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ANALYSIS OF SLOSHING IMPACT ON OVERHEAD LIQUID STORAGE STRUCTURES

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ABSTRACT

This paper presents analysis to study the effects of sloshing in overhead liquid storage tank. In such structure a large mass concentrated at the top of slender supporting structure makes the structure vulnerable to horizontal forces e.g. due to earthquakes. This study focuses mainly on the response of the elevated Intze type water tank to dynamic forces by both equivalents static method and finite element analysis using commercial software. To find out the design parameters for seismic analysis and also the importance in the sloshing effect consideration during the design. Here an elevated Intze type water tank is analysed and designed. The analysis is carried out for two cases namely, tank full condition considering only the hydrostatic effects and tank full condition considering the sloshing effect using STAAD Pro. From the analysis it is concluded that, to consider the sloshing effect along with the effect of hydrodynamic pressure on container wall of the tank during the design is very important in earthquake prone regions. The results obtained from analyses are discussed considering the importance of the structure during seismic activity.

KEYWORDS: Sloshing, Hydrostatic Load, Convective Mass, Impulsive Mass, STAAD Pro Modelling

INTRODUCTION

Sloshing, the motion of the free liquid surface inside its container is one of the major concerns in design of liquid storage tanks, moving tankers fuel tank of space vehicles and also in ships. In major cities and also in rural areas elevated water tanks forms an integral part of water supply scheme and these tanks must remain functional to meet the demand in any extreme situation like earthquake, fire, etc.

Seismic safety of liquid storage tanks is of considerable importance. Water storage tanks should remain functional in the post-earthquake period to ensure potable water supply to earthquake-affected regions and to cater the need for firefighting. Industrial liquid containing tanks may contain highly toxic and inflammable liquids and these tanks should not lose their contents during the earthquake.

During the earthquakes, a number of large elevated water tanks were severely damaged[1] whereas others survived without damage. An analysis of the dynamic behaviour of such tanks must take into account the motion of the water relative to the tank as well as the motion of the tank relative to the ground.

Based on previous study[1],[2] of earthquakes, the main concerns for failure of water tanks are,

- Consideration is not given to sloshing effects of liquid and flexibility of container wall while evaluating the seismic forces on tanks.

- It is recognized that tanks are less ductile and have low energy absorbing capacity and redundancy compared to the conventional building systems which is not considered properly.
- Unsuitable design or wrong selection of supporting system and underestimated demand or overestimated strength of the tank.

This study is concentrated mainly on Sloshing Effect that is happening in the water tank during Earthquake, and how to overcome it. Sloshing is defined as the periodic motion of the free liquid surface in a partially filled container. It is caused by any disturbance to partially filled liquid containers. Depending on the type of disturbance and container shape, the free liquid surface can experience different types of motion including simple planar, non-planar, rotational, irregular beating, symmetric, asymmetric, quasi periodic and chaotic.

If the liquid is allowed to slosh freely, it can produce forces that cause additional hydrodynamic pressure in case of storage tanks and additional vehicle accelerations in case of moving tanker and space vehicles. The basic problem of liquid sloshing involves the estimation of hydrodynamic pressure distribution, forces, moments and natural frequencies of the free-liquid surface. These parameters have a direct effect on the dynamic stability and performance of storage structures which is brought down as a clear picture from the following analysis.

From Literatures, the following conclusions are made,

Most of the codes[18] put emphasis on ground-supported tanks and very limited information is available on elevated tanks[3]. Unlike for buildings, most of the documents do not provide lower bound limit on spectral values for tanks. Most of the literatures suggest the consideration of both convective and impulsive components in seismic analysis of tanks not only the impulsive component and more weightage should be given to convective mode. This effectively results in reduction in severity of tank base shear as compared to building base shear. The need for this study is that, Indian code needs inclusion of convective mode of vibration in the seismic analysis of tanks and more importance should be given to Sloshing, rather than considering it as a parameter to fix the free float of the tank.

IDEALIZATION OF ELEVATED WATER TANK

Impulsive and Convective Mass

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[4]. 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 (m_i), 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 convective liquid mass (m_c) and it exerts convective 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[4] on tank wall and base is given in Figure 1

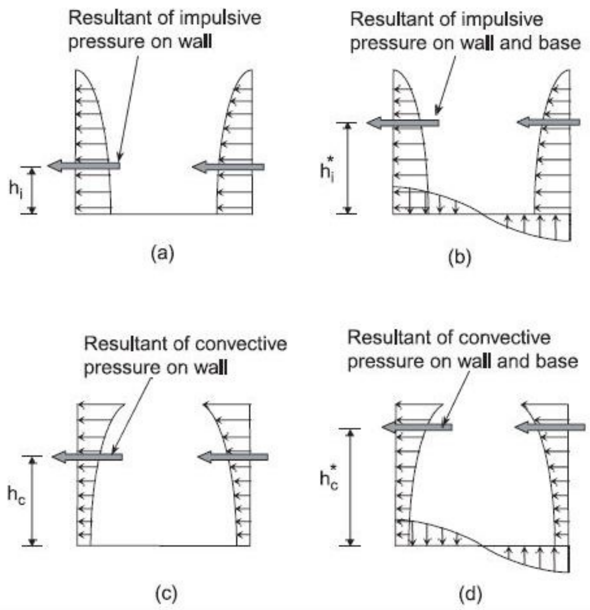

Figure 1: Qualitative Description of Hydrodynamic Pressure Distribution on Tank Wall and Base

where,

h_i - is the height at which the resultant of impulsive hydrodynamic pressure on wall is located from the bottom of tank wall.

h_i^* - is the height at which the resultant of impulsive pressure on wall and base is located from the bottom of tank wall

h_c - is the height at which resultant of convective pressure on wall is located from the bottom of tank wall

h_c^* - is the height at which resultant of convective pressure on wall and base is located

Mass Idealization

If a closed tank is completely full of water or completely empty, it is essentially a one-mass structure. If, as is usual, the tank has a free water surface there will be sloshing of the water during an earthquake and t5his makes the tank essentially a two-mass structure. In this case, the dynamic behaviour of an elevated tank may be quite different. For certain proportions of the tank and the structure the sloshing of the water may be the dominant factor, whereas for other proportions the sloshing may have small effect. Therefore, an understanding of the earthquake damage, or survival, of elevated water tanks requires an understanding of the dynamic forces associated with the sloshing water.

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 and is being commonly used in most of the international codes. Structural mass m_s include 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.

The response of the two-degree of freedom system can be obtained by elementary structural dynamics. However, for most elevated tanks it is observed that the two periods are well separated. Hence, the system may be considered as two uncoupled single degree of freedom systems. This method will be satisfactory for design purpose, if the ratio of the period of the two uncoupled systems exceeds 2.514. If impulsive and convective time periods are not well separated, then coupled 2-DOF system will have to be solved using elementary structural dynamics. In this context it shall be noted that due to different damping of impulsive and convective components, this 2-DOF system will have non-proportional damping.

For elevated tanks[5], the two degree of freedom system of Figure 2c can be treated as two uncoupled single degree of freedom systems (Figure 2d), one representing the impulsive plus structural mass behaving as an inverted pendulum with lateral stiffness equal to that of the staging, K_s and the other representing the convective mass with a spring of stiffness, K_c. For tank shapes other than circular and rectangular (like intze, truncated conical shape), the value of h / D shall correspond to that of an equivalent circular tank of same volume and diameter equal to diameter of tank at top level of liquid; and m_i , m_c , h_i, h_i*, h_c , h_c* and K_c of equivalent circular tank shall be used.

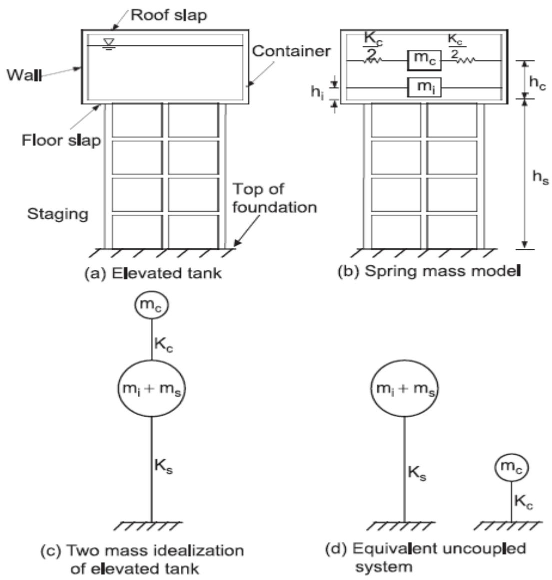

Figure 2: Two Mass Idealization of Elevated Tank

DESIGN OF OVERHEAD LIQUID STORAGE STRUCTURE

In this study overhead liquid storage structure is referred as Intze type water storage tank. Intze type tank, is the one that in which below the cylindrical container is a conical shell with a dome shaped tank floor that provides an economical substitute for otherwise thick floor slabs in elevated tanks. The dimensions of the conical walls and the spherical bottom domes are such that the outward thrust from the spherical dome is balanced by the inward thrust from the conical shell. Because of its optimal load balancing shape, the Intze-type containers are widely used. The basic dynamics of elevated tanks is somewhat complex, especially those related to the movement of fluids in the tank. However, the estimation of design forces for the supports is relatively simpler. Under lateral accelerations, the fluids in the upper regions of the tank do not move with the tank wall, thus generating seismic waves or sloshing motion of fluids (convective behaviour). On the contrary, fluids nearer the base of the tank move with the tank structure and, therefore, add to the inertial mass of the tank structure (impulsive behaviour). The portion of the tank fluid that acts in the impulsive mode depends largely on the aspect ratio (height/diameter) of the tank. For tanks of very-low-aspect ratio, very little tank fluid acts in the impulsive mode. The period of sloshing motions are typically long (up to 10 s) and are influenced by the ground displacement rather than the ground acceleration that typically affects impulsive modes of vibration. Conventional earthquake-resistance design is based on the premise that structures can undergo large plastic deformations without collapse. This concept allows the structure to be designed for seismic forces significantly less than those required if the structure had to remain elastic. The seismic performance of such structures rests heavily on the ductility, the energy-absorbing capacity of the detailed structural components, and the redundancy due to alternative load paths. The factor used to reduce the elastic seismic forces to arrive at design forces is, therefore, a function of these properties. The design forces for less ductile systems would be larger than those for more ductile systems. It is expected that the supporting structure of elevated tanks would experience inelastic deformations and, as a consequence, the acceleration response can be reduced by using an appropriate ductility factor. However, this reduction is applied to only impulsive forces, and no reduction is permissible for convective forces as a result of ductility.

FEM ANALYSIS USING STAAD PRO

The Intze tank is designed using STAAD Pro., and analysed for 2 cases. They are,

- Tank with its full capacity by considering only hydrostatic forces only.
- Tank with its full capacity by considering Sloshing Effect along with hydrostatic effect.

Finite Element Modelling

FEM of the Intze tank is rendered for the following dimensions, The Intze Tank is to be designed for the capacity of 10,00,000 litres with staging height of 20 m above ground on a hard strata in Seismic zone IV by using concrete of grade M20 and Steel of grade Fe415.

- Top dome plate thickness: 150mm
- Tank wall plate thickness: 300mm
- Bottom conical dome plate thickness: 500mm
- Top ring beam dimension: 350*500mm
- Bottom ring beam dimension: 1000*730mm
- Circular ring beam dimension: 600*1200mm
- Top ring dimension: 350*500mm
- 8 columns of diameter : 750mm
- And Of height (including 1m inside GL) : 2160mm
- Bracings : 300*600mm
- Raft circular foundation: 450mm (Depth) 13.65m (dia)
- And the reinforcements are also calculated and provided in an appropriate manner liable to IS 456.

In second case of considering Sloshing effect, the tank is modelled as a 2DOF system, with both convective and impulsive mass are lumped on respective nodes at their respective heights which are obtained from calculations. Since spring link is not provided by STAAD, the equivalent stiffness value of the spring material is calculated and material having equivalent stiffness is chosen. From codal provisions, Convective spring stiffness K_c can be calculated using following formula or by using graph (Figure 2a of IS 1893 Part II),

$$K_c = 0.836 * \frac{mg}{h} * \tanh^2\left(\frac{3.68h}{D}\right)$$

here,

m = 1006147 kg,

g = 9.81 m/s^2

h = 5 m and

D = 16 m.

Therefore K_c = 1103598.317 kg/m (10823.3678kN/m)

The section should possess a value of $K_c/2$ = 10823.3678.

by equating $K_c/2 = AE/l$ required Area of the section is = 461.859 mm^2.

Choosing approximately equal area section, IS tube 38383.6 (A = 462 mm^2)

Similarly for rigid link provide I- beam. and the tank is analysed.

Determination Soil Spring Constants

For tanks resting on soft soils, effect of flexibility of soil may be considered while evaluating the time period. Generally, soil flexibility does not affect the convective mode time period. However, soil flexibility may affect impulsive mode time period[10].

In case of foundation, the soil - structure interaction properties are well analysed and soil spring constant values are found out to give approximately the same reactions at the supports by using formulae as given bellow, As a crude approximation, the following expressions, which are frequency independent are used for undamped soil,

$$K_x = \frac{8Ga}{2 - \upsilon}$$

$$K_\phi = \frac{8G\,(a^3)}{3(1 - \upsilon)}$$

Where,

K_x, K_ψ - Static - stiffness coefficients for a rigid circular base mat of radius "a".

G - Shear modulus of the soil.

υ - Poissons' ratio of the soil.

A - Radius of the Circular Mat.

By assuming the tank is rest on a gravel type soil, the following properties are chosen,

Average Radius of the circular ring mat, a = 5m.

Shear modulus of the soil, G = 300 kN/m^2

Poissons' ratio of the soil, υ = 0.25

Static - stiffness coefficients for whole footing,

K_x = 6857.14 kN/m

K_ψ = 133333.33 kN/m

Static - stiffness coefficients for each column support,

K_x = 6857.14 / 8 = 857.175 kN/m

K_ψ = 133333.33 / 8 = 16666.67 kN/m

These stiffness K_x is applied in Global positive X-direction, and

K_ψ is applied in Global positive Y-direction.

Loading Pattern

An Earthquake Load that happened in El-centro (California) in 1940 of magnitude M6.9 and intensity of X on MMI scale is applied, by using "Time History Analysis". The time vs acceleration data (4001 values) is given as input in a tabulation format, and the results are tabulated.

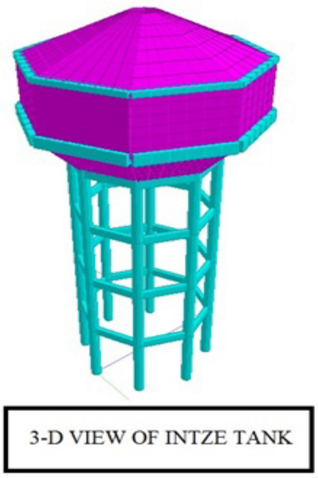

Figure 3: 3D View of Intze Tank Modelled Using STAAD Pro

RESULTS AND DISCUSSIONS

Nodal Displacement

The displacement of nodes of the tank during the applied earthquake motion is shown in figure for the two cases and their support reactions are given in corresponding tables.

Figure 4 shows Tank with its full capacity subjected to Time history Earthquake load, and the nodal displacement are based only by considering hydrostatic forces in the tank.

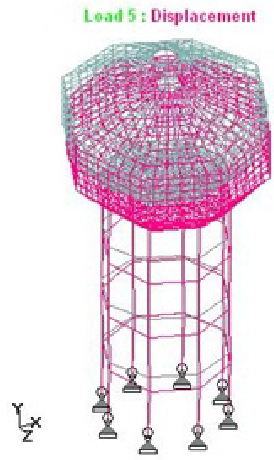

Figure 4: Tank with Its Full Capacity by Considering Only Hydrostatic Forces.

Figure 5: Tank with Its Full Capacity Considering Hydrostatic Forces Along with Sloshing Forces in the Tank

Table 1: Support Reactions of Intze Tank by Considering Hydrostatic Forces

Support Reactions (KN)			
Node	Horizontal		Vertical
	FX	FZ	FY
1	3.086	49.609	9.715
9	11.321	38.885	28.623
17	-0.891	27.991	27.899
25	-5.889	36.042	9.903
33	3.075	46.885	-16.824
41	9.546	37.07	-25.002
49	4.068	27.914	-23.164
57	-7.549	37.757	-6.21

Combination Load Case 5: Combining the effect of Earthquake load and hydrostatic load as given in STAAD Pro., software. Figure 5 shows tank with its full capacity subjected to Time history Earthquake load, and the nodal displacement are based only by considering hydrostatic forces along with Sloshing forces in the tank.

Table 2: Support Reactions of Intze Tank by Considering Sloshing Along with Hydrostatic Forces

Support Reactions			
Node no.	Horizontal		Vertical
	Fx kN	Fz kN	Fy kN
1	0	69.29	0
9	13.063	52.486	-7.288
17	0	37.681	-10.315
25	-13.062	52.486	-7.288
33	0	69.291	0
41	13.063	52.486	7.288
49	0	37.681	10.315
57	-13.063	52.486	7.288

Combination Load Case 4: Combining the effect of Earthquake load and effect due to sloshing. It can be inferred from the tables that the reaction in X and Y direction is Zero at the supports 1 and 33 for sloshing case, and also Zero in X direction for the support node 17 and 49. But it was not in the case of ordinary Hydrostatic loading.

Modal Calculation

The Mode shapes and Critical Elements of design staging and tank are analysed separately for Hydrostatic case and Sloshing case and the results are tabulated bellow, First 6 modes are considered and their participation factor in all three mutual perpendicular directions x, y, z are tabulated.

Table 3: Mode Shapes for Hydrostatic Case

Mode Shapes					
Mode	Frequency Hz	Period Seconds	Participation X %	Participation Y %	Participation Z %
1	0.103	9.725	80.691	0	1.355
2	0.103	9.678	1.349	1.138	82.125
3	0.593	1.685	0.017	98.836	1.057
4	0.846	1.182	0.137	0	0
5	2.343	0.427	16.482	0	0.068
6	2.728	0.367	0.059	0.024	14.045

Table 4: Mode Shapes for Sloshing Case

Mode Shapes					
Mode	Frequency Hz	Period Seconds	Participation X %	Participation Y %	Participation Z %
1	0.075	13.407	87.414	0	0
2	0.075	13.393	0	0	88.208
3	0.457	2.187	0	100	0
4	0.571	1.751	0	0	0
5	2.023	0.494	11.294	0	0
6	2.169	0.461	0	0	10.217

From these tables it is interpreted that there is increase in time period for Mode 1 and 2 of Sloshing case when compared to Hydrostatic case. It is clear from the above table that in each mode only one direction participation is there in sloshing case whereas there is a small contribution in other directions also in hydrostatic case.

Comparison of Responses in Critical Members

The critical elements of tank and stagging are shown seperately in figure 6 and 7 for hydrostatic case, while for Sloshing case in figure 8 & 9.

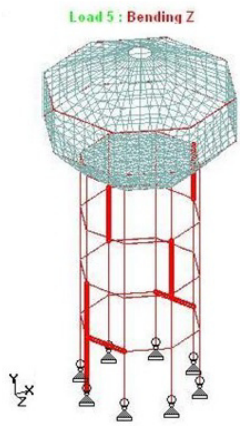

Figure 6: Critical Beam Elements of the Tank in Hydrostatic Case

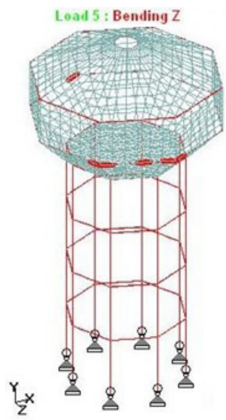

Figure 7: Critical Beam and Column Elements of the Staging in Hydrostatic Case

As obvious, all critical elements are found only in bottom ring. Beam 103 has maximum axial force of 16.193 kN. And beam 341 has maximum shear force of 10.631 kN and it has a maximum moment in x-direction of 3175.025 N-m. And beam 43 has maximum moment in y and z direction as 11254.24 N-m and 4464.358 N-m respectively.

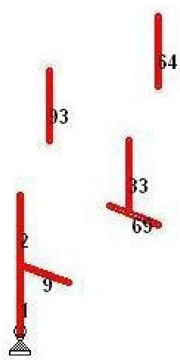

Figure 6a: Position of Critical Beam Elements of the Tank in Hydrostatic Case

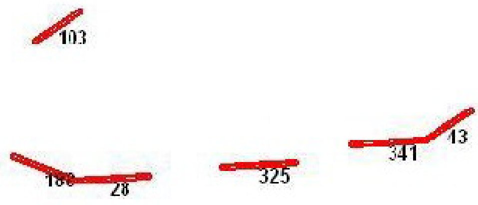

Figure 7a: Position of Critical Beam and Column Elements of the Staging in Hydrostatic Case

Out of 7 critical members 5 are from last 2 staging. Beam 33 has maximum axial force of 128.686 kN. And beam 1 has maximum shear force of 49.609 kN and it has a maximum moment in y-direction of 2.48e5 N-m. And beam 69 has maximum negative moment in x direction as 3640.88 N-m while beam 2 has maximum moment in z-direction as 1.8e5 N-m respectively.

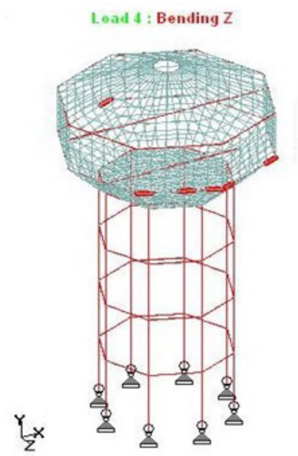

Figure 8: Critical Beam Elements of the Tank in Sloshing Case

Figure 9: Critical Beam and Column Elements of the Staging in Sloshing Case

Beam 103 has maximum axial force of 44.949 kN and beam 341 has maximum shear force of 15.793 kN and it has a maximum moment in y & z-direction as of 18587.43 N-m & 6553.734 N-m respectively. And beam 484 has maximum moment in x-direction as 3706.991 N-m.

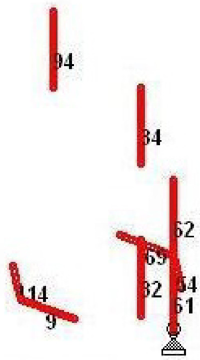

Figure 8a: Position of Critical Beam Elements of the Tank in Sloshing Case

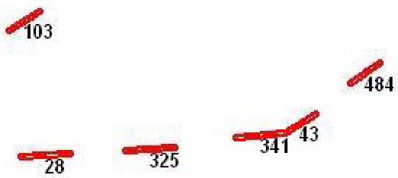

Figure 9a: Position of Critical Beam and Column Elements of the Staging in Sloshing Case

Beam 94 has maximum axial force of 200.441 kN. And beam 69 has maximum shear force of 146.6 kN and it has a maximum moment in z-direction of 2.87e5 N-m. And beam 9 has maximum negative moment in x-direction as 5263.829 N-m while beam 61 has maximum moment in z-direction as 3.46e5 N-m.

For the beams maximum moment considered for the design of critical member by manual calculation is 3300 N-m. which is adequate for hydrostatic case (3175.025 N-m) but not for sloshing case (3706.991 N-m). But the maximum shear considered for the design of critical member is adequate for both the cases.

For column members the axial force considered for the critical member is 150kN which is adequate for hydrostatic case (128.686kN) and not for Sloshing case (200.441 kN). Which clearly shows the need of consideration of Sloshing Impact in the design of water tank.

Stress Distribution on Tank Plates

Based on major principle stress failure theory, the stresses are plotted for both cases as shown in the figures bellow.

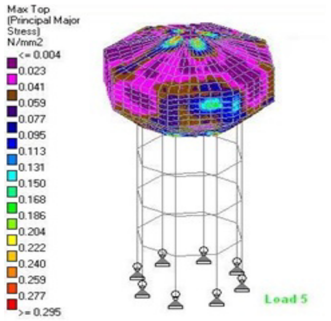

Figure 10: The Stress Distribution According to Major Principle Stress Theory for Hydrostatic Loading

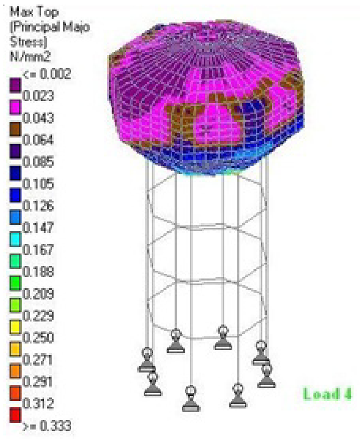

Figure 11: The Stress Distribution According to Major Principle Stress Theory for Sloshing Case

It is easily seen from above diagrams that the high range of stress is formed at top dome, cylindrical wall as well as in conical bottom in the case of hydrostatic case, while, heavy stresses are accumulated only in conical bottom in Sloshing case.

CONCLUSIONS

Following conclusions are made based on the aforementioned analysis presented in this paper.

- There is almost 40% increase of time period for first and second mode on comparing hydrostatic case and sloshing case which indicates more consideration should be given to sloshing case rather than hydrostatic case.
- On comparing the critical beam elements of tank, the maximum axial force in sloshing case increases nearly as thrice as in hydrostatic case, 47% in shear force and 16% increase of bending moment in x-direction, while 65% in y-direction and 47% in z-direction.
- On examining the critical elements of staging, the maximum axial force in sloshing case increases 56% more than in hydrostatic case, 56% in shear force and 45% increase of BM in x-direction, while 40% in y-direction and 59% in z-direction.
- The check for critical members also reveals that the tank is stable for hydrostatic case of analysis but not when sloshing is included in the analysis for which the critical elements values are exceeding the limiting values
- It is clear that all critical quantities are increasing while considering sloshing effect in our design procedure. In order to avoid the failure[1] which was mentioned earlier it is mandatory to consider. The Sloshing effect in the design and necessary precautions should be taken in earthquake prone region rather than considering the sloshing as the criteria only for fixing the free board. Since this sloshing of water considerably differs the parametric values used in design and economy of construction.

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REFERENCES

1. Durgesh C Rai, *Performance of elevated tanks in Mw 7.7 Bhuj earthquake of January 26th, 2001 Proc. Indian Acad. Sci. (Earth Planet. Sci.),* 112, No. 3, September 2003, pp. 421 to 429
2. Durgesh C. Rai, M. Eeri, *Seismic Retrofitting of R/C Shaft Support of Elevated Tanks*, *Earthquake Spectra*, Volume 18, No. 4, pages 745–760, November 2002
3. Jaiswal. O. R, Durgesh C Rai, Sudhir K Jain, *Review of Code Provisions on Design Seismic Forces for Liquid Storage Tanks*, Document No. :: IITK-GSDMA-EQ01-V1.0, 2007.
4. Sudhir K Jain and Jaiswal. O. R, *Modified Proposed Provisions AseismicDesign Liquid Storage Tanks Part I - Commentary And Examples* Journal Of Structural Engineering Vol. 32, No. 4, October–November 2005 pp. 297–310
5. Sudhir K Jain and Jaiswal. O. R, *Modified Proposed Provisions ASeismicDesign Liquid Storage Tanks Part I - Codal Provisions* Journal Of Structural Engineering Vol. 32, No. 3, August–September 2005, pp 195-206.
6. IITK-GSDMA Guidelines For Seismic Design Of Liquid Storage Tanks, 2007.
7. Chirag N. Patel, Shashi N, Vaghela, H. S. Patel, *Sloshing Response Of Elevated Water Tank Over Alternate Column Proportionality* , International Journal of Advanced Engineering Technology pp 60-63, Oct.-Dec., 2012.
8. Housner. G. W, *The Dynamic Behavior Of Water Tanks* , Bulletin of the Seismological Society of America. Vol. 53, No. 2, pp. 381-387. February, 1963
9. *Recommendations of Workshop on Revision of I.S. Codes on Liquid Retaining Structures*, November 10 and 11, 2005.
10. Mangulkar Madhuri. N, Gaikwad Madhukar V., *Review On Seismic Analysis Of Elevated Water Tank* International Journal of Civil Engineering and Technology (IJCIET), Volume 4, Issue 2, March - April (2013)
11. Sudhir K Jain and Sajjad Sameer U, *A Review of Requirements in Indian Codes for Aseismic Design of Elevated Water Tanks,* Bridge and Structural Engineer- Vol XXIII, No1, Mar 1993.
12. Ibrahim, R. A.; Pilipchuk, V. N.; Ikeda, T. *Recent Advances in Liquid Sloshing Dynamics* Applied Mechanics Reviews, vol. 54, issue 2, 2001, pp. 133-139
13. Shenton, H. and Hampton, F. *Seismic Response of Isolated Elevated Water Tanks* Journal of Structural Engineering, Vol 125 issue 9, Sep 2009, pp. 965–976.
14. Ibrahim R. A, *Liquid Sloshing Dynamics – Theory and Applications,* Cambridge University Press 2005, ISBN – 13 978-0-521-83885-6 hard back
15. *Slosh Suppression,* NASA Space vehicle Design criteria (Structures) NASA SP – 8031, May 1969.
16. Ramamrutham. S, Narayan. S, *Design of Reinforced Concrete Structures (conforming to IS 456): Working Stress Method and Limit State Method*, Dhanpat Rai publication, 11th edition, 1993, ISBN -10 81-87433-12-4.

17. Punmia. B. C Jain Ashok Kr., Jain Arun Kr., *Reinforced Concrete Structures Volume 2*, Laxmi publications, 1992. ISBN: 978-81-318-0666-1

18. IS Codes : IS 1893-2002 Part I & II Criteria for Earthquake Resistant Design of Structures, IS 4326-1993 Code of practice for Earthquake Resistant Design and Construction of Buildings, IS 11682-1985 Criteria for Design of RCC Staging for Overhead Water Tanks, IS 456-2000 Code of Practice for plain and Reinforced Concrete.