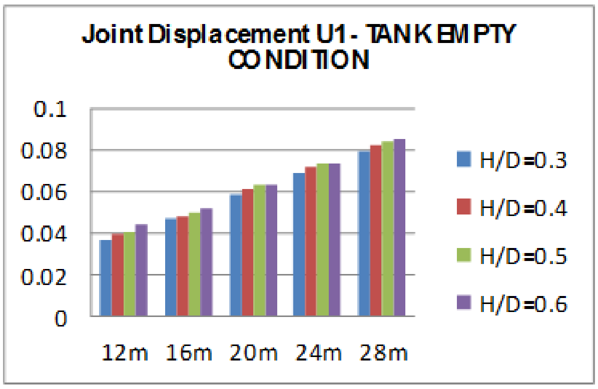


Figure 4: Joint Displacement U1 - TANK EMPTY CONDITION in m

Table 9: Joint Displacement U1 - TANK FULL CONDITION

H/D	0.3	0.4	0.5	0.6
Staging height	m	m	m	m
12m	0.042137	0.04288	0.04348	0.04433
16m	0.04987	0.05194	0.05433	0.05718
20m	0.064831	0.06579	0.06671	0.07158
24m	0.076209	0.07693	0.07808	0.08411
28m	0.086638	0.08799	0.08945	0.09652

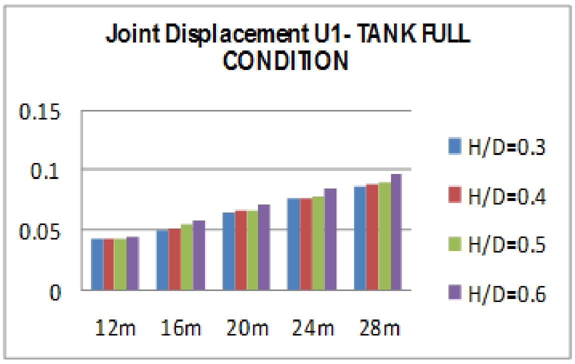


Figure 5: Joint Displacements U1 - TANK FULL CONDITION in m

Table 10: Axial Force in Columns - TANK EMPTY CONDITION

H/D	0.3	0.4	0.5	0.6
Staging height	kN	kN	kN	kN
12m	1051.64	1111.25	1180.15	1354.96
16m	1149.12	1284.35	1348.81	1455.23
20m	1255.26	1313.17	1348.99	1469.37
24m	1363.15	1421.98	1459.04	1575.17
28m	1470.57	1530.29	1568.24	1826.57

Table 11: Axial Force in Columns - Tank Full Condition

H/D	0.3	0.4	0.5	0.6
Staging height	kN	kN	kN	kN
12m	1614.56	1673.62	1696.65	1985.75
16m	1715.02	1747.6	1806.65	2102.11
20m	1824.36	1884.38	1877.19	2111.42
24m	1935.41	1997.71	1993.39	2227.27
28m	2045.93	2110.42	2108.63	2340.7

Table 12: Moment in Columns M2 - TANK EMPTY CONDITION

H/D	0.3	0.4	0.5	0.6
Staging height	kN-m	kN-m	kN-m	kN-m
12m	159.495	162.206	162.493	164.13
16m	135.576	142.142	142.843	150.723
20m	122.575	125.746	130.803	132.092
24m	112.304	116.828	121.73	123.324
28m	103.171	109.278	114.11	115.93

Table 13: Moment in Columns M2 - TANK FULL CONDITION

H/D	0.3	0.4	0.5	0.6
Staging height	kN-m	kN-m	kN-m	kN-m
12m	169.833	177.404	182.232	207.88
16m	148.838	158.114	163.5	181.246
20m	138.345	139.98	142.346	153.862
24m	129.157	129.845	132.187	142.5
28m	121.383	121.421	123.764	129.788

Table 14: Moment in Columns M3 - Tank Empty Condition

H/D	0.3	0.4	0.5	0.6
Staging height	kN-m	kN-m	kN-m	kN-m
12m	408.804	423.306	431.84	448.756
16m	360.841	363.636	366.111	392.993
20m	313.967	325.262	327.712	331.791
24m	288.07	298.374	300.979	303.048
28m	268.647	278.342	281.166	311.895

Table 15: Moment in Columns M3 - Tank Full Condition

H/D	0.3	0.4	0.5	0.6
Staging height	kN-m	kN-m	kN-m	kN-m
12m	451.235	458.173	462.997	507.013
16m	383.436	397.859	420.986	449.087
20m	343.276	347.39	353.649	376.162
24m	315.253	318.779	324.366	344.856
28m	294.481	297.34	302.545	320.416

Table 16: Shear Force in bracings V2 - Tank Empty Condition

H/D	0.3	0.4	0.5	0.6
Staging height	kN	kN	kN	kN
12m	237.477	284.115	320.697	380.522
16m	242.099	286.614	331.819	381.682
20m	222.792	255.862	277.839	304.509
24m	209.74	239.166	262.861	283.804
28m	197.812	227.852	252.272	267.116

Table 17: Shear Force in bracings V2 - TANK FULL CONDITION

H/D	0.3	0.4	0.5	0.6
Staging height	kN	kN	kN	kN
12m	248.268	285.611	335.767	382.441
16m	253.184	322.646	334.833	358.032
20m	232.95	264.52	290.755	312.305
24m	219.327	247.824	271.437	291.6
28m	206.793	232.899	254.693	272.454

Table 18: Moment in bracings M3 - TANK EMPTY CONDITION

H/D	0.3	0.4	0.5	0.6
Staging height	kN-m	kN-m	kN-m	kN-m
12m	372.147	396.387	406.587	493.935
16m	348.977	380.052	409.062	494.279
20m	337.964	359.294	366.803	387.585
24m	316.967	334.927	341.543	361.021
28m	307.691	316.87	325.225	344.331

Table 19: Moment in bracings M3 - TANK FULL CONDITION

H/D	0.3	0.4	0.5	0.6
Staging height	kN-m	kN-m	kN-m	kN-m
12m	389.531	398.502	445.391	496.498
16m	376.805	382.64	418.691	441.509
20m	364.228	369.179	384.308	403.782
24m	342.299	345.358	370.661	376.538
28m	318.313	322.133	324.073	351.344

Table 20: Torsion in bracings T - TANK EMPTY CONDITION

H/D	0.3	0.4	0.5	0.6
Staging height	kN-m	kN-m	kN-m	kN-m
12m	20.6344	26.1683	37.8807	51.4344
16m	17.9757	22.0139	32.657	44.8196
20m	16.3917	20.7286	22.668	24.6143
24m	15.3248	19.3184	21.0899	22.9218
28m	14.3512	18.0437	19.6812	21.3019

Table 21: Torsion in bracings T - TANK FULL CONDITION

H/D	0.3	0.4	0.5	0.6
Staging height	kN-m	kN-m	kN-m	kN-m
12m	21.6188	27.1433	38.5507	52.4375
16m	18.8314	23.109	33.387	45.8566
20m	17.1719	21.4186	23.642	25.6443
24m	16.058	20.0184	22.931	23.6215
28m	15.0352	19.5237	20.1212	22.7059

Table 22: Optimized diameter of column mm

H/D	Diameter in m			
Staging height	0.3	0.4	0.5	0.6
12m	500	500	500	500
16m	500	500	500	500
20m	600	600	600	600
24m	600	600	600	600
28m	600	600	600	600

Table 23: Total Concrete quantity m³

H/D	Total Concrete quantity m³			
Staging height	0.3	0.4	0.5	0.6
12m	220.5	226.5	231.79	237.45
16m	268.937	274.589	280.24	285.89
20m	315.85	321.505	327.157	332.808
24m	367.268	372.92	378.572	384.224
28m	418.952	424.604	430.256	435.908

Table 24: Total Steel quantity tonnes

H/D	Total Steel quantity tonnes			
Staging height	0.3	0.4	0.5	0.6
12m	0.2948	0.22051	0.2171	0.20817
16m	0.44051	0.40649	0.40371	0.33357
20m	0.52526	0.50635	0.49071	0.46559
24m	0.67642	0.65195	0.63074	0.60129
28m	0.85518	0.85271	0.78269	0.76284

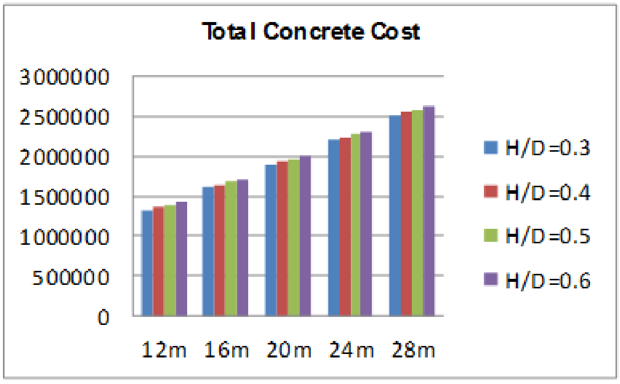


Figure 6: Total Concrete Cost in Rs

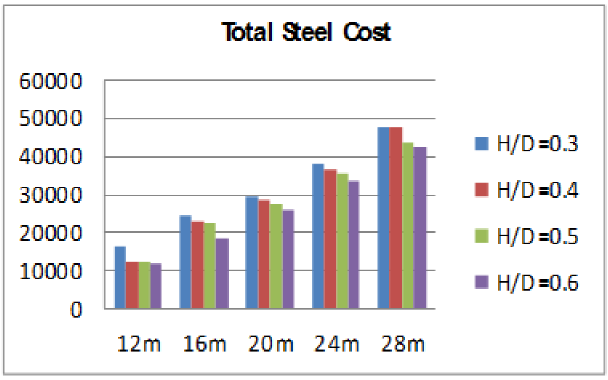


Figure 7: Total steel Cost in Rs

5. Conclusion

1. A Small accidental eccentricity may cause asymmetrically localized yielding in staging members due to unequal displacement of staging edges caused by coupled lateral torsional vibration.
2. Time Period in case of Convective mode is found to be varying between 4 sec to17sec.For medium soil condition Sa/g is calculated using formula 1.36/T , resulting in very low values of Sa/g. For buildings there is limitation on time period on 4 sec as per 1893-2002 part II However these limitations are removed from code for tank.

3. For tank full and tank empty conditions, as staging levels increases; Base Shear with Base Moment decreases and Roof Displacement increases.
4. For tank full and tank empty conditions, Base Shear and Base Moment is decreases as H/D ratio and staging height increases.
5. For tank full and tank empty conditions, joint displacement is increases as H/D ratio and staging height increases.
6. For tank full and tank empty conditions, Base reaction and Base Moment are increases as H/D ratio and staging height increases.
7. For tank full and tank empty conditions, Axial force in columns is increases as H/D ratio and staging height increases.
8. For tank full and tank empty conditions, Shear force and Moment is decreases as H/D ratio and staging height increases.
9. For tank full and tank empty conditions, Shear force, torsion and Moment is a decrease as H/D ratio and staging height increases.
10. Tank Empty condition has less Base Shear and Base Moment compared to tank full condition.
11. As H/D ratio and staging height increases concrete and steel cost increases.

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