Seismic Performance of Elevated Water Tank with Different Bracing Pattern Considering Fluid Structure Interaction

[1] Meraj Ahamad, [2] V.K. Singh

[1] PG Student (M.Tech Structural Engineering), [2] Associate Professor

[1][2] Civil Engineering Department, Institute of Engineering and Technology, Lucknow- 226022 (India)

[1] merajcivil16@gmail.com, [2]vedant.vinay@gmail.com

Abstract: ***This paper presents the performance of elevated water tank (Intze tank) with variable of bracings system under seismic and gravity loads. The main aim of this study is to understand the behavior of different arrangement of bracings system to gives optimum performance under given loads and conditions. In the present study, three types of bracings system horizontal, radial, and X bracing has been analyzed for an elevated water tank having 800 m^3 capacity situated in Zone III using multiple software like SAP and ETABS. In this analysis response spectrum method has been used for software analysis and equivalent static method used for manual calculation as per IS:1893-2014(II) and compare the seismic parameters for staging portion as per IS:1893-2016(I), Eurocode-8, ASCE-7 by Etabs software. It is found that the maximum time period of model 3 (X bracing) is 69.89% and model 2 (Radial bracing) is 8% less than model 1 (Horizontal bracing), base shear of model 3 is 196.40% and model 2 is 11.57% more than model 1, overturning moment of model 3 is 193.73% and model 2 is 11.25% and storey displacement of model 3 is 74.94% and model 2 is 10.40% less than model 1.***

Keywords: Intze Tank, SAP (V20.2), ETABS(V17.0.1),Response Spectrum Method, IITK-GSDMA Guideline.

1. INTRODUCTION

Water tank are very important for public utility and industries. An elevated water tank is large water storage container constructed for the purpose of holding water supply at certain height through pressurization the water distribution system. There are some different way for storage of water such as underground, on ground and elevated water tank. An elevated water tank is supported by frame or shaft type staging system. The frame type staging performs better as compared to shaft type staging under seismic loading. Bracings are used in frame type staging system and these are classified as per IS:11682-1985 i.e horizontal, radial, cross bracing .

2. OBJECTIVES OF WORK

The main objective of this work is to understand the behavior of different arrangement of bracings system to gives optimum performance under given loads and conditions and compare the seismic parameters for staging portion as per IS:1893-2016(I), Eurocode-8, ASCE-7.

3. DESCRIPTION OF WATER TANK

Elevated water tank having 800 m^3 capacity situated in Zone (III) supported on R.C. frame staging of 16 m height from the ground level with three types of bracing systems horizontal, radial and X bracing . Geometrical and seismic properties of water tank shown in **table 3.1-3.2.**

Table 3.1 Geometrical Properties

S.N	Parameters	Value
1	Capacity	800 m^3
2	Thickness of top dome	100 mm

	Rise of top dome (h_1)	1.85 m
	Radius of dome (R_1)	9.1 m
3	Size of top ring beam	(260x260)mm
4	Dia. of cylindrical wall (D)	11 m
	Height of wall with free board	8.1 m
	Thickness of wall	300 mm
5	Size of bottom ring beam	(1000x500)mm
6	Thickness of conical dome	400 mm
	Length and height of dome	2.9 m & 2.1m
	Angle of inclination	45^0
7	Thickness of bottom dome	250 mm
	Rise of bottom dome (h_2)	1.85m
	Radius of dome (R_2)	4.14 m
	Diameter (D_o)	6.9 m
8	Size of circular girder	(550x950)mm
9	Dia. & number of column	600mm & 8
10	Size of bracing	(300x600)mm
	Spacing along the height	4m
11	Height of staging	16m

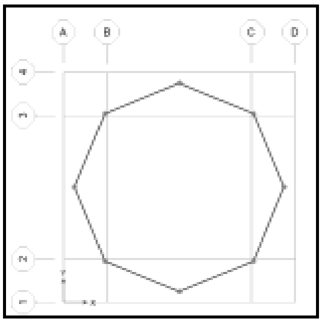
Table 3.2 Material and Seismic data

1	**Concrete grade (Beam, Column, Slab)**	**M-30**
2	Steel grade	Fe-500
3	Zone factor (Z)	0.16 (III)
4	Importance factor (I)	1.5
5	Response reduction factor (R)	4 (SMRF)
6	Type of soil	II (Medium)

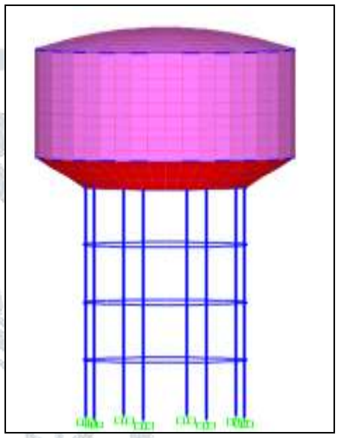
4. PROBLEM DESCRIPTION

- Model1-Elevated water tank with horizontal bracing.
- Model 2- Elevated water tank with radial bracing.
- Model 3- Elevated water tank with X bracing.

4.1 Plan and 3-D view for different models - Plan and 3-D view for model 1-3 are shown in **fig. 4.1-4.3**

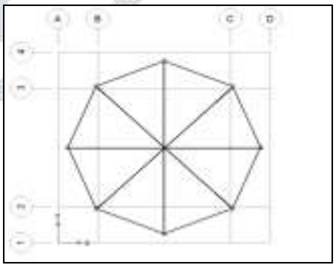


(a)



(b)

Fig.4.1 (a) Plan and (b) 3-D view for model 1 (Horizontal bracing)



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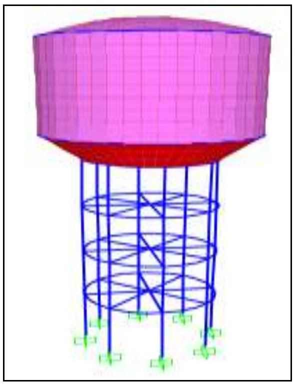

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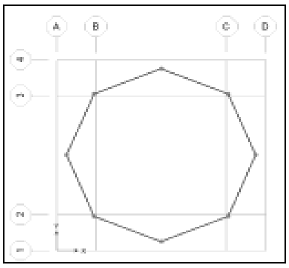
Fig.4.2 (a) Plan and (b) 3-D view for model 2 (Radial bracing)



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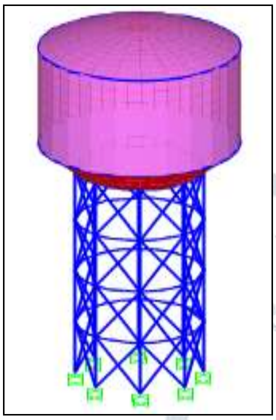

(b)Fig.4.3 (a) Plan and (b) 3-D view for model 3 (X bracing)

5. ANALYSIS AND RESULTS

5.1 Procedure for seismic calculation as per IS-1893:2014 (II)[14]-

Step1-Approximate dimensions for each component of water tank is fixed according to its capacity.

Step 2- Evaluate the seismic weight of the water tank with staging and calculate the C.G of empty container from top of footing **(Ref. IITK GSDMA)[11].**

Step 3- Find the parameters of spring mass model based on h/D ratio of water tank i.e (m_i, m_c h_i, h_i^*, h_c, h_c^*) as per IS-1893:2014(II) **(clause 4.2.2)** and calculate staging stiffness by software or manual **(Ref.Sameer)[1]** . **Step4-** Calculate the time period (T) for impulsive &convective mode **(clause4.3.1.3)**

$T_i = 2\pi\sqrt{(m_i+m_s)/K_s}$...........(Impulsive mode)

$T_c = C_c \sqrt{(D/g)}$ …………(Convective mode)

Step5-Compute design horizontal seismic coefficient for impulsive & convective. **(clause 4.5)** $(A_h) = \frac{Z}{2} \times \frac{I}{R} \times \frac{Sa}{g}$

$(A_h)_i = 1\times (A_h)$................(Impulsive mode)

$(A_h)_c = 1.75x(A_h)$.............(Convective mode)

Step 6- calculated the base shear at bottom of staging**. (clause 4.6.2)**

$V_i = (A_h)_i\,(m_i+m_s)\,g$ ….(Impulsive mode)

$V_c = (A_h)_c\, m_c g$………(Convective mode)

Total base shear,

$$V = \sqrt{V_i^2 + V_c^2}$$

Step7- Calculate the base moment at bottom of staging. **(clause 4.7.2)**

$M_i^* = (A_h)_i\,[\,m_i\,(h_i^*+h_s) + m_s h_{cg}\,]\,g$ ..(Impulsive)

$M_{c*} = (A_h)_c m_c\,(h_c^*+h_s)\,g$……….(Convective)

Total moment,

$$M^* = \sqrt{(M_i^{*2} + M_c^{*2})}$$

Step 8- Find hydrodynamic pressure on wall and base of slab in impulsive & convective mode**. (clause 4.9)**

Pressure on wall,

$P_{iw} = Q_{iw}(y)(A_h)_i\rho\, g\, h\, \cos\varphi$…(Impulsive mode)

$P_{cw} = Q_{cw}(y)(A_h)_c\, \rho g D(1-\cos^2\varphi/3)\cos\varphi$ (Convective)

Pressure on slab,

$P_{ib} = 0.866\,(A_h)_i\,\rho\, g\, h\ \sin h\,(1.732\, x/h)\,/\cos h\,(0.866\, l'/h)$.....(Impulsive mode)

$P_{cb} = Q_{cb}\,(x)\,(A_h)_c\,\rho g D$…(Convective mode)

Pressure on wall due to its inertia,

$P_{ww} = (A_h)_i\, t\, \rho_m\, g$

Pressure due to vertical excitation, **(clause 4.10)**

$P_v = (A_v)\,\rho\, g\, h\,(1-y/h)$

Maximum hydrodynamic pressure at base of wall,

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

Step 9- Finally calculate sloshing wave height,

$d_{max} = (A_h)_c x\, RxD/2$ **(clause 4.11)**

5.2 Weight Calculation of Tank- Weight of various components of tank shown in **table 5.1. (Ref. IITK GSDMA)[11]**

Table 5.1 Weight of tank

Component	Weight (kN)
Top Dome	271.59
Top Ring Beam	59.78
Cylindrical Wall	2156.62
Bottom Ring Beam	471.23
Conical Dome	815.4
Bottom Dome	321.09
Circular Girder	283.15
Columns	904.77
Bracings	292.68

Total weight of container = 4378.86 kN

Weight of staging = 1197.45 kN

m_s = 4378.86 +1197.45/3 = 4778.01 kN

C.G of empty container = 4.75 m

C.G from the top of footing (h_{cg}) =21.22m

Stiffness of staging (Ref. Sameer) [1]

=29850.78 kN/m

Weight of water = V x ρ x g =7995.15 kN

Volume of water = W/g= 815m^3> 800m^3

Mass of water (m)= 815000 kg,

let h be height of equivalent circular cylinder,

$\pi (D/2)^2 \times h = 815$

For h /D = 8.57/ 11 = 0.78 **(IS-1893 : 2014 II clause4.2.2)**

m_i / m = 0.73, m_i = 594950 kg

m_c / m =0.29, m_c= 236350kg

h_i / h = 0.37, h_i = 3.17 m,

h_i^* / h = 0.58, h_i^* = 4.97 m

h_c/h = 0.68, h_c = 5.82m,

h_c^*/ h = 0.72, h_c^*= 6.17m,

C_c= 3.3, I= 1.5, R=4, Z=0.16 (III),

$(A_h)_i$=0.034, $(A_h)_c$= 0.019....(Tank full)

$(A_h)_i$ =0.051……………..(Tank empty)

5.3 Seismic analysis of water tank for model 1 by equivalent method as per IS:1893-2014 (II)-

5.3.1 Time Period- It is found that the time period of tank full condition is 50.63% more than tank empty condition for impulsive mode. It means the time period increase with increase level of water in the tank. The calculated time period is given in **table 5.2.**

Table 5.2 Time Period

Tank condition	Time Period (sec)	
	Impulsive (T_i)	Convective(T_c)
Tank full	1.19	3.49
Tank Empty	0.79	—

5.3.2 Base Shear- It is observed that the base shear for tank full condition is 50.81% more than tank empty condition. It represents the increase in base shear with increase level of water in the tank. The calculated base shear is shown in **table 5.3**

Table 5.3 Base shear

Tank condition	Base Shear (kN)		
	Impulsive (V_i)	Convective (V_c)	Total (V_T)
Tank Full	357.80	44.05	360.50
Tank Empty	239.04	—	239.04

5.3.3 Base Moment (Overturning Moment)- It is observed that base moment of tank full condition is 49.82% more than tank empty condition. It represents the increase in base moment with increase level of water in the tank. The calculated base moment is given in **table 5.4**.

Table 5.4 Base Moment

Tank condition	Base Moment (kN-m)		
	Impulsive (M_i^*)	Convective (M_c^*)	Total (M^*)

Full	7547.84	976.66	7610.76
Empty	5079.78	__	5079.78

5.3.4 Hydrodynamic Pressure-The maximum hydrodynamic pressure is about 6.29 % of hydrostatic pressure at base of wall in container of tank (ρgh=74.55kN/m^2).The calculated hydrodynamic pressure is shown in **table 5.5.**

Table 5.5 Hydrodynamic Pressure

Hydrodynamic Pressure	kN/m^2
Impulsive pressure on wall (P_{iw})	1.99
Convective pressure on wall (P_{cw})	0.08
Pressure due to wall inertia (P_{ww})	0.10
Pressure due to vertical acc^n (P_v)	4.20
Maximum pressure at base of wall	4.69
Impulsive pressure on slab (P_{ib})	1.95
Convective pressure on slab (P_{cb})	0.40

5.3.5 Sloshing wave height-

d_{max} = $(A_h)_c$xRxD/2 =0.019x4x11/2 = 0.42 < 0.5 m provided free board . (Safe)

6. Seismic analysis of staging portion by Etabs software (Tank full) - For staging analysis, it is necessary to apply container weight on circular girder in UDL form.

6.1 Time Period- Time Period 'T' of a Structure is the time taken by it to undergo one complete cycle of oscillation.

$$T=2\pi\sqrt{\frac{m}{k}}$$

From the result, maximum time period of model 3 is 69.89% and model 2 is 8 % less than model 1. It is shows that model 3 is more stiffer as compare to model 1 and 2. The time period for all model is shown in **table 6.1** and time period variation with different modes shown in **fig. 6.1.Table 6.1 Time Period**

Mode No	Time- Period (Sec)		
	Model 1 (horizontal bracing)	Model 2 (Radial bracing)	Model 3 (X - bracing)
Mode 1	1.475	1.357	0.444
Mode2	1.475	1.357	0.444
Mode3	1.081	1.081	0.29
Mode4	0.312	0.277	0.29
Mode5	0.312	0.277	0.215
Mode6	0.124	0.135	0.121
Mode7	0.124	0.135	0.121
Mode8	0.122	0.122	0.09
Mode9	0.122	0.122	0.064
Mode10	0.100	0.117	0.064
Mode11	0.094	0.091	0.052
Mode12	0.094	0.065	0.052

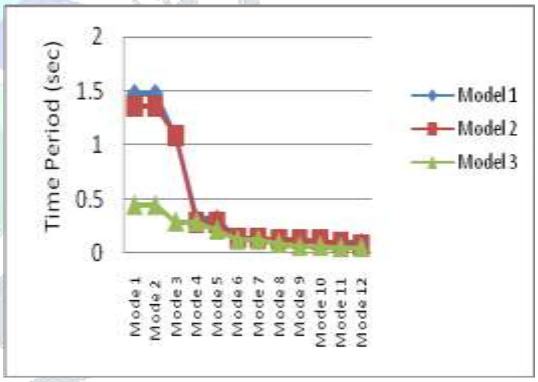

Fig 6.1 Variation of time period

6.2 Base shear- Base shear is an estimate of maximum expected lateral force on the base of the structure due to seismic activity. Base shear is directly proportional to weight of structure.

Base shear,

$$V_B = A_h W$$

From the result, maximum base shear of model 3 is 196.4% and model 2 is 11.57% more than model 1.The calculated value of base shear is shown in **table 6.2** and **fig. 6.2 .**

Table 6.2 Base Shear

Model	Base shear (kN)
Model 1 (Horizontal bracing)	359.68
Model 2 (Radial bracing)	401.30
Model 3(X-bracing)	1066.10

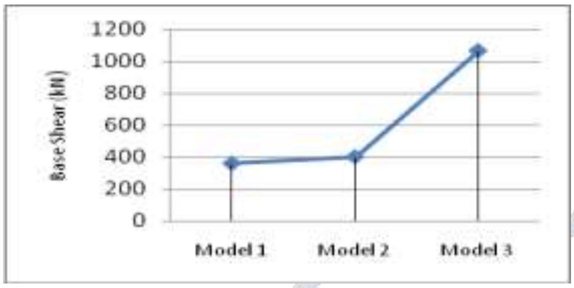

Fig 6.2 Base shear

6.3 Overturning Moment- From the result, maximum overturning moment at bottom of staging of model 3 is 193.97% and model 2 is 9.35% more than model 1. The calculated base moment shown in **table 6.3** and **fig. 6.3**.

Table 6.3 Overturning Moment-

Model	Overturning Moment (kN-m)
Model 1 (Horizontal)	8567.20
Model 2 (Radial bracing)	9531.59
Model 3(X-bracing)	25185.41

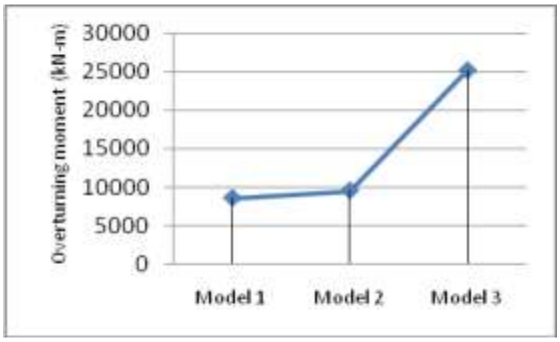

Fig 6.3 Overturning moment

6.4 Storey Displacement- Storey displacement may be defined as the lateral displacement of any particular storey from its mean position with respect to the base of the structure. . According to **Shudhir K. Jain**[3] allowable displacement is calculated as 'H/500', Where H is total height of Storey. From the result , it is found that the maximum storey displacement of model 3 is 74.93% and model 2 is 10.40 % less than model 1. The calculated Storey displacement given in **table 6.4.** and variation of storey displacement is shown in **fig. 6.4 .**

Table 6.4 Storey Displacement in X and Y direction-

Storey	Storey Displacement (mm)			P. Limit H/500 (mm)
	Model 1 (Horizontal)	Model 2 (Radial)	Model 3 (X)	
4	24.433	21.891	6.122	32
3	19.247	16.769	4.566	24
2	12.19	10.372	2.809	16
1	5.354	4.179	1.447	8

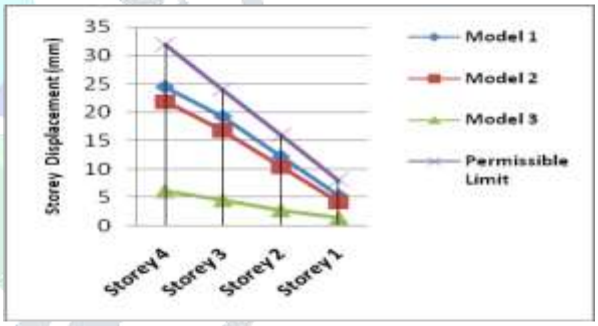

Fig. 6.4 Variation of storey displacement

6.5 Storey Drift- As per IS 1893:2016 (I) the storey drift in both X and Y direction not be more than 0.004h, where 'h' is the storey height. From the result , it is found that the maximum storey displacement of model 3 is 75.10% and model 2 is 9.35 % less than model 1 . The calculated storey drift is given in **table 6.5** and variation of storey drift shown in **fig. 6.5 .**

Table 6.5 Storey drift in X and Y direction

Storey	Storey Drift (mm)					
	Mode l 1	Mode l 2	Mode l 3	IS code 0.00	EN 8 cod	ASC E7 code

				4 h	e 0.0 1 h	0.015 h
4	5.186	5.122	1.556	16	40	60
3	7.057	6.397	1.757	16	40	60
2	6.836	6.199	1.362	16	40	60
1	5.354	4.179	1.447	16	60	60

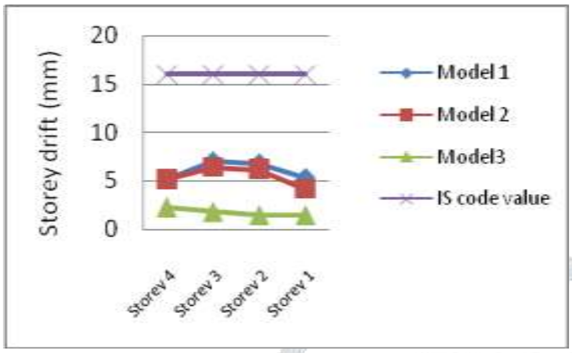

Fig. 6.5 Variation of storey drift

7. CONCLUSIONS

1) The maximum value of time period observed in model 1 and minimum in model 3. It means model 1 is more flexible and model 3 is more stiffer.

2) Base shear increase with the increase in mass and stiffness of structure. The maximum value of base shear observed in model 3 and minimum in model3. It means that the during earthquake model 3 is subjected to higher lateral forces at the top of staging as compare to model 1 and 2.

3) From the above results, maximum value of storey displacement of model 1 is not exceeds the maximum allowable value as per IS code so there are no chances of failure in staging of tank.

4) The maximum value of drift in model 1 and minimum value in model 3 which show that model 3 is more rigid as compared to model 1 and 2.

5) Free board to be provided in tank based on the maximum value of sloshing wave height. (d_{max}= 0.44 < 0.5 m free board provided) (safe).

From the above study, it can be concluded that X- bracing system is better arrangement for water tank under seismic forces and total base shear and base moment in tank full condition are more than that total base shear and base moment in tank empty condition, design will be governed by tank full condition.

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