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Seismic Analysis of Intze Water Tank with Different Bracing Configurations

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***Abstract*: Elevated water tanks are one of the most important public utility structures and considered as the main lifeline elements. Elevated water tanks should be capable of keeping the expected performance i.e. operation during and after earthquakes. The most of the failures are always reveals in the staging system of water tanks. In this paper, four different types of horizontal braces with Intze type water tank's staging are analyzed using STAAD.ProV8ifor dynamic response spectrum analysis. This paper is focused on studying the stability of elevated water tanks during seismic motion. The tank's response i.e. displacement, maximum bending moment, maximum shear force and base shear under these seismic zone II, III and IV have been calculated.**

***Keywords*: Intze tank, Earthquake response, Tank staging with braces, STADD.Pro.V8i.**

1. Introduction

Water is a necessary commodity for all living and non-living beings. Besides drinking and other day-to-day purposes, water is also required for firefighting; industrial and commercial use. Government of India is paying the maximal attention toward the water supply scheme in order to make the drinking water available for both rural and urban population. During the past earthquake, many water tanks were damage and misadventure was faced by the inhabitant. Water tanks are meant for storing and maintaining pressure in the water mains and any damage in water tanks shall lead to a lot of inconvenience to the public. Thus, water tanks needs to analysis as earthquake resistant structure.

Elevated water tanks create pressure of 1psi per 2.31 feet of elevation at the outlet. Thus a tank elevated to 70 feet creates about 30psi of discharge which is sufficient for the most domestic and industrial requirements. Beams and column type staging of water tanks gives the conception of a multi storage frame structure of a building but the mechanism of beams and column is very differed in water tank staging system due to the heavy load of the container. So, such a phenomenon is developing an active interest in studying the dynamic behavior of the staging system.

2. Layout of elevated water tanks

The economical shape and size of an elevated water tank are depended upon some functional as follows,

- Tank capacity.
- The maximum depth for water.
- Staging heights.
- Number of braces and their frame type.
- Allowable bearing capacity of foundation.
- Seismic zone and Site conditions.

3. Dynamic response spectrum analysis

The method involves a calculation of maximum response from given set of ground motion and estimated for given damping of level with a smooth design spectrum during several earthquakes. Response spectrum is the curve plotted between the maximum response of single-degree-of-freedom (SDOF) system subjected to earthquake and its frequency. Response spectrum illustrates the locus of maximum response of an SDOF system for given damping ratio. Thus it helps to get peak responses under liner range of a structure. To analyze identified frequencies in SDOF system, mass and stiffness give an equation where the lateral stiffness of water is a fixed quantity and mass is varies in change with the water level. The frequency equation for an idealized SDOF system is,

$$\omega = \sqrt{k/m}$$

Where,

ω = natural frequency (rad/sec)
k = effective lateral stiffness (lbf/in)
m = total mass of the system (lbf-sec^2/in)

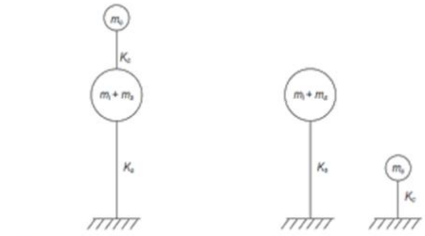

Fig. 1. Mass idealization for elevated tank

4. Computation of dynamic quantities

The code IS: 1893 (Part 2)-2002 provide equalization for dynamic analysis for the elevated water tanks.

A. Horizontal Seismic Coefficient

The seismic coefficient A_h will be calculated by using formula

$$A_h = \frac{Z}{2} x \frac{S_a}{g} x \frac{I}{R}$$

Where,
Z = Zone factor as per Table 2 of IS 1893 (Part 1)-2002,
I = Importance factor as per Table 1 of IS 1893 (Part 2)-2002,
R = Response reduction factor as per Table 2 of IS 1893 (Part 2)-2002,
Sa/g = Average response acceleration coefficient as given by Fig. 2 and table 3 of IS: 1893 (Part 1)-2002 and subjected to clause 4.5.1 to 4.5.4 of standard.

B. Base Shear

The base shear for elevated tank on impulsive mode, just about the base of staging is given by,

$$V_i = (A_h)_i(m_i + m_s)\ g$$

In which $(A_h)_i$ is horizontal seismic coefficient for impulsive mode, m_i is impulsive mass of liquid on container, m_s is mass of container one–third mass of staging, g is acceleration due to gravity.
And in convective mode the base shear is given by

$$V_c = (A_h)_c\ m_c\ g$$

In which $(A_h)_c$is horizontal seismic coefficient for convective mode, m_c is convective mass of liquid on container.
So the base shear will be obtained by combining the impulsive and convective mode

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

In which Vis total base shear by elevated tank, V_i is base shear in impulsive mode, V_c is base shear in convective mode.

C. Hydrodynamic Pressure

The pressure exerted by the liquid in the tank is

$$P = Q_w\ (A_h)_i\ \rho\ g\ h \cos\phi$$

And $$Q_w = 0.866\ [\ 1 – (y/h)2\ ]\ \tanh\ [0.866\ (D / h_l)]$$

In which P is hydrodynamic pressure on tank wall, Q_w is coefficient of pressure on tank wall, ρ is mass density of liquid, ϕ is circumferential angle, h_l is maximum depth of liquid, y is vertical distance of a point on tank wall from bottom of tank wall.

D. Pressure due to Wall Inertia

Pressure on the tank wall due to its inertia is given by

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

In which ρ_d = mass density of tank wall, t = thickness of wall.

5. Process of analysis on STAAD.ProV8i

In this software, response spectrum analysis evince is fitted for defined spectrum and as well as a number of international code specified spectra. For analyzing and study of reinforce cement concrete tanks on different height with different staging pattern in seismic zone II, III and IV following procedure is adopted given step by step as follow.

Step 1: Structure fabrication
- Beginning of New project in space with a file locator, available on the drive.
- Give the file name and its location.
- The units for length and force are in meter and kilo newton respectively.
- Click next and finish.

Step 2: Geometrical Modeling
- In snap node edit, we have to change the grid plane and construction line as per geometry on X and Y space.
- Creation of nodal points in space X and Y as per design specification.
- Connect all node and create a circular repeat.
- Clicks apply and the three-dimensional model is in space X, Y and Z.
- Coordinate 0, 0, and 0 in X, Y and Z direction is serialized.

Step 3: Properties Installation
- In general segment of modeling, section property will define.
- In define tap, all properties of column, beam and thickness will be defined as per design.
- Properties of the beam, column, wall etc. is selected one by one and then assigned on the model.
- Don't forget to select the material during defining of properties.

Step 4: Supports Conditions
- In the modeling section select the support option.
- The support tap creates all type of supports i.e. fixed, pinned, roller etc.
- Click on create option and create support as per design.
- Select all support nodes of the model and assign the support properties.

Step 5: loads and Load Combination
- In modeling segment load and definition is selected.
- On the definition tap, we have all condition like wind, seismic, snow, reference load definition etc.
- Choice the definition and select the add option then as per Indian stander code section generated the loads for different seismic zones as per design.
- Assign the properties of definition tap.
- Click on load case detail and define all loads, dead load, live load, wind load, seismic load, floor load etc. as per design properties.
- Assign the given load on three-dimensional structure and add on load case detail. Generate the load combinations.
- Load combinations applied on model and click on each generate load.

Step 6: Model Analysis

- Click on analysis/Print section and command print option for all and select add.
- Click in perform analysis print all command and Click analysis in task bar then our model is ready for results.

Step 7: Results Exploration

- The run analysis, process the whole structure and show all the error, warning and note if it can be detected in the structure.
- Click on view output file and click on done and all results explore on output views.
- Then go to the post processing section and select generated load cases and click ok. It will show the value of deflection, bending, shear, torsion and axial force in any model. Select the parameters of model and note done the results.

6. Detail of frame data

The Table.1 shows all the variables which are describing different seismic zones, bracing, conditions of tank and all the parameters which is going to be used in analyzing of Intze tank for the present study.

Table 1
Intze tank model detail

S. No.	Name of parameter	Value of parameter
1.	Seismic zones	II, III, IV
2.	Seismic zone factor	II = 0.10, III = 0.16 IV = 0.24
3.	Types of bracing pattern	Simple bracing. Cross bracing. Radial bracing. Rectangular bracing.
4.	Condition	Tank Full Tank Empty
5.	Height of staging	20 m
6.	Number of column	8
7.	Soil type	Medium soil
8.	Types of support	Fixed support
9.	Response reduction factor	2.5
10.	Importance factor (I)	1.5
11.	Damping ratio	5 %
12.	Capacity of container (V) in KL	1000
13.	Diameter of cylindrical wall	15.57 m
14.	Rise of top dome	3.081 m
15.	Thickness of top dome	0.08 m
16.	Top ring beam	0.2 x 0.2 m^2
17.	Thickness of cylindrical wall	0.17 m
18.	Height of cylindrical wall	4.622 m
19.	Middle ring beam length	1 m
20.	Middle ring beam height	0.25 m
21.	Height of conical wall	2.309 m
22.	Thickness of conical wall	0.38 m
23.	Diameter of bottom dome	11.40 m
24.	Rise of bottom dome	2.156
25.	Thickness of bottom dome	0.38 m
26.	Bottom ring beam	1.25 x 0.62 m^2
27.	Brace size	0.6 x 0.4 m^2
28.	Number of braces on tank	4
29.	Number of column on tank	8

7. Bracing patterns on Intze Tank Staging

Water tower without brace, would have inherent stability against force applied in every direction (all three axis; left-right, up-down, forward and backward) but there is nothing about this arrangement that would effectively prevent bent, rotation, or twisting about the structure's vertical axis. So the structure needs braces for supporting them in all condition. According to IS: 11682 – 1985 If the height of staging is greater than 6m above foundation, the column shall need of horizontal bracing.

Fig. 2. Staging with simple brace

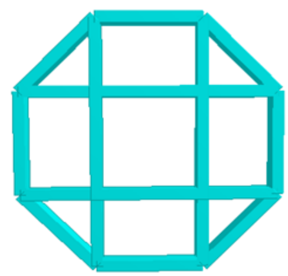

Fig. 3. Staging with cross brace

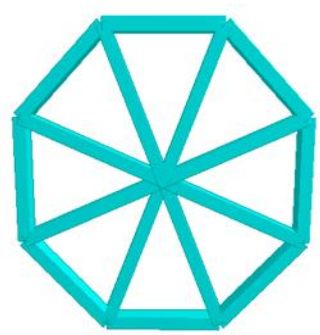

Fig. 4. Staging with radial brace

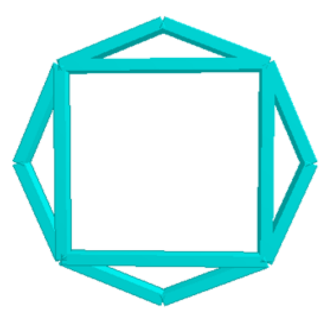

Fig. 5. Staging with rectangular brace

8. Intze tank with horizontal brace staging

In this paper four types of brace used and creates four staging pattern for supporting the container and transfer the load easily to the foundation without any failure. In this study, we analyzed24 models for checking their best performance and handling during seismic waves. For an example a three dimensional FE model of cross type brace staging is shown as follows.

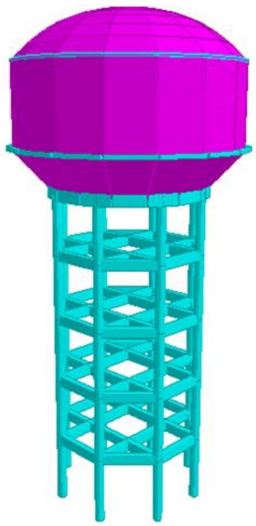

Fig. 6. Finite element model in Stadd.ProV8i

9. Explication on Intze Tank Staging

A. Displacement on Structure

Displacement or deflection is the backdown form initial position to final moving position of a structural element. It just because of enforces on structure by earthquake/seismic reaction. Fig 4.8 shows the displacement of structure during earthquake. The maximum displacement is possible in element i.e. beam, column, joints, brace and toe of elevated water tank.

B. Base shear on structure

During seismic activity, seismic wave forms forces on the base of any structures that maximum expected lateral forces estimated as base shear. The structure always fixed at the base foundation level. During seismic forces, foundation cannot hold the structure strongly so structure deflects, and base shear is diffused all along with the height of the structure. Base shear also depend upon the soil condition of the site.

C. Maximum shear force on structure

A shear forces is a forces that acts on a plane passing through the body. It can separates structure in two different parts in inverse directions. It always acts on the large part of structure and fails the design. For detecting the cause of failure we need to analysis of maximum share force for safe design.

D. Maximum bending moment on structure

Bending moment is the bend of structure element form its axis when external force or moment is applied on structure. Tensile stress and compressive stress are proportionally increased with bending moment. It gives ideas dealing with forces on structure same in real situation. It shows where and how the moment will act on the structure i.e. how a structure will rove during application of a load.

10. Results

Result of all braces with their properties in study are shown in table form and their graphs also have been includes as follows.

Table 2
Displacement value of tank at the empty and filled condition for seismic zones

Braces on staging	Empty condition			Filled condition		
	zone II	Zone III	Zone IV	Zone II	Zone III	Zone IV
Simple	26.287	41.787	62.53	33.404	50.726	74.674
Rectangular	24.744	39.75	58.55	31.237	47.002	68.919
Cross	24.595	39.022	58.354	31.219	46.947	68.821
Radial	24.592	39.015	58.341	31.192	46.893	68.733

Table 2 shows the value of displacement due to staging for different braces with tank filled and empty condition in seismic zones II, III and IV.

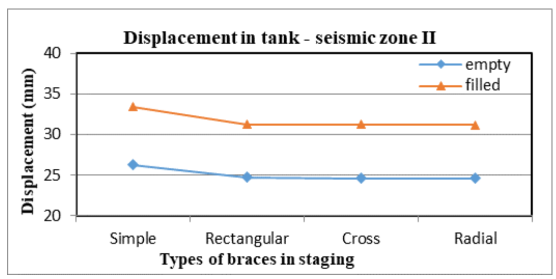

Fig. 7. Displacement values of tank with different staging in seismic zone II for empty and filled condition

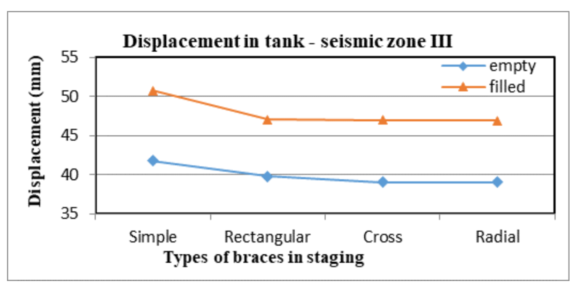

Fig. 8. Displacement values of tank with different staging in seismic zone III for empty and filled condition

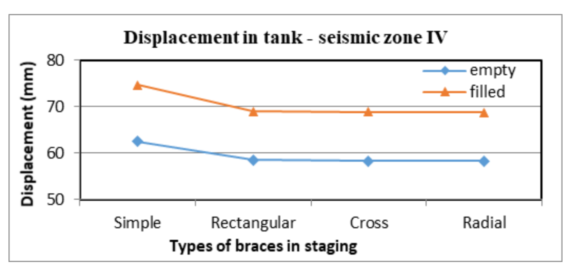

Fig. 9. Displacement values of tank with different staging in seismic zone III for empty and filled condition

Table 3
Bending moment value of tank at the filled and empty condition for seismic zones

Braces on staging	Empty condition			Filled condition		
	Zone II	Zone III	Zone IV	Zone II	Zone III	Zone IV
Simple	374.682	423.438	489.779	1190.6	1246.4	1324.7
Rectangular	385.549	436.582	504.627	1202.8	1262.4	1341.8
Cross	372.085	421.413	487.184	1188.3	1245.6	1322.1
Radial	369.943	418.318	482.818	1185.8	1242.0	1316.9

Table 4
Shear force value of tank at the empty and filled condition for seismic zones.

Braces on staging	Empty condition			Filled condition		
	Zone II	Zone III	Zone IV	Zone II	Zone III	Zone IV
Simple	456.97	496.85	550.077	1614.9	1662.3	1725.5
Rectangular	477.43	520.38	577.622	1635.3	1685.5	1752.3
Cross	456.52	496.61	550.065	1614.1	1660.5	1722.4
Radial	454.86	493.96	546.093	1611.7	1657.2	1717.7

Fig. 7, 8 and 9 are shown the graph of displacement values in seismic zone II, III and IV respectively, and the graphs are plotted between displacement (mm) and types of braces in staging for empty and filled condition of tank. The displacement value is increasing as the increase in seismic zone intensity. The displacement value is lower for the empty condition and shows higher values for filled condition. The maximum value of displacement is shown by simple type brace staging and goes on decrease for rectangular, cross and minimum is shown by radial type brace staging in tank.

The variation of bending moment for different staging with braces is shown in Table 3 for empty condition and filled condition of container in seismic zone II, III and IV.

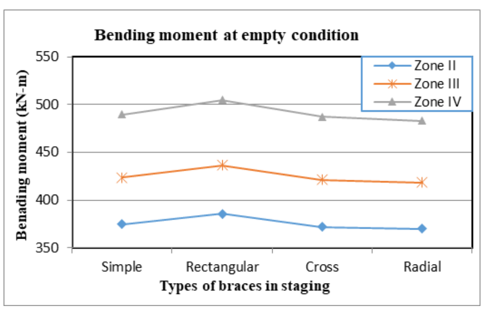

Fig. 10. Bending moment at the empty condition of tank

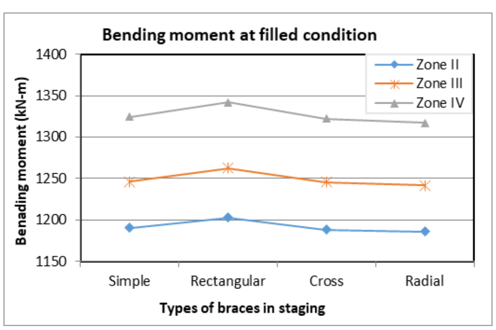

Fig. 11. Bending moment at the filled condition of tank

The Fig. 10 and 11 shows the graphical representation of maximum bending moments for staging with different braces at the empty condition and filled condition of tank. The graphs are plotted between bending moment (kN-m) and the types of braces for bending moment values in seismic zones.

The values of maximum bending moment are lower for empty condition and increase for filled condition. The higher value of bending moment is shown by rectangular type brace staging element and it goes on decrease for simple, cross and lower value of bending moment is shown by radial type brace staging elements for all seismic zones.

The variation in values of shear forces is shown in Table.4 atthe empty and filled condition of tank for all braces pattern with staging in seismic zone II, III and IV.

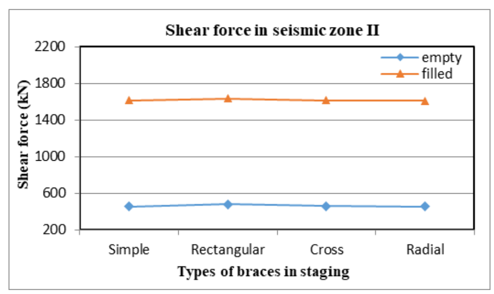

Fig. 12. Shear force value for braces in seismic zone II

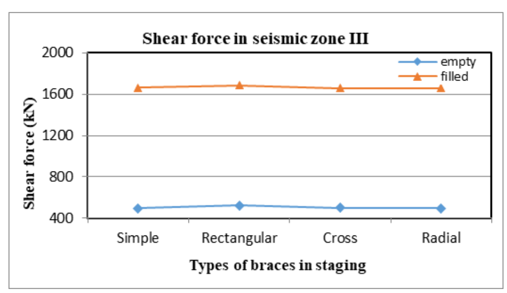

Fig. 13. Shear force value for braces in seismic zone III

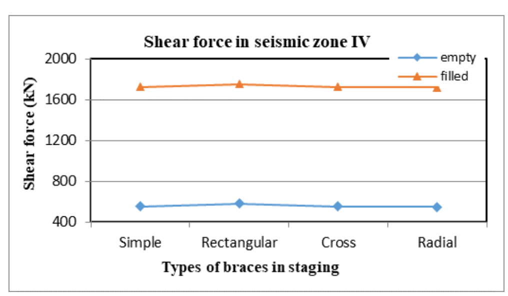

Fig. 14. Shear force value for braces in seismic zone IV

Table 5
Base shear value of tank at the filled and empty condition for seismic zones

Braces on staging	Empty condition			Filled condition		
	Zone II	Zone III	Zone IV	Zone II	Zone III	Zone IV
Simple	302.166	483.322	724.625	355.57	568.7	852.6
Rectangular	329.303	526.729	789.704	382.708	612.1	917.7
Cross	337.623	540.036	809.654	391.027	625.4	937.7
Radial	340.54	544.709	816.661	393.948	630.1	944.7

The Fig. 12, 13 and 14 is shown the representation of shear force vales for seismic zones II, III and IV. The graphs are plotted between shear force (kN) and types of braces in staging for the empty and fill condition of tank. From the graphs the value of shear force is higher for the rectangular type staging elements and goes in decrease for simple, cross and less values are shown in radial type brace staging in all seismic zones.

The Table 5 is shows the variation in base shear of tank for empty and filled condition of container with staging of different braces in seismic zone II, III and IV.

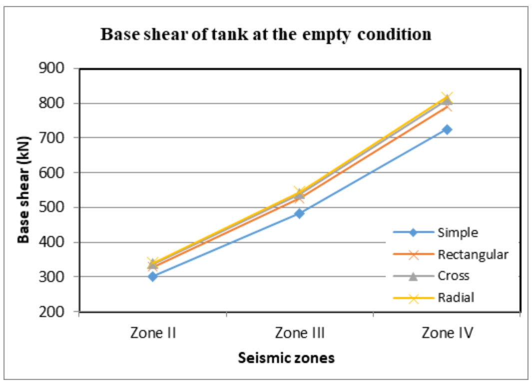

Fig. 15. Base shear values at the empty condition of tank in seismic zones

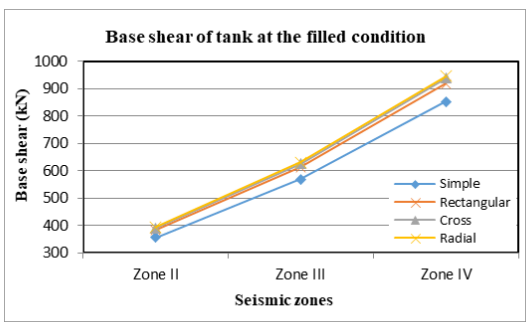

Fig. 16. Base shear values at the empty condition of tank in seismic zones

The Fig. 15 and 16 shows the values of base shear at the empty and filled condition of tank respectively. The graphs are plotted between base shear (kN) and seismic zones II, III and IV for braces patterns with staging. The base shear value is increases for the higher seismic zones in both the condition of tank. The value of base shear is less for the simple type brace staging and increase for rectangular, cross and the value is maximum for the radial type brace staging.

11. Conclusion

In the study, an Intze type water container with different staging has been modeled using software STAAD.ProV8i to carry out the complete analysis of elevated water tank. Response spectrum analysis is used for the structure under seismic zones II, III and IV. The important conclusions arrived at in this paper are as follows.

1. The tanks have less base shear in empty condition as compared to filled condition. The base shear increases due to increase in seismic zone intensity. Base shear is less for the lower seismic zones and goes on increase for the higher seismic zones.
2. The displacement value is reduced considerably due to horizontal braces in staging. The minimum displacement is shown by radial type brace staging.
3. The value of shear force increases for the higher seismic zones and the lower values of shear force are shown by radial type brace staging.
4. The bending moment values are changing in staging due to different braces. The lower value of maximum bending moment is shown by radial type brace staging in all seismic zones i.e. II, III and IV.
5. Rectangular type brace staging have less displacement then simple type brace staging but the shear and bending values higher. Therefore, it is avoided for the field jobs in seismic zone II, III and IV.
6. The radial type brace staging have minor effect due to seismic loads and the responses of staging with radial type brace give strong stability as compare to other brace staging. Therefore, it can minimize the chances of collapse of the elevated water tank.

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