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Seismic Demand Evaluation of Different Bracing Systems on Elevated Reinforced Concrete Water Tanks

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

***Abstract*—This paper deals the response of elevated water tank with different bracings system under seismic and gravity loads. In the present work, three types of bracings system horizontal, diagonal and inverted-V bracing with 800 m^3 capacity situated in Zone V (soft soil) using software like SAP (V20.2) and ETABS(V17.0.1) software done by response spectrum method and the compare the seismic parameters for staging of tank as per IS:1893-2016(I), Eurocode-8, and ASCE-7 by Etabs software. It is observed that the maximum time period of model 3 (Inverted-V bracing) is 63.18% and model 2 (Diagonal bracing) is 58.10% less than model 1 (Horizontal bracing) and base shear of model 3 is 138.89% and model 2 is 131.12% more than model 1 and storey displacement of model 3 is 68.67% and model 2 is 49.43% less than model 1 and maximum overturning moment of model 3 is 137.17% and model2 is 130.16% less than model 1 .**

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

1. INTRODUCTION

Generally large number of elevated tank is used in water storages facilities .These water tanks are play a very important role in municipal water supply such as drinking, cooking, washing and fire fighting systems etc. There are some different ways for storage of water such as underground, on ground and elevated water tank. Elevated water tanks are resting on a supporting staging to provide necessary pressure for the water distribution system obtained by gravity otherwise water distributed through pumping system. In case high rise building this technique (pumping system) is more reliable. The frame type staging is gives better performance as compare to shaft type staging during earthquake by Durgesh C. rai[2].

2. OBJECTIVES OF WORK

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

3. DESCRIPTION OF WATER TANK

Elevated water tank with 800 m3 capacity situated in Zone-V (Soft soil) supported on R.C. frame staging of 16 m height from the ground level with three bracing systems horizontal, diagonal and Inverted-V. Geometrical and material properties of water tank shown in table 3.1-3.2.

Table 3.1 Geometrical Properties of Tank

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	7.6+0.50=8.1m
	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

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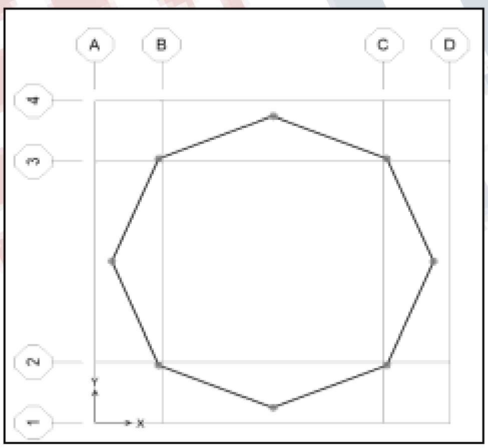
9	Dia. & number of column	600mm & 8
10	Size of bracing	(300x600)mm
	Spacing along the height	4m
11	Height of staging	16m

Table 3.2 Material and Seismic data-

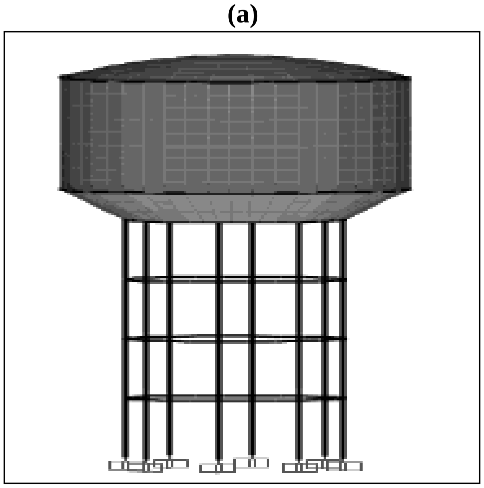
1	Concrete grade (Beam, Column, Slab)	M-30
2	Steel grade	Fe-500
3	Zone factor (Z)	0.36 (V)
4	Importance factor (I)	1.5
5	Response reduction factor (R)	4 (SMRF)
6	Type of soil	III(Soft Soil)

4. PROBLEM DESCRIPTION

- Model1-Elevated water tank with horizontal bracing
- Model2-Elevated water tank with diagonal bracing
- Model3-Elevated water tank with inverted V bracing

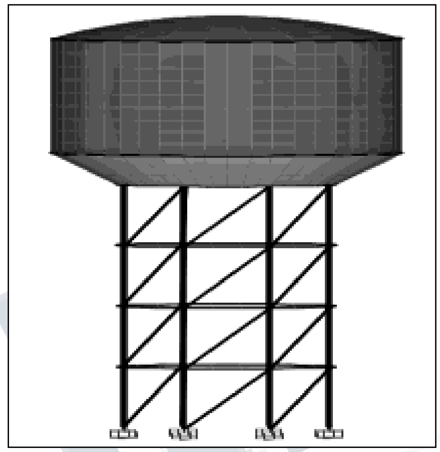


(a)



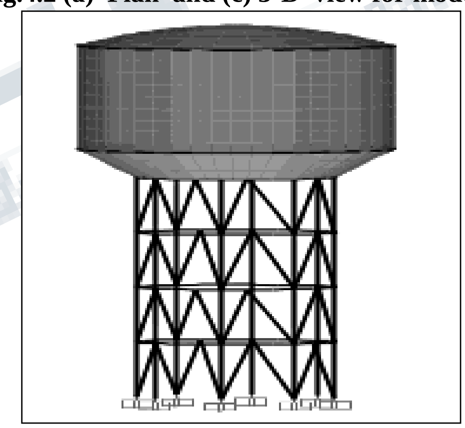
(b)

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



(c)

Fig.4.2 (a) Plan and (c) 3-D view for model 2



(d)

Fig. 4.3 (a) Plan and (d) 3-D view for model 3

5. ANALYSIS AND RESULTS

5.1 Steps for seismic calculation by equivalent static method (ESM) as per IS-1893:2014 (II)[14]

Step1-Approximate dimensions calculation for each component of water tank on basic of its capacity.

Step 2- Calculate the seismic weight of the water tank and evaluate the centre of gravity of empty container from top surface of footing (Ref. IITK GSDMA)[11].

Step 3- Find the parameters of spring mass system based on h/D ratio of elevated 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 manual or software (Ref. Sameer)[1] .

Step4-Calculate the time period (T) for impulsive and convective mode (clause4.3.1.3)

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$T_i = 2\pi\sqrt{(m_i+m_s)/K_s}$.....(For impulsive mode)
$T_c = C_c\sqrt{(D/g)}$ …(For 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 for impulsive and 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 is given in **table 5.1**. (Ref. IITK GSDMA)[11]

Table 5.1 Weight of components 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=0.36 (III),
$(A_h)_i$=0.09,
$(A_h)_c$= 0.06....(Tank full)
$(A_h)_i$ =0.14……………..(Tank empty)

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

5.3.1 Time Period- It is observed that the time period of tank full condition is 50.63% more than tank empty condition for impulsive mode. The calculated time period is shown in **table 5.2.**

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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 found that the base shear for tank full condition is 45.88% 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	974.13	139.11	957.29
Tank Empty	656.21	__	656.21

5.3.3 Base Moment (Overturning Moment)- It is found that base moment of tank full condition is 44.97% 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 shown in **table 5.4**.

Table 5.4 Base Moment

Tank condition	Base Moment (kN-m)		
	Impulsive (M_i^*)	Convective (M_c^*)	Total (M^*)
Full	19979.47	3084.19	20216.11
Empty	13944.50	__	13944.50

5.3.4 Hydrodynamic Pressure-. The maximum hydrodynamic pressure is about 16.86% of hydrostatic pressure at base of wall in container of tank (ρgh=1000x9.81x7.6=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})	5.26
Convective pressure on wall (P_{cw})	2.43
Pressure due to wall inertia (P_{ww})	2.65
Pressure due to vertical acc^n (P_v)	9.57
Maximum pressure at base of wall	12.57
Impulsive pressure on slab (P_{ib})	5.19
Convective pressure on slab (P_{cb})	0.27

5.3.5 Sloshing wave height- d_{max} = $(A_h)_c$xRxD/2 =0.019x4x11/2 =1.32 > 0.5 m provided free board . (Not Safe)

6. SEISMIC ANALYSIS OF STAGING PORTION BY ETABS SOFTWARE (Tank full)

For staging analysis, it is compulsory to apply container weight on circular girder in form of uniform distributed load.

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 analysis, the maximum time period of model 3 is 63.18% and model 2 is 58.10% less than model 1. It means 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 (Diagonal bracing)	Model 3 (Inverted-V bracing)
Mode 1	1.475	0.618	0.543
Mode2	1.475	0.618	0.543
Mode3	1.081	0.354	0.330
Mode4	0.312	0.300	0.305
Mode5	0.312	0.300	0.295
Mode6	0.124	0.123	0.125
Mode7	0.124	0.123	0.118
Mode8	0.122	0.091	0.087
Mode9	0.122	0.070	0.075
Mode10	0.100	0.056	0.063
Mode11	0.094	0.056	0.063
Mode12	0.094	0.055	0.057

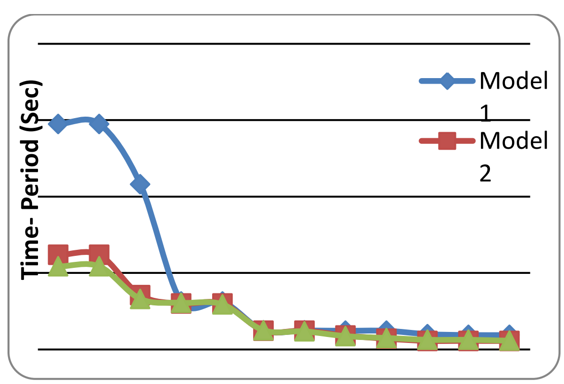

Fig 6.1 Variation of time period

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6.2 Base shear- Base shear is an estimated of maximum expected lateral forces on the base of the staging due to seismic condition. Base shear is directly proportional to weight of structure. Base shear,

$$V_B = A_h W$$

From the analysis, maximum base shear of model 3 is 138.89% and model 2 is 131.12% more than model 1.The calculated base shear is given in **table 6.2** and **fig. 6.2 .**

Table 6.2 Base Shear X and Y Direction

Model	Base shear (kN)
Model 1 (Horizontal bracing)	993.77
Model 2 (Diagonal bracing)	2296.86
Model 3(Inverted-V bracing)	2374.06

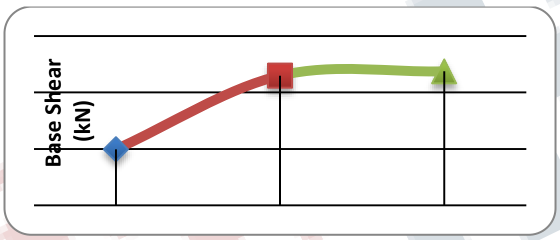

Fig 6.2 Base shear

6.3 Overturning Moment- From the analysis, maximum overturning moment at bottom of staging of model 3 is 137.17% and model 2 is 130.16% 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)	23670.05
Model 2 (Diagonal)	54479.82
Model 3(Inverted-V)	56138.17

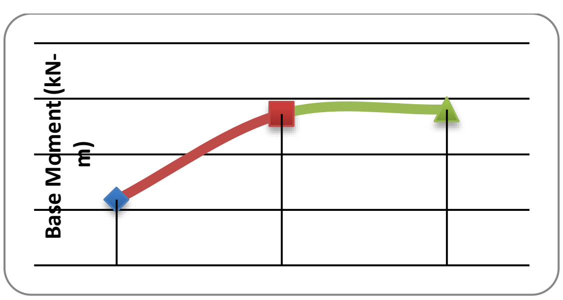

Fig 6.3 Overturning moment

6.4 Storey Displacement- Storey displacement defined as the lateral displacement of any storey from its mean position w.r.t 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 analysis , it is found that the maximum storey displacement of model 3 is 68.67% and model 2 is 49.43% less than model 1. The calculated Storey displacement is shown 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** (Diagonal)	**Model 3** (Inverted-V)	
4	**64.71**	**32.72**	20.27	32
3	**50.32**	**24.07**	14.36	24
2	**30.90**	14.98	8.38	16
1	**12.02**	6.52	3.13	8

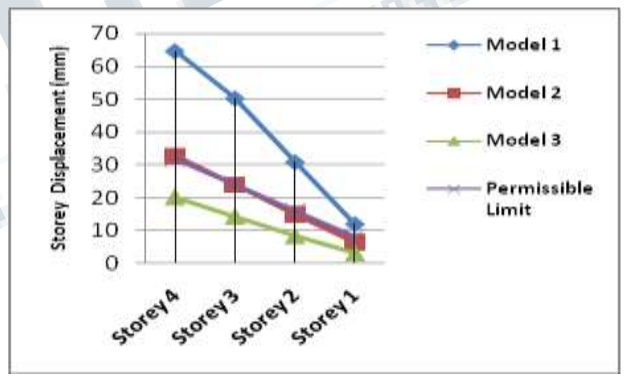

Fig. 6.4 Variation of storey displacement

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 analysis, From the analysis , it is found that the maximum storey displacement of model 3 is 68.17% and model 2 is 53.26 % less than model 1 . The calculated storey drift is shown 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 D rift (mm)					
	Model 1	**Model 2**	**Model 3**	IS code 0.004 h	EN 8 code 0.01 h	ASC E7 code 0.015 h
4	14.49	9.09	6.19	16	40	60
3	**19.45**	8.66	6.01	16	40	60
2	**18.93**	8.46	5.08	16	40	60
1	12.03	6.52	3.31	16	60	60

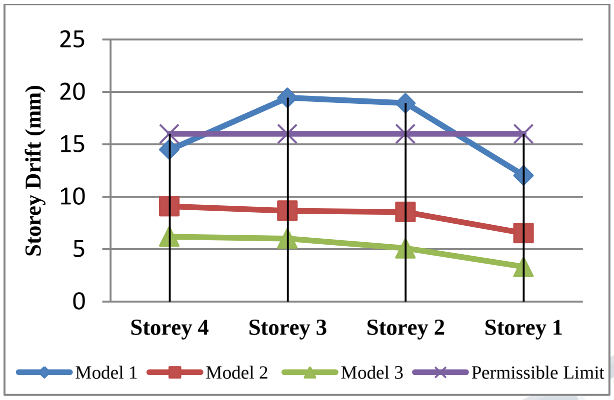

Fig. 6.5 Variation of storey drift

6.6 Storey Stiffness- As per IS:1893-2016(I) storey stiffness is lower storey is higher than its above storey . It is observed that model 1 is fail at storey 3 and 2. From the analysis the maximum value of storey stiffness in model 3 is 778.91% and model 2 is 558.19% is higher than model 1.

Storey	**Storey Stiffness (kN/m)**		
	Model 1 (Horizontal)	**Model 2** (Diagonal)	**Model 3** (Inverted-V)
4	100950	436318.6	564896.90
3	**76360.38**	454696.4	595993.70
2	**78889.69**	538457.10	703939.70
1	124414.50	818889.70	1093498

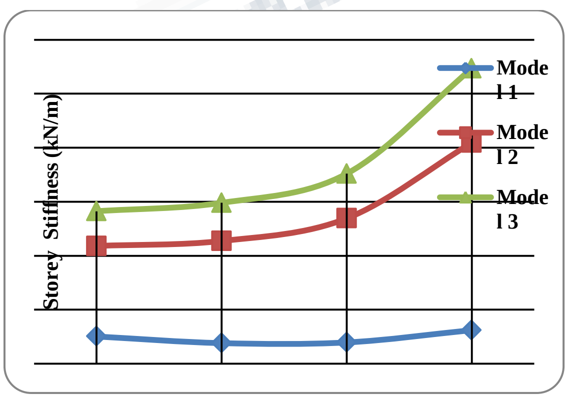

Fig. 6.6 Variation of Storey Stiffness

7. CONCLUSIONS

1) The natural time period is directly proportion to mass and inversely proportion to stiffness of structure. The maximum value of time period observed in model 1 and minimum in model 3. This is indicate that model 1 is more flexible as compare to model 2 and 3.

2) Base shear increase with the increase in mass and stiffness of structure. From the results, the maximum value of base shear observed in model 3 and minimum in model 1. 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 results, the maximum value of storey displacement of model 1 and 2 is exceeds the maximum permissible value so there are chances of failure in staging portion of tank in model 1 and 2. It is show that the tank becomes more stiffer when provided with non-modular bracing i.e diagonal and inverted-V.

4) The maximum storey stiffness found in model 3 and minimum in model 1 therefore tank provided with diagonal and inverted-V bracing is less chances to damages.

5) Free board to be provided in tank based on the maximum value of sloshing wave height. From the analysis, sloshing wave height is higher than provided free board (d_{max} 1.32>0.50 m) in this case increase the size of free board.

From the above study, it can be conclude that inverted-Vbracing system is better arrangement for water tank under seismic conditions.

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