Seismic Response and Optimization of Multi Decked Water Tanks with Variations in Height / Diameter Ratio

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Abstract: ***The main objective of this study is to evaluate the seismic response and optimization of multi decked water tanks with variations in height of staging and diameter of tank under different loading conditions and strengthening the conventional type of staging. 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, axial forces and moments of the structure along different direction by using response spectrum method 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. 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 tanks are very important for public utility and for industrial structure, many new ideas and innovation has been made for the storage of water in different forms and fashions. In general, there are three kinds of water tanks i.e. water tank resting on ground, underground tanks and elevated tanks. 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 as 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, Majority of them were shaft staging while a few were on frame staging type. Elevated water tanks consist of huge water mass at the top of a slender staging which are most critical consideration for the failure of the tank during earthquakes. Elevated water tanks are critical and damage of these structures during earthquakes may endanger drinking water supply, cause to fail in preventing large fires and substantial economic loss. Since, the elevated tanks are frequently used in seismic active regions also hence, seismic behavior of them has to be investigated in detail .Due to the lack of knowledge of supporting system, some of the water tank were collapsed or heavily damaged. So, there is need to focus on seismic safety of lifeline structure with respect to alternate supporting system which are safe during earthquake and also take more design forces.

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. 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.

B. Description of Model

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. Structural mass *ms*, 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.

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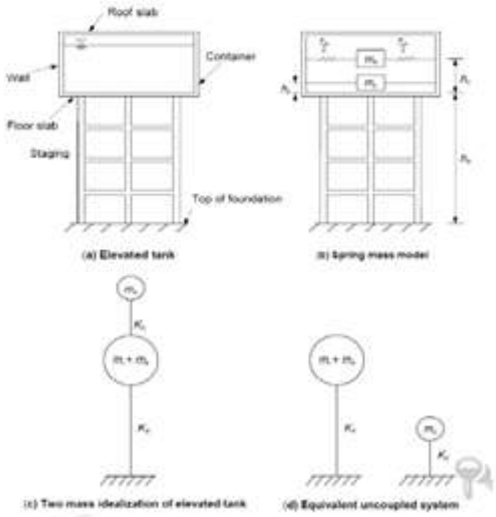

3. Design Horizontal Seismic Coefficient

a) 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 $T \geq 0.4$

For medium soil sites

Sa /g = 2.5 for $T < 0.55$

= 1.36/*T* for $T \geq 0.55$

For soft soil sites

Sa /g = 2.5 for $T < 0.67$

= 1.67/*T* for $T \geq 0.67$

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

b) 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.

c) Units

- Mass of container in kilo newton.
- Mass of staging in kilo newton.
- Hydrostatic pressure in kilo newton per square meter.
- Stiffness in newton per meter.

d) Equations

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

4. 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	16M,20M,24M			
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

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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. 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 3: 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

Table 4: 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

5. Analysis and Results

Table 5: Base shear

H/D	0.3	0.4	0.5	0.6
Staging height	KN	KN	KN	KN
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

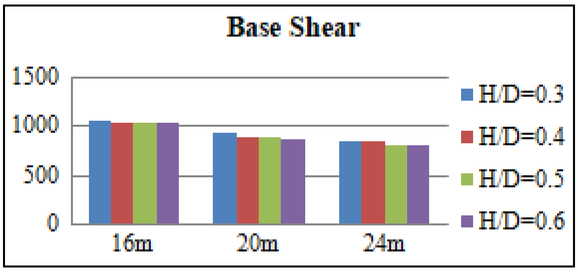

Figure 1: Base shear

Table 6: Base Reactions Tank Empty Condition

H/D	0.3	0.4	0.5	0.6
Staging height	KN	KN	KN	KN
16m	1038.84	1041.124	1041.21	1140.621
20m	886.317	915.388	919.131	935.389
24m	839.71	835.47	809.045	850.155

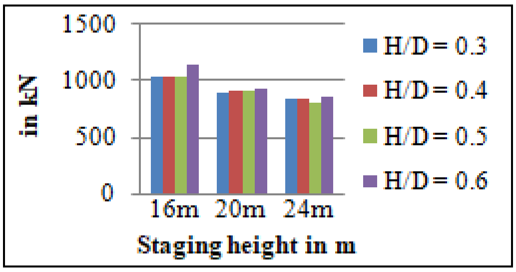

Figure 2: Base Reactions Tank Empty Condition in kN

Table 7: Base Reactions Tank Full Condition

H/D	0.3	0.4	0.5	0.6
Staging height	KN	KN	KN	KN
16m	1087.94	1106.56	1118.55	1253.721
20m	962.631	965.368	955.197	1023.369
24m	879.43	888.39	892.125	932.815

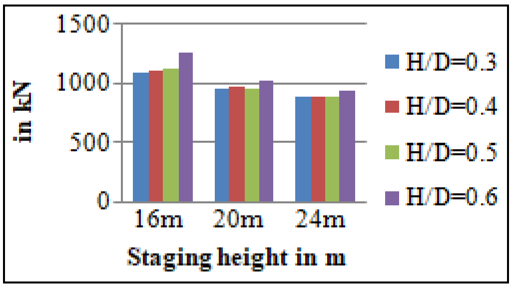

Figure 3 : Base ReactionsTank Full Condition in kN

Table 8: Joint Displacement Tank Empty Condition

H/D	0.3	0.4	0.5	0.6
Staging height	m	m	m	M
16m	0.000039	0.00071	0.00131	0.00213
20m	0.000035	0.00145	0.00161	0.0024
24m	0.000032	0.00163	0.00181	0.00277

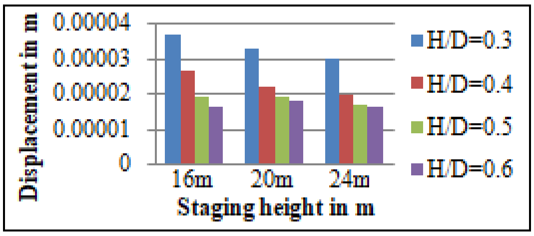

Figure 4: Joint Displacement Tank Empty Condition in m

Table 9: Joint Displacement Tank Full Condition

H/D	0.3	0.4	0.5	0.6
Staging height	m	m	m	M
16m	0.000039	0.00071	0.00131	0.00213
20m	0.000035	0.00145	0.00161	0.0024
24m	0.000032	0.00163	0.00181	0.00277

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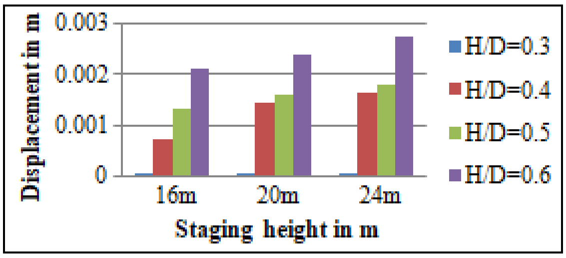

Figure 5: Joint Displacement Tank Full Condition in

Table 10 : Shear Force in Tank Empty Condition

H/D	0.3	0.4	0.5	0.6
Staging height	kN	kN	kN	kN
16m	173.18	178.785	179.512	189.626
20m	155.592	154.689	159.358	167.904
24m	137.421	142.38	143.467	145.892

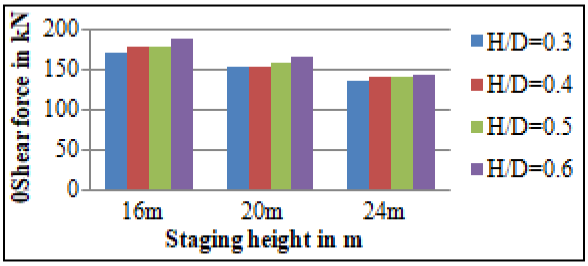

Figure 6: Shear Force in Columns Tank Empty Condition in kN

Table 11: Shear Force in Columns Tank Full Condition

H/D	**0.3**	**0.4**	**0.5**	**0.6**
Staging height	kN	kN	kN	kN
16m	181.388	192.346	195.422	216.888
20m	163.017	165.436	168.326	179.267
24m	150.294	152.203	154.882	164.733

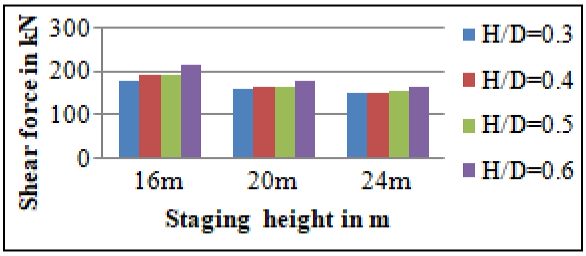

Figure 7: Shear Force in Columns Tank Full Condition in kN

Table 12: Moment in bracings Tank Empty Condition

H/D	0.3	0.4	0.5	0.6
Staging height	kN-m	kN-m	kN-m	kN-m
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

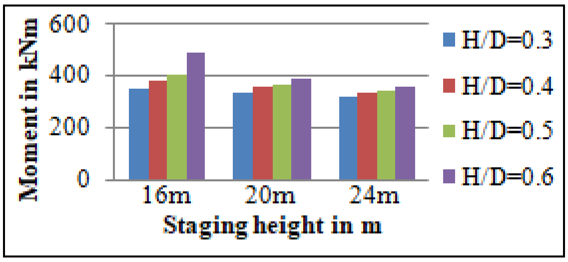

Figure 8: Moment in bracings Tank Empty Condition in kNm

Table 13: Moment in bracings TANK FULL CONDITION

H/D	0.3	0.4	0.5	0.6
Staging height	kN-m	kN-m	kN-m	kN-m
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

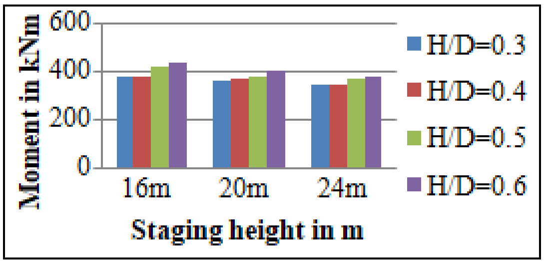

Figure 9: Moment in bracings Tank Full Condition in kNm

Table 14: Torsion in bracings Tank Empty Condition

H/D	0.3	0.4	0.5	0.6
Staging height	kN-m	kN-m	kN-m	kN-m
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

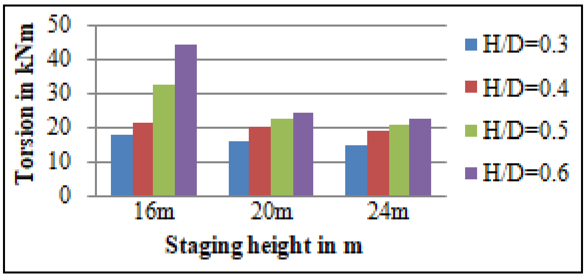

Figure 10: Torsion in bracings Tank Empty Condition in kNm

Table15: Torsion in bracings TANK FULL CONDITION

H/D	0.3	0.4	0.5	0.6
Staging height	kN-m	kN-m	kN-m	kN-m
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

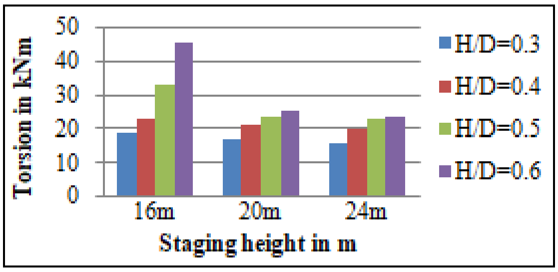

Figure 11: Torsion in bracings Tank Full Conditionin kNm

Table 16: Total Concrete quantity m³

H/D	Total Concrete quantity m³			
Staging height	0.3	0.4	0.5	0.6
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

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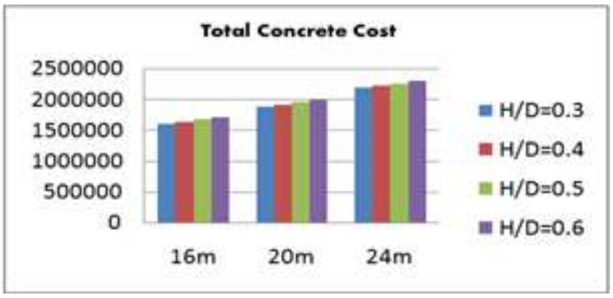

Figure 12: Total Concrete Cost in Rs

Table 17: Total Steel quantity tones

H/D	Total Steel quantity tones			
Staging height	0.3	0.4	0.5	0.6
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

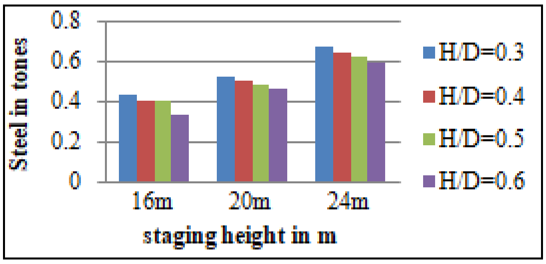

Figure 13: Total steel Cost in Rs

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

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