Seismic Analysis of Over Head INTZE Water Tank Subjected to Sloshing Effect

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***Abstract*- Water supply is a life line facility that must remain functional in natural disaster. These structures have large mass concentrated at the top of slender supporting structure hence these structure are especially vulnerable to horizontal forces due to earthquakes. The Intze water tank were collapsed or heavily damaged during the earthquakes because of unsuitable design of supporting system or wrong selection of supporting system and underestimated demand or overestimated strength. So, it is very important to select proper supporting system and also need to study the response of Intze water tank subjected to seismic forces in different zones and to find out the design parameters for seismic analysis. It is also necessary to consider the sloshing effect on container roof slab. The effect of hydrodynamic pressure and pressure due to wall inertia & effect of vertical ground acceleration in the seismic analysis must be considered in the seismic analysis of Intze water tank.**

Index terms- Intze Water Tank, Sloshing effect, SAP 2000

I. INTRODUCTION

All over the world, most of the failures of large water tanks after/during earthquakes are suspected to have resulted from dynamic buckling caused by overturning moments of seismically induced liquid inertia and surface slosh waves and also because of unsuitable design of supporting system or wrong selection of supporting system and underestimated demand or overestimated strength.

A water tower built in accordance with the Intze Principle has a brick shaft on which the water tank sits. The base of the tank is fixed with a ring anchor (Ringanker) made of iron or steel, so that only vertical, not horizontal, forces are transmitted to the tower. Due to the lack of horizontal forces the tower shaft does not need to be quite as solidly built. This type of design was used in Germany between 1885 and 1905

During lateral base excitation seismic ground acceleration reasons hydrodynamic stress at the tank wall which depends at the geometry of tank, top of liquid, homes of liquid and fluid-tank interplay. Proper estimation of hydrodynamic strain calls for a rigorous fluid-shape interaction evaluation. In the mechanical analogue of tank-liquid system, the liquid is split in two components as, impulsive liquid and convective liquid.

Column-Beam type staging is always considered better than RC shaft type staging because of more absorbing capacity of seismic forces and huge redundancy compared to shaft type staging. Column-Beam type staging have more flexural members like beams and columns to absorb heavy lateral loads during seismic action. The failure pattern in such staging to be known earliest, if damage occurs in staging pattern then the forces distributed to other part of the structure, also to be detail as per Indian standard code to resist lateral forces and able to sustain deformation.

II. LITERATURE REVIEW

George Housner et. al., [1963][1]: In 1960 Chilean faces earthquakes, some elevated water tank stand without damage and some tank are damaged heavily. An analysis of such elevated tanks is taken into account movement of liquid relative to tank and movement of tank relative to tank. The simplified dynamic analysis is carried out with simplified expression and to know the exact behaviors of elevated water tank under dynamic loadings.

For structural engineers dynamic analysis of such tanks is very important and such analysis is carried out for empty tank and full tank condition with sloshing effects. For tank with full liquid considered as one-mass structure and the tank with partially filled with liquid considered as two mass structures, behavior of such structure under seismic and sloshing effect is completely different. So therefore proper understanding of dynamic behavior of tank is very important.

Sarvesh K Jain et. al., [1993][2]: Elevated water tank to be analyzed for two degree and single degree of freedom system because the full tank behaves like single mass and partially filled tank behaves like two mass structure. For seismic stability of the water tank the structure to be analyzed for (a) empty condition

(b) full tank condition and (c) partially filled tank condition in partially filled tank due to sloshing of liquid the impulsive and convective hydrodynamic pressure to be applied to tank side walls so the sloshing effect on elevated water tank to considered for optimum design of it.

Durgesh C Rai et. al., [2002] [3]: Circular elevated water tank are more vulnerable to seismic effect. During bhuj earthquake the circular type water tank damaged more due to seismic effects. It is evident from the current Bhuj study they considered staging as building structure but actual seismic behavior is completely different for tank.

So the selection of staging type is very important in analysis, the structure with weak staging results in failure under seismic loading and staging to be detailed according to IS13920 detailing under such circumstances it can withstand.

Sudhir K Jain and O.R.Jaiswal et. al., [2005][4]: By referring international codes Sudhir and Jaiswal proposed some modification in IS 1893-(Part-II),the modification are as follows.

The design horizontal seismic co efficient, response reduction and importance factor to be referred according IS 1893 which is given in table while designing elevated water tank.

The impulsive and convective hydrodynamic pressure to be calculated according to code and spring mass modal to be made for single and two mass modal to know the exact dynamic behavior on tank.

The analysis results to evaluate for critical case with taking the effect of sloshing and permitted board to be given grounded on wave altitude due to sloshing. If permitted board not able to provide then the top dome to be designed for uplift pressure due to sloshing effects.

SUMMARY OF LITERATURE REVIEW

Elevated water tank is analyzed for two degree and single degree of freedom system because the full tank behaves like single mass and partially filled tank behaves like two mass structures. For seismic stability of the water tank the structure is analyzed for (a) empty condition (b) full tank condition and (c) partially filled tank condition in partially filled tank due to sloshing of liquid the impulsive and convective hydrodynamic pressure to be applied to tank side walls so the sloshing effect on elevated water tank is considered in zone 2 and zone 5 for optimum design of it. The effect of sloshing to be considered while designing the elevated water tank. Sufficient permitted board to be allowed based on sloshing wave height. For structural engineers dynamic analysis of such tanks is very important and such analysis is carried out for empty tank and full tank condition with sloshing effects, in this study.

III. OBJECTIVES

This Present study is concentrated on the effects of sloshing on Analysis of Elevated Intze overhead water tank. The objectives of this study are as follows:

1. To study the sloshing impact on circular elevated intze water tank with seismic loading condition according to IS 1893-2002 (Part-II).
2. To consider effect of different staging systems on the overall behaviour of E.S.R. The comprehensive study will be concluded by suitable conclusions based on the results obtained.
3. To study and compare the results which are obtained from SAP 2000 for tank empty, tank with full capacity and tank full capacity with sloshing.
4. To Study the seismic parameters for zone-2 and zone-5.
5. To study the critical load parameters under the following conditions.

a) When tank is empty.
b) When tank is full, by considering hydrostatic forces.
c) When tank is full, by considering sloshing effect.

IV. METHODOLOGY

Following methodology is adopted to analyses elevated intze water tank.

1. R.C.C Elevated intze water tank is considered for the study and it is analyzed in SAP2000 Software.
2. There are six models are considered.
   - A. Water tank subjected to gravity load with empty water.
   - B. Tank subjected to gravity load with full water.
   - C. Tank subjected to seismic load for zone-2.
   - D. Tank subjected to seismic load for zone-5.
   - E. Tank subjected to seismic and sloshing effect for zone-2.
   - F. Tank subjected to seismic and sloshing effect for zone-2.
3. Analyse the models by Equivalent static analysis using IS 1893-2002(Part-II).
4. Initially member sizes are assumed for beam and columns, later member sizes are optimised based on the system adopted.
5. From the Conclusions are made based on the results obtained.

MASS IDEALIZATION:

If elevated water tank is fully filled with liquid then it has been analyzed as one mass structure, if it is partly filled with liquid then it has been analyzed as two mass structure by taking the effect of sloshing movement of liquid and in both the cases the ductile behavior of the structure is completely different. So effect due to sloshing to be taken into account in partly filled liquid tank and spring-mass module to be done for both the cases.

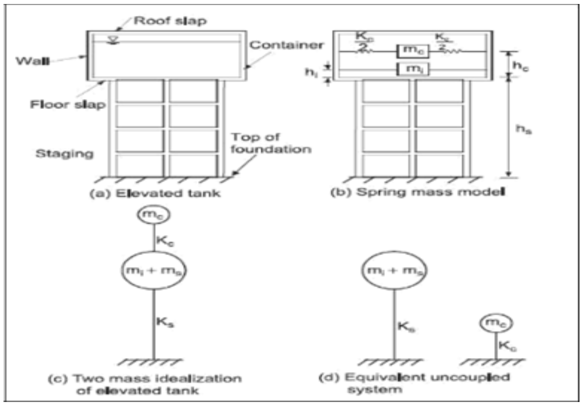

Figure: Two Mass Idealization of Elevated Tank

In the fig shown, the elevated water tanks to be modeled as two uncoupled single degree freedom structure, in which one expressing mass of structure plus impulsive mass behaves like reversed pendulum with stiffness which is equivalent to staging (Ks) and on other side it signifying convective mass with stiffness due to spring(Kc).

For tank shapes like intze, conical other than round and four-sided tank rate of h / D will resemble towards of an comparable round container of similar capacity also dia. equivalent to dia. of chamber at container level of water; & m i , m c , h i, h i*, h c , h c* and K c of equivalent round container will be used.

RECOMMENDATIONS OF IS 1893 PART – II:

1. TIME PERIOD

A) Impulsive Method

Time period of impulsive method, in second specified by

$T_i = 2 \pi ((m_i + m_s)/K_s)\ 0.5$

The toughness of the staging is the lateral energy would be apply to the center of gravity of elevated water storage container to origin equivalent unit lateral movement. The elasticity of braced beam will be measured in manipulating the lateral stiffness (Ks) of water storage tank with moment-resisting frame.

B) Convective Method

Time period of convective method, in second given by

$T_c = 2\pi\ (m_c / K_c)\ 0.5$

mc and Kc value can be obtained from IS 1893 part II for circular and rectangular tanks. Subsequently the mathematical equations for mc and K c are known, the equation for T c can be instead stated such as:

$Tc = Cc\ (D/g)\ 0.5$(Circular tank)

$Tc = Cc\ (L/g)\ 0.5$ (Rectangular tank)

2. DAMPING

Damping will be in use as 0.5 percent of critical for convective method for all kinds of water and for all kinds of storage tanks and for impulsive case damping will be taken as 2 percent of critical damping for steel water storage containers and 5 percent of the critical damping for masonry or concrete water storage containers.

3. HORIZONTAL SEISMIC COEFFICIENT The designed horizontal seismic coefficient, Ah will

acquired from subsequent expression, subject to modifications

$$Ah = \frac{Z\ I}{2\ R} * \frac{Sa}{g}$$

where,

Z = Zone factor given in Table 2 of IS 1893 (Part-II):2002

I = Importance factor given in Table 3.1,

R = Response reduction factor given in Table 3.2, and Sa/g= Average response acceleration coefficient as given by Fig. 2 and Table 3 of IS1893 -Part -II: 2002.

4. SLOSHING WAVE HEIGHT

The amplitude of the sloshing is analytical study of the amount of the ground motion. Wave height due to maximum sloshing is specified as follows,

$d\ max = (A\ h\ )\ c \times R \times D^2$ (Circular tank)

$d\ max\ = (A\ h\ )\ c \times R \times L^2$(rectangular tank)

Where,

D - Inner diameter of circular tank,

L - Circular and Rectangular tank inside length corresponding to the course of earthquake force.

5. HYDRODYNAMIC PRESSURE

During lateral seismic effect, the pressure generated on tank wall is horizontal hydrodynamic pressure and base governed by hydrodynamic pressure in vertical direction.

A) Hydrodynamic Pressure due to impulsive effect (as per IS1893-PartII)

The Pressure generated by impulsive motion of liquid on circular liquid tank wall and base is specified as follows,

$Piw = Q\ iw(y)\ (A\ h\ )\ i\ \rho\ g\ h \cos \varphi$

$Qiw\ (y) = 0.866 \times (1 - (y/h\ )\ ^2) \times \tan h\ (\ 0.866 \times (D/h))$

P iw - Horizontal hydrodynamic impulsive pressure on the wall, ρ – Liquid density, φ – Angle due to Circumferential, y – It is the distance between the point on container wall corresponding to bottommost of container wall.

B) Hydrodynamic Pressure due to convective effect (as per IS1893-PartII) The Pressure generated by convective motion of liquid on circular liquid tank wall and base is specified as follows, Horizontal convective pressure on side barrier p cw, is specified as follows

$Pcw = Qcw\ (y)\ (A\ h\ )c\ \rho\ g\ D\ (1 - \cos^2\varphi\ ) \times \cos \varphi$

The vertical direction pressure due to convective motion of liquid on tank base slab (y = 0)

$Pcb = Q\ cb\ (x) \times (A\ h\ )\ c \times \rho\ g\ D$

V.TANK MODELLING AND LOADING DATA

1. Top dome plate thickness: 150mm
2. Tank wall plate thickness: 200mm
3. Bottom conical dome plate thickness: 300mm
4. Top ring beam dimension: 350*500mm
5. Bottom ring beam dimension: 800*500mm
6. Circular ring beam dimension: 400*500mm
7. Top ring dimension: 350*500mm
8. columns Dimensions : 400*600mm
9. And Of height (including 1m inside GL) : 2600mm
10. Bracings : 300*450mm
11. Water pressure: 49.05KN/m2.
12. Sloshing effect: 3.29KN/m2.

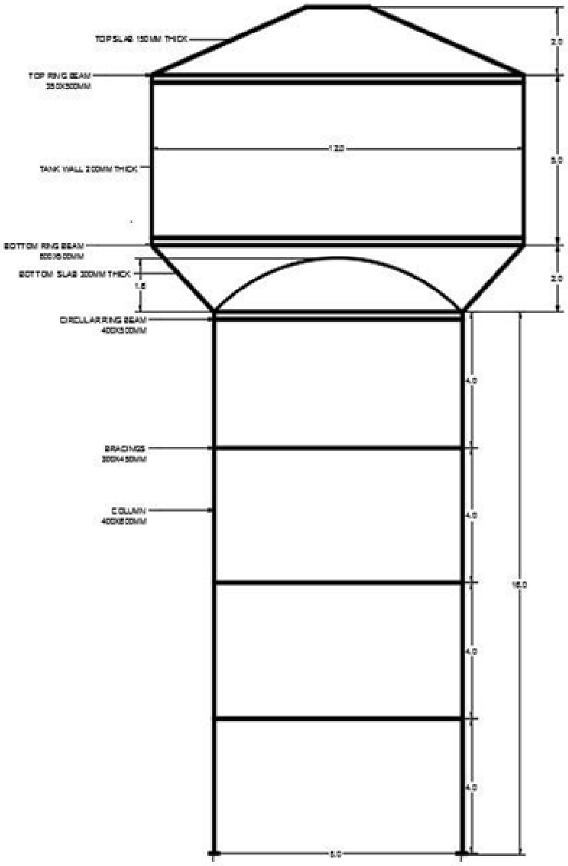

Figure:Cross Sectional elevation of intze water tank with dimensions are in Meters

Analyzed Models in SAP 2000:

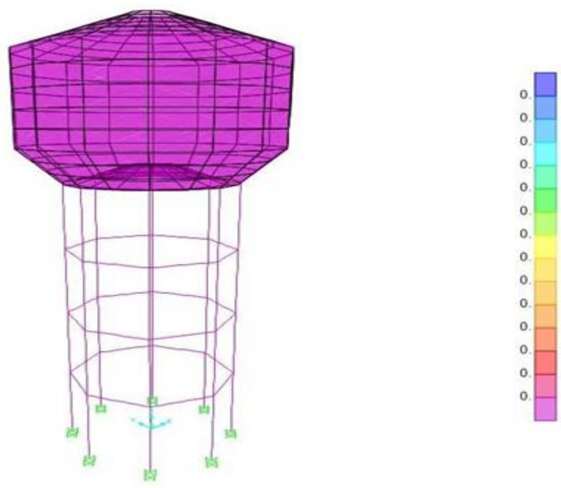

Figure: Deformation of water tank with no water pressure.

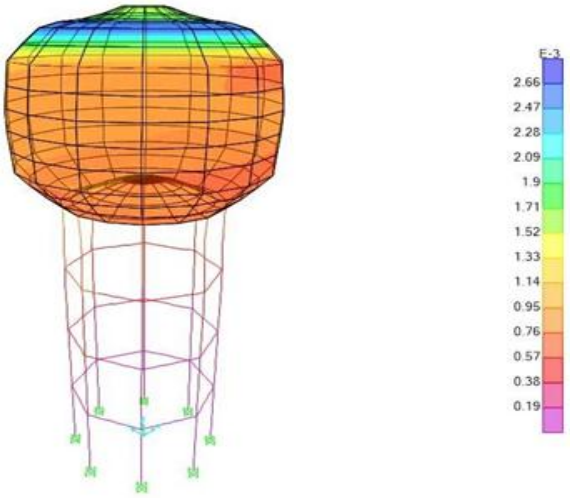

Figure: Deformation of water tank with water pressure

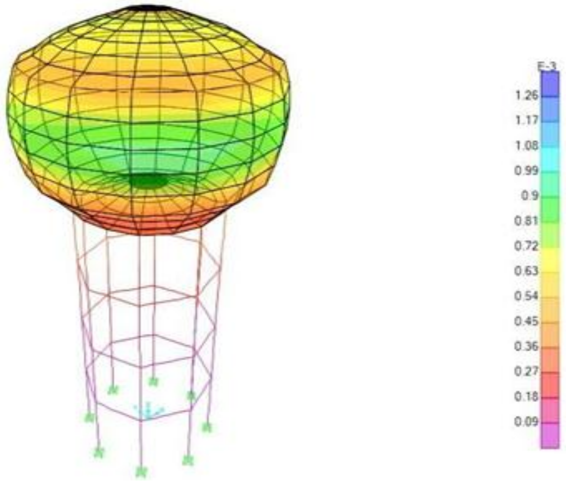

Figure: Deformation of water tank with water pressure in Zone-2.

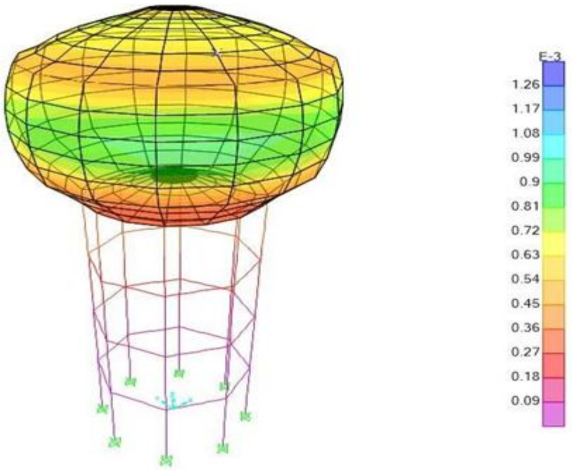

Figure: Deformation of water tank with water pressure in Zone-5.

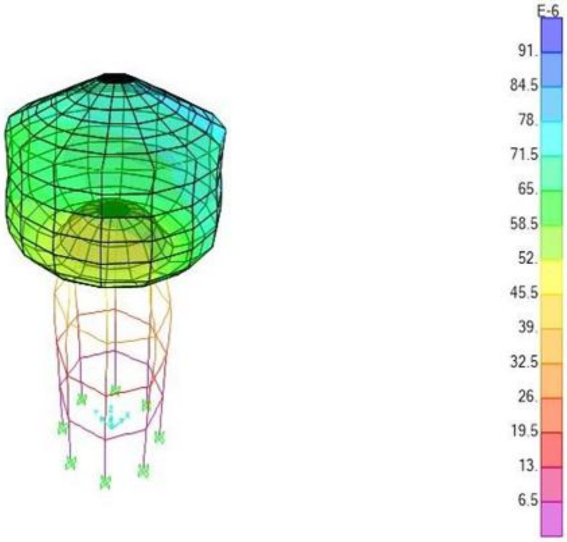

Figure: Deformation of water tank with sloshing in Zone- 5.

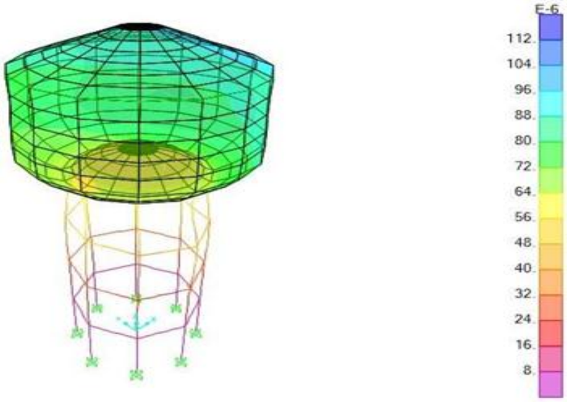

Figure: Deformation of water tank with sloshing in Zone- 2.

VI. RESULTS AND DISCUSSIONS.

[1] SUPPORT REACTIONS

Table: Support reactions of Intze Tank with water pressure and gravity load.

SUPPORT REACTIONS				
Node	Load Condition	Horizontal		Vertical
		Fx KN	Fz KN	Fy KN
780	LOAD CASE 3	0.693	-0.00000332	2523.069
784	LOAD CASE 3	-0.457	-0.18	2521.629
788	LOAD CASE 3	0.555	-0.000002656	2018.455
792	LOAD CASE 3	-6.658E- 07	-0.189	2015.433
796	LOAD CASE 3	-0.274	0.108	1512.978
800	LOAD CASE 3	1490.089	-59.876	536.141
804	LOAD CASE 3	0.002686	228.882	- 0.004654
808	LOAD CASE 3	- 0.0008373	548.195	- 3367.018

Table: Support reactions of Intze Tank with Hydrostatic pressure subjected to seismic load in Zone-2

SUPPORT REACTIONS				
Node	Load Condition	Horizontal		Vertical
		Fx KN	Fz KN	Fy KN
780	LOAD CASE 4	17.186	0.332	1597.721
784	LOAD CASE 4	25.094	-6.551	1641.934
788	LOAD CASE 4	33.616	-0.46	1760.397
792	LOAD CASE 4	25.808	5.975	1864.654
796	LOAD CASE 4	18.059	-0.351	1877.473
800	LOAD CASE 4	26.411	-6.509	1840.617
804	LOAD CASE 4	34.622	0.491	1712.093
808	LOAD CASE 4	25.754	7.072	1610.182

Table: Support reactions of Intze Tank with Hydrostatic pressure subjected to seismic load in Zone-5.

SUPPORT REACTIONS				
Node	Load Condition	Horizontal		Vertical
		Fx KN	Fz KN	Fy KN
780	LOAD CASE 4	-0.425	0.0009525	1787.414
784	LOAD CASE 4	-0.351	-0.286	1788.704
788	LOAD CASE 4	0.001235	-0.46	1760.394
792	LOAD CASE 4	0.363	-0.289	1717.882
796	LOAD CASE 4	0.448	-0.02	1687.794
800	LOAD CASE 4	0.318	0.27	1693.312
804	LOAD CASE 4	-0.017	0.491	1712.102
808	LOAD CASE 4	-0.339	0.293	1757.469

Table: Tank with full capacity by considering sloshing effect in seismic zone-2

SUPPORT REACTIONS				
Node	Load Condition	Horizontal		Vertical
		Fx KN	Fz KN	Fy KN
780	LOAD CASE 4	62.975	1.193	1104.521
784	LOAD CASE 4	91.249	-22.838	1260.33
788	LOAD CASE 4	121.014	-0.46	1760.405
792	LOAD CASE 4	91.963	22.263	2246.26
796	LOAD CASE 4	63.848	-1.212	2370.638
800	LOAD CASE 4	94.251	-24.134	2223.611
804	LOAD CASE 4	124.681	0.492	1712.07
808	LOAD CASE 4	93.594	24.697	1227.235

Table: Tank with full capacity by considering sloshing effect in seismic zone-5

SUPPORT REACTIONS				
Node	Load Condition	Horizontal		Vertical
		Fx KN	Fz KN	Fy KN
780	LOAD CASE 4	-0.642	-102.501	1990.362
784	LOAD CASE 4	34.962	-83.821	2483.574
788	LOAD CASE 4	-0.189	-62.743	2840.848
792	LOAD CASE 4	-35.182	-83.952	2483.168
796	LOAD CASE 4	0.643	-102.658	1990.363
800	LOAD CASE 4	36.092	-83.742	1493.908
804	LOAD CASE 4	0.189	-62.419	1130.933
808	LOAD CASE 4	-35.873	-83.611	1493.504

[2] Critical Beam and Column Staging

Table: Critical beam and column of Intze Tank with water pressure and gravity load

Bea o	Load Case N	Node	Axial force	Shear Force		Bending moment		
			Fx KN	Fy KN	Fz KN	Mx KN-m	My KN-m	Mz KN-m
34	COMBINATION LOAD CASE 4	308	400.502	-73.366	12.401	2.4936	1.0413	-7.2176
32	COMBINATION LOAD CASE 4	310	334.674	231.008	12.493	0.8775	2.4208	-7.1791
40	COMBINATION LOAD CASE 4	315	230.253	-333.741	15.728	5.687	1.1169	-7.0209
38	COMBINATION LOAD CASE 4	312	73.157	398.633	12.399	-0.9396	2.3612	-7.0251
17	COMBINATION LOAD CASE 4	389	50.974	10.131	6.126	-0.3895	1.8615	0.0099
19	COMBINATION LOAD CASE 4	387	43.088	-28.798	6.118	1.038	1.5817	0.0078
8	COMBINATION LOAD CASE 4	391	28.695	42.93	6.128	-1.5905	1.0406	0.01
12	COMBINATION LOAD CASE 4	263	21.921	4.646	91.165	38.9984	-46.0199	-6.5571

Table: Critical beam and column of Intze Tank with Hydrostatic pressure subjected to seismic load in Zone-5.

Be ao	Load Case	Node	Axial force	Shear Force		Bending moment		
			Fx KN	Fy KN	Fz KN	Mx KN-m	My KN-m	Mz KN-m
27	COMBINATION LOADCASE 4	318	444.097	83.056	12.579	-0.6149	-4.2269	4.0898
17	COMBINATION LOAD CASE 4	310	385.635	262.448	11.964	3.7049	-3.2104	-2.9622
33	COMBINATION LOAD CASE 4	311	261.411	383.684	15.871	-2.9904	-0.1603	3.2709
36	COMBINATION LOAD CASE 4	389	122.499	-24.374	6.183	-0.8124	-4.0907	-0.0085
12	COMBINATION LOAD CASE 4	263	111.09	53.589	121.095	68.1267	-92.7989	-14.168
45	COMBINATION LOAD CASE 4	395	102.166	-68.259	6.144	-2.2693	-3.3944	0.0017
6	COMBINATION LOAD CASE 4	269	76.672	33.425	117.373	12.0566	-121.7412	15.2939
96	COMBINATION LOAD CASE 4	787	74.608	-0.472	1717.981	1.3808	159.5419	0.3821

Table: Critical beam and column Tank with full capacity by considering sloshing effect in seismic zone-5

Beam No	Load Case	Node	Axial force	Shear Force		Bending moment		
			Fx KN	Fy KN	Fz KN	Mx KN-m	My KN-m	Mz KN-m
27	COMBINATION LOAD CASE 4	318	448.356	83.778	12.525	0.1336	-6.0496	1.9417
17	COMBINATION LOAD CASE 4	310	404.393	273743	11.237	4.8545	-5.6689	0.0485
33	COMBINATION LOAD CASE 4	311	271.048	399.742	16.353	-4.0653	0.5976	0.7503
12	COMBINATION LOAD CASE 4	263	160.063	81.861	148.597	87.0535	-134.872	-17.977
96	COMBINATION LOAD CASE 4	787	149.183	-0.472	1717.986	1.3807	319.3972	0.761
36	COMBINATION LOAD CASE 4	389	123.243	-24.522	6.234	-0.8194	-4.2077	-0.0087
44	COMBINATION LOADCASE 4	396	120.038	- 23.887	6.236	-0.8431	-3.9723	-0.0109
45	COMBINATION LOAD CASE 4	395	100.79	- 67.338	6.176	-2.3132	- 3.4366	-0.0018

[3] Time Period

Table: Time period for all condition of the intze water tank

MODAL	Tank with hydrostatic load	Tank with no hydro static load	Tank with hydro static load in zone-2	Tank with hydro static load in zone-5	Tank with sloshing and hydro static load in zone- 2	Tank with sloshing and hydro static load in zone-5
1	1.104402	1.1527	1.0419	1.0419	1.52867	1.041942
		47	42	42	6	
		1.0153	0.9352	0.9352	1.29610	
2	0.973363	55	75	75	8	0.935275
		1.0048	0.8950	0.8950	1.12740	
3	0.953234	43	1	1	5	0.89501
		0.1818	0.1717	0.1717	0.21395	
4	0.175719	74	42	42	1	0.171742
		0.1522	0.1394	0.1394	0.15870	
5	0.14625	56	25	25	1	0.139425
		0.1389	0.1352	0.1352	0.14762	
6	0.135817	9	41	41	9	0.135241
		0.1257	0.1213	0.1213	0.12775	
7	0.121612	42	04	04	4	0.121304
		0.1173	0.1131	0.1131	0.12600	
8	0.113868	35	48	48	1	0.113148
		0.1171	0.1039	0.1039	0.11453	
9	0.11376	28	13	13	5	0.103913
		0.1078	0.0972	0.0972		
10	0.104864	6	9	9	0.11439	0.09729
		0.0802	0.0793	0.0793	0.10599	
11	0.079802	43	57	57	1	0.079357
12	0.074098	0.0749	0.0728	0.0728	0.09118	0.072802
		85	02	02	9	

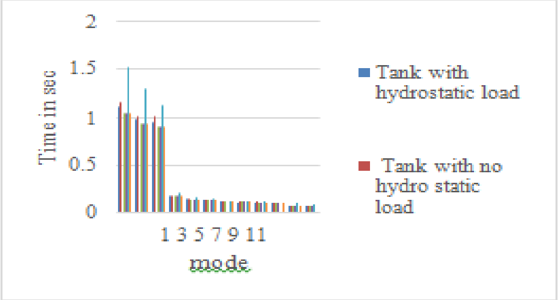

Figure: Plot mode v/s Time Period

VII. CONCLUSIONS

1. From the study on comparing beam elements of tank, the maximum axial force in sloshing case increases nearly by 45% as in hydrostatic case, 28% in shear force and 25% increase of bending moment.
2. On examining the critical elements of staging, the maximum axial force in sloshing case increases nearly as 35% as in hydrostatic case, 25% in shear force and 5% increase of bending moment.
3. From the results obtained 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 as obtained from analysis by considering hydrostatic forces.
4. It is clear that all critical quantities are increasing while considering sloshing effect in our design procedure. In order to avoid the failure much preference to be given to sloshing in earthquake prone region and sufficient free board to be provided to govern the sloshing movement of liquid.

FUTURE SCOPE

1. By the use of advanced software like ABAQUS try to model the exact Sloshing wave formation.
2. To check the effect of Sloshing during Earthquake for more critical soil condition.
3. To analyze about the participation of higher modes due to Sloshing effect in a very detailed manner.
4. What will be the effect in case of altering the geometry of tank, in order to optimize the design.
5. Analyze the different Slosh suppression techniques and suggest he most efficient method of Control of Sloshing.
6. In case of providing of baffle walls, have to find out what is the best suitable material, either concrete or any composite material.
7. How this technique can be applied to other areas where the major problem is sloshing such as fuel tanks of space vehicles, ships, moving tankers.
8. Have to formulate the exact position, shape and the no of baffle walls to be provided.

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