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Earthquake Analysis of Water Tank for Different Staging Height and Sloshing Effect

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***Abstract:* -- From the old experiences of few earthquakes, like Bhuj earthquake in India elevated water tanks were heavily harmed or failed. Liquid loads behave very differently to dry loads at the time of the earthquake. When the liquid starts to slosh in the tank, it causes huge weight shifts. Elevated water tank must remain functional after an earthquake as it is useful to provide water and firefighting system, Therefore it is important to study in detail. This paper presents a study of earthquake analysis of elevated water tank for different staging height having the same capacity. It is necessary to have a control system for effectively reducing slosh. The purpose of this study is to know the behavior of liquid under motion or vibration by comparing sloshing frequency numerically, experimentally and by ANSYS. And also to analyze the model of a water tank with different bracing patterns, staging heights to know the minimum deflections.**

Key words: - Sloshing, Different Staging Height, Seismic Analysis, STADD PRO.

I. INTRODUCTION

Earthquakes are major calamities which have a potential to causing disturbance to infrastructure and lifeline facility. Water is basic needs for daily life. An elevated water tank is a large container built for the purpose of water supply it consists large water mass at the top of slender staging which is considering critical during an earthquake. For certain proportion of tank and structure, the sloshing of water during an earthquake is also a dominant factor. The presence of a free fluid surface which allows motions related to container called liquid sloshing. Seismic ground motion cause hydrostatic and hydrodynamic pressure on the tank which depend on the dimention of tank, the percentage of liquid, properties of liquid, fluid tank interaction. etc. Most of the people developed a mathematical model, theoretical solution for calculating or studying sloshing effects. Therefore an understanding of earthquake damage for elevated service reservoir requires information about dynamic forces, staging height associated with sloshing liquid is important

II. LITERATURE REVIEW

A. Various literature has introduced in the form of technical papers, magazines on seismic analysis of water tank for different staging heights

A.R. Ghaemmaghami (2010) et al investigated the behavior of water tank in 2D space. They studied effect of horizontal and vertical ground motions for small and large tanks. They conclude that time history analysis method also beneficial for rectangular liquid tank analysis using FEM. For getting damping property of liquid this method is most beneficial. They take wall flexibility criteria for analyzing liquid storage tank. Dr. Suchita Hirde (2011) et al. evaluated the performance of water tank for different seismic zones of India for different staging heights and capacity of the water tank for different soil conditions. Total 240 models analysis carried out with the help of Esr-Gsr software. Earthquake force decreases with increase in staging height and increase with rising zone factor for medium, soft, hard soil condition. Chirag N. Patel (2012) et al demonstrated the dynamic behavior of water tank with considerable answers such as displacement, base shear, base moments, sloshing, torsional vulnerability etc. therefore only frame type staging without bracings, by providing number of columns placed along the periphery of the circle are not enough to bear the water tank container. A.M. Jabar (2012) et al expressed the behavior of the supporting system which is more effective under the different earthquake time history records with SAP2000. Two different supporting systems such as radial and cross-bracing compare with basic systems. Tank response includes base shear, overturning moments and also roof displacements. Higher roof displacement values are obtained in full fill up conditions for all patterns.

Ankush N. Asati (2014) et al evaluated seismic behavior effect studied for constant capacity and no. of the column, for different types of staging arrangement in plan and variations in numbers of stages in elevation by FEM. Total nine combinations were studied using response spectrum method. Therefore radial arrangement with six staging levels is best suited for ten numbers of the column and also roof displacement, base moment, base shear compares with different staging level. R. J. Aware (2014) et al studied seismic design of water tank for various staging height and also different zones of India. They compared nodal displacements for various 20 models. Conclusions are by increasing staging height nodal displacements also increasing, so for higher zone got maximum values of displacement respectively. G. P. Deshmukh (2015) et al calculated the behavior of various staging under different loading conditions and make stronger the conventional type of staging by equivalent static analysis for five various type of bracing systems applied to the staging of elevated water tank in zone IV is carried out using STAAD Pro. By preparing eleven models for different bracing pattern they calculate base shear and nodal displacement for empty, half fill, full conditions. They conclude that alternate cross bracing pattern provide minimum displacement but from a construction point of view, the economy of complete construction alternate diagonal bracing pattern advantageous. N. R. Patil (2015) et al studied influencing variables are displacement, maximum forces in column and base shear are comparing for different staging heights. Base shear decreases as the height of staging increases this means that the earthquake force is reversely proportional to the height of staging. Displacement increases with the increase in staging height this effect is seen up to certain stage then it remains roughly constant.

B. Seismic analysis of water tanks requires information about sloshing of liquid, so various literatures has introduced on liquid sloshing also

M. S. Chalhoub (1990) et al. represented the evaluation of two cylindrical shaped water tanks one directly fixed to earthquake simulator equipment and other was fixed on the base of a scaled nine-story steel structure prototype. Solution calculated from linear wave theory compare with experimental results. Since base isolation reduces accelerations then impulsive components of fluid pressure are decreased. Therefore liquid vessel are placed in top stories of building, base isolation is very effective.

Jae Kwan Kim (1996) et al studied liquid-structure interaction affects on the seismic response of partially filled containers are taken including walls flexibility. Solutions get by using the Rayleigh-Ritz method with the help of proper end conditions. Hydrodynamic pressure differs in transverse direction and also in vertical direction on the wall surface of container. They Studied sloshing behavior by considering effect of wall flexibility.

L. A. Patkas (2007) et al demonstrated half full cylinder and sphere by deriving equations mathematically and also they get sloshing frequency and masses for analysis. Numerically sloshing forces are getting by using equation of motion and masses are evaluated by modal analysis. Mass of the convective liquid has inverse relation i.e. decrease with increasing liquid depth.

S. M. Gardarsson (2007) et al extensive investigate the resonant frequency in a particular wave response for two tanks, one for horizontal bottom and another for horizontal bottom with sloping beaches. Value of frequency depends on the direction of vibrations. Sloshing response evaluated experimentally by hysteresis phenomenon with nonlinear system.

O. R. Jaiswal (2008) et al explained about the numerical and experimental study for obtaining sloshing frequency of liquid for different shapes of tank and with obstructions. For rectangle, square, circular shape of tanks, they evaluate sloshing frequency numerically and compared results experimentally and also with finite-element method. They conclude that as size of obstruction greater the first sloshing frequency will be less.

A.R. Ghaemmaghami (2010) et al studied small and large tank under the effect of both longitudinal and vertical ground motion by 1940 EI-Centro earthquake records by FEM method. As compare to horizontal effect vertical acceleration of dynamic response on tank less effective when both considered together. Result shows wall flexibility and fluid damping property had plays very important role in seismic analysis of tank. They verify results with numerically and literature available.

Minho Ha (2012) et al studied time history method of pressure on the inside wall of the tank are measured and motion of the free surface of sloshing liquid are recorded. The sloshing phenomenon is simulated by employing the volume of a fluid method implemented in a (CFD) computational

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fluid dynamics code evaluating Reynolds-Averaged navier strokes equation.

Roshan Ambade (2012) et al explained sloshing effect decreases with the use of baffles at the base of the tank. They mainly focus the containers initial motion and after impact with and without baffles. Tank with baffles is much better designed for reducing sloshing effects. It is concluded that volume of fluid is suitable to predict the maximum tank sloshing.

Qiang Zang (2015) et al evaluated two methods to lower sloshing modes in a container. One is command smoothing second is a combined input shaping and command smoothing. Both methods eliminate slosh to a very lower level. They explained theoretical and experimental analysis and control infinite number of sloshing modes

III. METHODOLOGY

A. In the present study, sloshing frequency can be evaluated by experimentally, numerically, and by ANSYS for the rectangular and circular tank

1) Evaluating sloshing frequency numerically

As per NZSEE sloshing frequency evaluated for different modes as below:

$$Fj = \frac{\sqrt{\alpha j} * \tanh\left(\alpha j * \frac{H}{L}\right)}{2\pi * \sqrt{L/g}}$$

For rectangular water tank Where,

H= Fluid level of water tank (m)

L= Half length of tank (m)

g = Acceleration due to gravity (m/s^2)

Fj= sloshing frequency if ith mode in hz.

$\alpha j = \pi/2, 3\pi/2, 5\pi/2, 7\pi/2$........

As per NASA SP-8009 sloshing frequency aluated for different modes as below-

$\omega_n = \sqrt{(\varepsilon_n g a^{-1} \tanh(\varepsilon_n h a^{-1}))}$

For circular water tank

Where,

ω_n= sloshing frequency of nth mode, g= longitudinal acceleration.

h= height of fluid in tank. a= tank radius.

εn= determine from root of first derivative of J1x. (Note - circular tank dimensions- tank radius 25 cm and height 28 cm rectangular tank- length-30 cm, width-20 cm, height-50cm for all sloshing frequency calculations)

2) Evaluating sloshing frequency experimentally

Fig. 1: Experimental photos for calculating sloshing frequency.

By preparing models of rectangular and circular shape tanks with the help of shake table we can notice the sloshing frequency for different modes.

3) Evaluating sloshing frequency by ANSYS

By following below steps prepare models in ANSYS parametric design language-

Preprocessor -- element - real constant- material - modelling- meshing.

Solution -- loads - solve.

General post processing -- read results - tables - graph/plots.

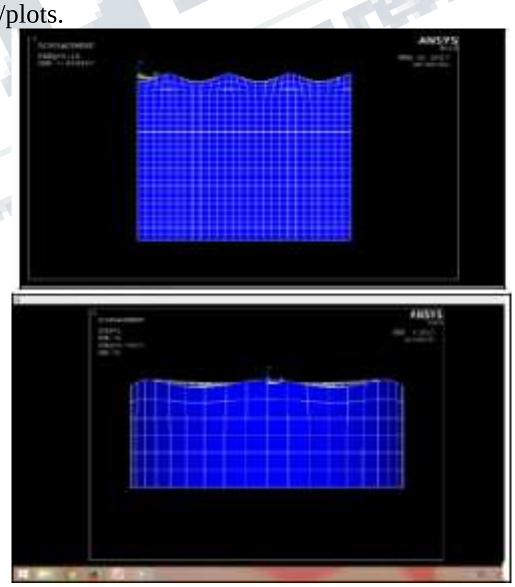

Fig. 2: In ANSYS calculating sloshing frequency.

B. In the present study different type of bracing patterns with different staging height analyzed for constant capacity of tank

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Capacity 500 cu.mec	Square Shape Tank	Circular Shape Tank
h/d or h/l	0.5	0.5
weight	more	less
base shear	more	less
	77.8 KN	**72.03** KN
weight	same	same
base shear	more	less

Table 1: Showing results of analysis of water tank for same h/d ratio having circular and square shape.

Capacity 1000 CU.MEC	Circular Shape Tank	Circular Shape Tank
h/d	0.32	0.5
base shear	less	more
(at full condition)	**115.34 KN**	130.04 KN
mass	Mc>Mi	Mc<Mi
overturning moment	less	more
total hydrodynamic pressure	less	more
deflection after analysis	less	more
resultant	less	more
Time period	less	more
After analysis results		
Deflection (MAX X)	**39.25** mm horizontal	43.07 mm horizontal
Resultant (MAX FY)	1417.135 KN	1517.150 KN

Table 2: Showing results of analysis of water tank for different h/d ratio having circular shapes.

As per methodology modeled water tank in STADD PRO software and analyzed. After analysis we get minimum deflection in h/d ratio 0.32 model having capacity 1000 cu.mec. So further variation for staging and bracing with the same model. And the results are as below-

IV. RESULTS

By keeping area of columns same with variations in numbers and diameter of columns results are as below-

No. of columns	Diameter	Area	Deflection
9	0.45	1.44	30.96
15	0.35	1.44	26.66
6	0.55	1.44	32.63
4	0.675	1.44	66.31
13	0.375	1.44	42.60

Table 3: Showing results of horizontal deflections for different number of columns.

A. Results of horizontal deflection at different staging height

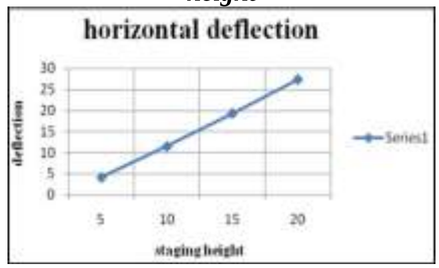

Fig. 3: Staging interval at 5 meters

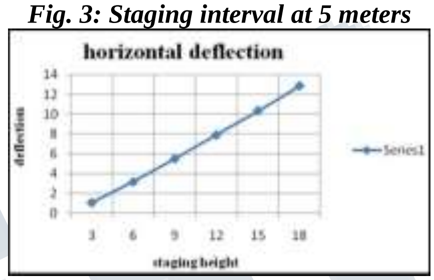

Fig. 4: Staging interval at 3 meters

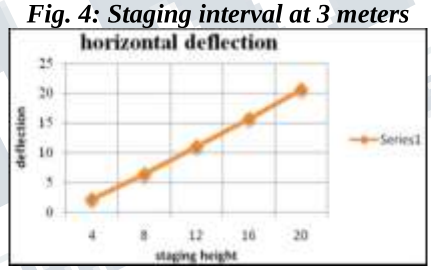

Fig. 5: Staging interval at 4 meters

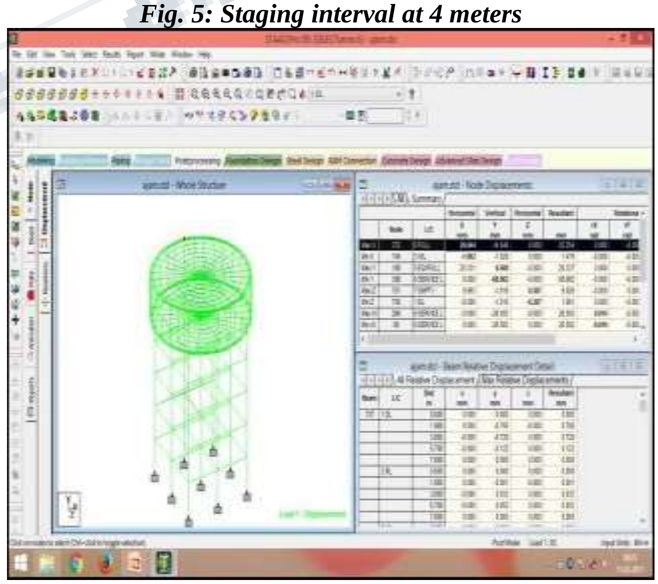

Fig. 6: Screen shot of maximum nodal displacement in STADD PRO

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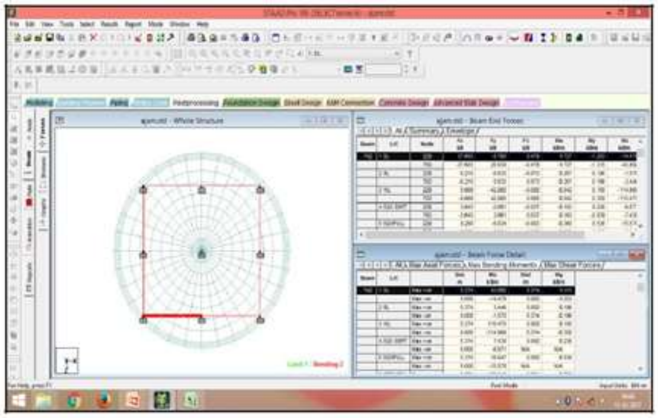

Fig. 7: Screen shot of maximum bending moment in STADD PRO.

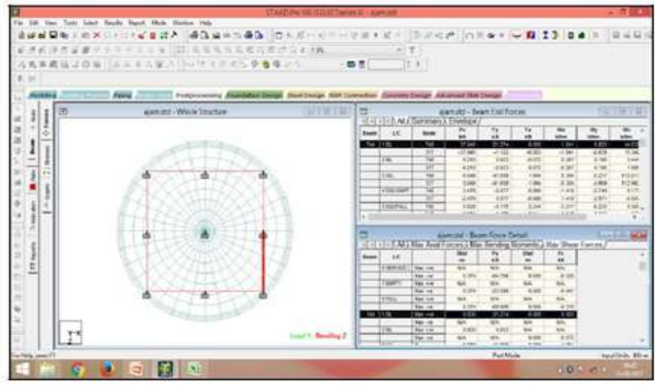

Fig. 8: Screen shot of maximum shear force in STADD PRO.

V. RESULTS OF SLOSHING FREQUENCIES FOR DIFFERENT WATER LEVEL ARE AS BELOW

Water level	Ht-0.05	Ht-0.05	Ht-0.05	Ht-0.10	Ht-0.10	Ht-0.10	Ht-0.15	Ht-0.15	Ht-0.15	Ht-0.20	Ht-0.20	Ht-0.20
Sr. no.	ANSYS	numerical	experimental	ANSYS	numerical	experimental	ANSYS	numerical	experimental	ANSYS	numerical	experimental
1	1.52	1.52	1.5	1.75	1.82	1.8	1.85	1.89	1.88	1.85	1.91	1.9
2	3.11	3.21	3.17	3.04	3.26	3.23	2.97	3.26	3.28	2.98	3.26	3.23
3	4.05	4.12	4.13	3.86	4.12	4.15	3.93	4.12	4.15	3.98	4.2	4.12
4	4.45	4.83	4.83	4.43	4.83	4.86	4.42	4.84	4.86	4.57	4.84	4.92

Table 4: Sloshing frequency for circular tank with different water levels.

Water level	Ht-0.1	Ht-0.1	Ht-0.1	Ht-0.2	Ht-0.2	Ht-0.2	Ht-0.3	Ht-0.3	Ht-0.3
Sr. No.	ANSYS	experimental	numerical	ANSYS	experimental	numerical	ANSYS	experimental	numerical
1	1.47	1.33	1.26	1.59	1.53	1.56	1.603	1.58	1.61
2	2.97	2.67	2.78	2.82	2.76	2.79	2.697	2.75	2.79
3	3.94	3.5	3.60	3.65	3.59	3.62	3.56	3.61	3.61
4	4.34	4.25	4.26	4.35	4.3	4.27	4.18	4.24	4.26

Table 5: Sloshing frequency for rectangular tank along X direction with different water levels.

Water level	Ht-0.1	Ht-0.1	Ht-0.1	Ht-0.2	Ht-0.2	Ht-0.2	Ht-0.3	Ht-0.3	Ht-0.3
Sr. No.	ANSYS	experimental	numerical	ANSYS	experimental	numerical	ANSYS	experimental	numerical
1	1.911	1.83	1.81	1.965	1.92	1.96	1.928	1.9	1.97
2	3.49	3.43	3.42	3.38	3.42	3.43	3.27	3.38	3.42
3	4.56	4.32	4.42	4.38	4.41	4.42	4.21	4.39	4.41
4	5.32	5.17	5.23	5.15	5.21	5.23	5.062	5.13	5.22

Table 6: Sloshing frequency for rectangular tank along Y direction with different water levels.

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VI. CONCLUSION

As per above analysis it is conclude that for water tanks at least 10 cm freeboard is essential so that water will not spill out of the tank at the time of earthquake and we can reduce damages from sloshing. As compare to square circular water tanks has less base shear with low h/d ratio. Above we analyze the geometry of bracing which will give minimum horizontal deflection with 15 numbers of columns having diameter 350 mm. By increasing staging height deflection increases because it will become more flexible at more heights.

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