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SEISMIC ANALYSIS OF AN ELEVATED WATER TANK CONSIDERING THE SLOSHING EFFECT

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Abstract - *The main objective of the present study is to evaluate the performance and behaviour of intze type of elevated water tank having radial staging configuration undertaking the parameter like base shear, base moment, top displacement, time period during empty and full tank condition considering the fixity condition. Further the effect of subsoil conditions on the seismic response of the tank has been studied by considering soil structure interaction (SSI). Also, the sloshing effect of liquid in the tank during dynamic loading has been considered.*

The study consists of the analysis and design of the Intze type elevated water tank of capacity 1MLD which is resting 16m above ground level on the staging containing 8 columns. The depth of the foundation is 1.2m below ground level. The location of the tank considered in seismic zone II. Numerical analysis has been carried out using FEM based software SAP 2000. It is observed from the study that the base shear and base moment in full tank condition tank is slightly higher than empty tank due to absence of water load. By providing the free board height of 1.8m which is greater than the sloshing wave height of 0.386 m we can reduce the additional stresses coming on the top dome. Since total base shear and base moment in tank full condition are more than that total base shear and base moment in tank empty condition, design will be governed by tank full condition.

***Key Words*: Sloshing effect, Intze tank, Impulsive pressure, Convective pressure, soil structure interaction.**

1. INTRODUCTION

Water is life line for every kind of creature in this world. All around the world liquid storage tanks are used extensively by municipalities and industries for water supply, firefighting systems, inflammable liquids and other chemicals. Thus, Water tanks plays a vital role for public utility as well as industrial structure having basic purpose to secure constant water supply from longer distance with sufficient static head to the desired location under the effect of gravitational force. Storage reservoirs and overhead tank are used to store water, liquid petroleum, petroleum products and similar liquids. All tanks are designed as crack free structures to eliminate any leakage. Water or raw petroleum retaining slab and walls can be of reinforced concrete with adequate cover to the reinforcement.

In general, there are three kinds of water tanks i.e. tank resting on ground, underground tanks and elevated tanks. Elevated tanks are supported on staging which may consist of masonry walls, R.C.C. tower or R.C.C. columns braced together. The walls are subjected to water pressure. The base has to carry the load of water and tank load. The staging has to carry load of water and tank. The staging is also designed for wind forces. From design point of view the tanks may be classified as per their shape- Rectangular tanks, Circular tanks, Intze type tanks. Spherical tanks conical bottom tanks and suspended bottom tanks. In water retaining structures a dense impermeable concrete is required therefore, proportion of fine and coarse aggregates to cement should be such as to give high quality concrete.

1.1 SEISMIC ANALYSIS OF ELEVATED WATER TANK

Equivalent static analysis of elevated water tanks is the conventional analysis based on the conversion of seismic load in equivalent static load. IS: 1893- 2016 has provided the method of analysis of elevated water tank for seismic loading. Historically, seismic loads were taken as equivalent static accelerations which were modified by various factors, depending on the location's seismicity, its soil properties, the natural frequency of the structure, and its intended use. Elevated water tank can be analysed for both the condition i.e. tank full condition and tank empty condition. For both the condition, the tank can be idealized by one mass structure. For equivalent static analysis, water-structure interaction shows, both water and structure achieve a pick at the same time due to the assumption that water is stuck to the container and acts as a structure itself and both water and structure has same stiffness.

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 was proposed by Housner (1963) and is being commonly used in most of the international codes. Here the entire structure and liquid which is in direct contact with the structure is considered as one mass called impulsive mass and the remaining liquid portion is considered as other mass called convective mass.

Gaikwad Madhukar and Mangulkar Madhuri (2013), Ankita Patel and BalChandra (2014), Neha Walde, Sakshi Manchalwar et al (2015), Abhijeet Babar and Jadhav (2016), Prashant Bansode et al. (2017), Ajmal Tokhi and Sahil Arora (2019) and many more have carried out studies on elevated water tank considering different staging conditions, different zonal conditions, different tank shapes and capacities. However, the effect of sloshing of water due to hydrodynamic nature deserves the performance of water tanks.

2. SCOPE AND OBJECTIVES

1. The proposed work involves the study on seismic behaviour of elevated water tank considering sloshing effects due to water.
2. Further analysis will be carried out for tank empty and full condition.

The objectives of the proposed study are
1. To evaluate the dynamic displacement of water tank subjected to ground motion using response spectrum analysis.
2. To evaluate the associated base shear due to dynamic loading.
3. Analyse the tank considering the soil structure interaction effects

3. MODELLING AND ANALYSIS

The study consists of the analysis and design of the Intze type of elevated water tank of capacity 1MLD which is resting 16m above ground level on the staging with 8 columns. The depth of the foundation is 1.2m below ground level. M30 grade concrete and Fe415 grade steel are considered as material properties. The location of the tank is considered in seismic zone II.

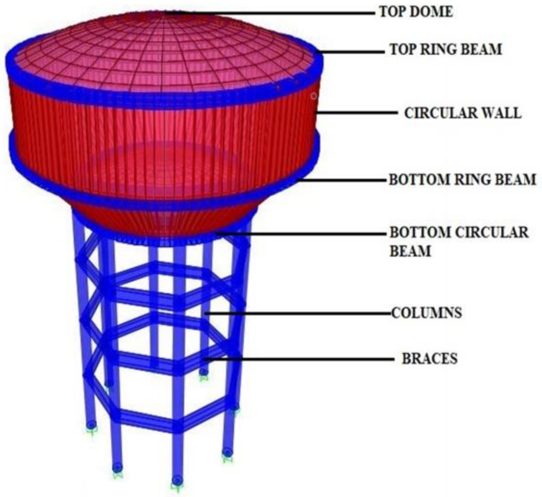

Fig -1: Intze tank

Table -1: Details of sizes of various components obtained from design.

Components	**Sizes(mm)**	**Calculations**	**Weight (KN)**
Top dome	100 thick	$2\pi\times9.35\times1.8\times0.1\times25$	264.36
Top ring beam	500×410	$\pi\times16.4\times0.5\times0.41\times25$	264.05
Wall	300 thick	$\pi\times16\times0.3\times4\times25$	1507.97
Bottom ring beam 1	1000×600	$\pi\times16.4\times0.6\times1\times25$	772.83
Conical dome	500 thick	$\pi\times(6.9+5.3)\times\sqrt{(6.9-5.3)^2+3^2}\times0.5\times25$	1628.91
Bottom dome	280 thick	$2\pi\times4.305\times1.6\times0.28\times25$	108.19
Bottom circular beam	700×1200	$\pi\times10.6\times0.7\times1.2\times25$	699.31
Columns	700 dia	$\frac{\pi}{4}\times(0.7)^2\times16\times8\times25$	1231.50
Braces	300×700	$0.3\times0.7\times4.05\times24\times25$	510.3
Water		$\frac{\pi}{4}\times16^2\times4\times9.81+(V_{cone}-V_{Bdome})\times9.81$	11053.63

Table -2: Parameters after numerical analysis for full tank condition

MODES	**IMPULSIVE**	**CONVECTIVE**
TIME PERIOD	1.19 sec	4.15 sec
DESIGN HORIZONTAL SEISMIC COEFFICIENT	0.028	0.014
BASE SHEAR	339.81 KN	70.987 KN
BASE MOMENT	7192.903 KNm	1533.310 KNm

Table -3: Parameters after numerical analysis for empty tank condition

TIME PERIOD	0.883 sec
DESIGN HORIZONTAL SEISMIC COEFFICIENT	0.0395
BASE SHEAR	234.592 KN
BASE MOMENT	4683.261 KNm

Table -4: hydrodynamic pressure calculations for full tank condition

Hydrodynamic pressure calculations	1. Impulsive pressure on wall =1.45 KN/m² 2. Impulsive pressure on slab base=1.082 KN/m² 3. Convective pressure on wall = 0.709 KN/m² 4. Convective pressure on slab base =0.219 KN/m²
Pressure due to inertia of wall.	0.195 KN/m²
Pressure due to vertical excitation.	2.14 KN/m²
Maximum hydrodynamic pressure.	2.708 KN/m²
Hydrostatic pressure. $\rho \times g \times h$	68 KN/m²

4. Analysis results of the elevated water tank

4.1 Empty tank condition for fixed base model.

Here the analysis is carried out by considering only the dead load and its combination. All the column supports are fixed. Response spectrum and time history analysis for the 2001 Bhuj earthquake data is carried out on the model.

In the below cases all the displacements are measured with respect to the top most center point of the tank which is also called as crown point.

The following results are obtained from the analysis of the various models.

Table-5: Modal time period and frequencies obtained for empty tank case

TABLE: Modal Periods And Frequencies

OutputCase	StepType	StepNum	Period	Frequency	CircFreq	Eigenvalue
Text	Text	Unitless	Sec	Cyc/sec	rad/sec	rad2/sec2
MODAL	Mode	1	0.941105	1.06258018	6.676388173	44.57415904
MODAL	Mode	2	0.941105	1.06258018	6.676388173	44.57415904
MODAL	Mode	3	0.941077	1.062612376	6.67659047	44.57686031
MODAL	Mode	4	0.135709	7.368707562	46.29895509	2143.593242
MODAL	Mode	5	0.135709	7.368707562	46.29895509	2143.593242
MODAL	Mode	6	0.116802	8.561464097	53.79326542	2893.715405
MODAL	Mode	7	0.116728	8.566911197	53.82749056	2897.39874
MODAL	Mode	8	0.106104	9.424697116	59.21711845	3506.667117
MODAL	Mode	9	0.106104	9.424697116	59.21711845	3506.667117
MODAL	Mode	10	0.10229	9.776129895	61.42523572	3773.059583
MODAL	Mode	11	0.089652	11.15421481	70.08399864	4911.766865
MODAL	Mode	12	0.089652	11.15421482	70.08399864	4911.766865

Table-6: Base shear and base moments obtained for empty tank for RS (Response spectrum) case

TABLE: Base Reactions

OutputCase	CaseType	StepType	StepNum	GlobalFX	GlobalFY	GlobalFZ	GlobalMX	GlobalMY	GlobalMZ
Text	Text	Text	Unitless	KN	KN	KN	KN-m	KN-m	KN-m
DEAD	LinStatic			5.929E-10	3.352E-10	8551.183	45321.2691	-45321.2691	-8.036E-10
MODAL	LinModal	Mode	1	1256.376	167.673	-4.328E-07	-3068.1492	22989.6533	-5770.132
MODAL	LinModal	Mode	2	167.673	-1256.376	-1.518E-07	22989.6533	3068.1492	-7547.4664
MODAL	LinModal	Mode	3	-0.0009594	0.0004799	-4.167E-08	-0.0088	-0.0176	-8715.1706
MODAL	LinModal	Mode	4	4504.998	-8617.759	0.001786	-209273.217	-109399.187	-69550.6075
MODAL	LinModal	Mode	5	8617.756	4504.996	0.002073	109399.1882	-209273.246	-21797.6365
MODAL	LinModal	Mode	6	-0.002228	-0.001925	-0.002175	-0.0226	-0.0216	-0.0433
MODAL	LinModal	Mode	7	-0.003471	0.005886	-0.003713	-0.0126	0.0174	0.0799
MODAL	LinModal	Mode	8	-13683.42	-148.868	-0.015	3284.4315	-301906.961	71733.1188
MODAL	LinModal	Mode	9	-148.864	13683.42	0.03	-301906.801	-3284.6855	73311.1374
MODAL	LinModal	Mode	10	-0.0005491	-0.002343	-0.038	-0.3228	0.1555	-115626.301
MODAL	LinModal	Mode	11	-10.286	18.121	-0.003331	-45.6098	-25.8366	150.5435
MODAL	LinModal	Mode	12	-18.112	-10.277	0.05	26.4968	-45.7987	41.5933
EQX	LinStatic			-283.235	-5.092E-10	-2.869E-09	2.469E-09	-5487.6917	1501.1467
EQY	LinStatic			-5.239E-10	-283.235	-2.051E-09	5487.6917	-6.195E-09	-1501.1467
RSX	LinRespSpec	Max		283.042	0.000002916	0.000008925	0.00006971	5180.2043	1500.1209
RSY	LinRespSpec	Max		0.000001782	283.042	0.00001603	5180.2043	0.00006409	1500.1209

Table-7: Displacement of crown point (Joint 35) for empty tank for RS case

TABLE: Joint Displacements

Joint	OutputCase	CaseType	StepType	StepNum	U1	U2	U3	R1	R2	R3
Text	Text	Text	Text	Unitless	m	m	m	Radians	Radians	Radians
35	DEAD	LinStatic			-1.9E-14	-1E-14	-0.00239	-9.6E-17	-6E-17	-2.2E-11
35	MODAL	LinModal	Mode	1	-0.03733	-0.00498	-1.4E-12	0.000027	-0.0002	3.66E-09
35	MODAL	LinModal	Mode	2	-0.00498	0.037334	-5.2E-13	-0.0002	-2.7E-05	2.49E-09
35	MODAL	LinModal	Mode	3	2.85E-08	-1.4E-08	2.12E-13	7.75E-11	1.56E-10	0.005227
35	MODAL	LinModal	Mode	4	0.015667	-0.02997	3.29E-09	0.004663	0.002438	1.49E-13
35	MODAL	LinModal	Mode	5	0.02997	0.015667	9.44E-10	-0.00244	0.004663	-2.5E-11
35	MODAL	LinModal	Mode	6	3.09E-09	-3.5E-10	1.95E-09	2.95E-10	-1.1E-08	-7.3E-11
35	MODAL	LinModal	Mode	7	-1.3E-09	3.59E-09	5.13E-09	8.05E-09	7.29E-09	8.01E-11
35	MODAL	LinModal	Mode	8	0.021239	0.000231	7.22E-09	-5.9E-05	0.005392	2.27E-11
35	MODAL	LinModal	Mode	9	0.000231	-0.02124	-3.2E-09	0.005392	0.000059	-2E-11
35	MODAL	LinModal	Mode	10	2.53E-10	-2.7E-09	9.31E-09	-6.9E-09	-4E-09	-0.00089
35	MODAL	LinModal	Mode	11	-3.2E-07	5.44E-07	1.78E-08	2.43E-06	1.38E-06	-4.3E-12
35	MODAL	LinModal	Mode	12	-5.4E-07	-3.1E-07	-1.1E-07	-1.4E-06	2.43E-06	2.74E-11
35	EQX	LinStatic			0.008666	1.21E-14	6.79E-16	-1.2E-12	0.000051	-5.5E-14
35	EQY	LinStatic			2.29E-14	0.008666	3.63E-16	-5.1E-05	-1.2E-12	2.75E-14
35	RSX	LinRespSp	Max		0.008401	2.05E-11	4.3E-12	6.47E-12	0.000046	3.8E-13
35	RSY	LinRespSp	Max		2.06E-11	0.008401	3.3E-12	0.000046	1.66E-12	1.91E-13

Table-8: Base shear and base moments obtained for empty tank for TH (Time History) case

TABLE: Base Reactions

OutputCase	CaseType	StepType	StepNum	GlobalFX	GlobalFY	GlobalFZ	GlobalMX	GlobalMY	GlobalMZ
Text	Text	Text	Unitless	KN	KN	KN	KN-m	KN-m	KN-m
DEAD	LinStatic			5.929E-10	3.352E-10	8551.183	45321.2691	-45321.2691	-8.036E-10
MODAL	LinModal	Mode	1	1256.376	167.673	-4.328E-07	-3068.1492	22989.6533	-5770.132
MODAL	LinModal	Mode	2	167.673	-1256.376	-1.518E-07	22989.6533	3068.1492	-7547.4664
MODAL	LinModal	Mode	3	-0.0009594	0.0004799	-4.167E-08	-0.0088	-0.0176	-8715.1706
MODAL	LinModal	Mode	4	4504.998	-8617.759	0.001786	-209273.217	-109399.187	-69550.6075
MODAL	LinModal	Mode	5	8617.756	4504.996	0.002073	109399.1882	-209273.246	-21797.6365
MODAL	LinModal	Mode	6	-0.002228	-0.001925	-0.002175	-0.0226	-0.0216	-0.0433
MODAL	LinModal	Mode	7	-0.003471	0.005886	-0.003713	-0.0126	0.0174	0.0799
MODAL	LinModal	Mode	8	-13683.42	-148.868	-0.015	3284.4315	-301906.961	71733.1188
MODAL	LinModal	Mode	9	-148.864	13683.42	0.03	-301906.801	-3284.6855	73311.1374
MODAL	LinModal	Mode	10	-0.0005491	-0.002343	-0.038	-0.3228	0.1555	-115626.301
MODAL	LinModal	Mode	11	-10.286	18.121	-0.003331	-45.6098	-25.8366	150.5435
MODAL	LinModal	Mode	12	-18.112	-10.277	0.05	26.4968	-45.7987	41.5933
EQX	LinStatic			-283.235	-5.092E-10	-2.869E-09	2.469E-09	-5487.6917	1501.1467
EQY	LinStatic			-5.239E-10	-283.235	-2.051E-09	5487.6917	-6.195E-09	-1501.1467
THX	NonModHist	Max		283.233	0.00000344	0.00001295	0.0001042	5610.606	714.3869
THX	NonModHist	Min		-134.79	-0.000002414	-0.000006307	-0.00004749	-2596.6647	-1501.136
THY	NonModHist	Max		0.000002257	283.233	0.00002421	2596.6648	0.00004461	1501.1361
THY	NonModHist	Min		-0.000001624	-134.79	-0.00001111	-5610.6059	-0.0000969	-714.3869

Table-9: Displacement of crown point for empty tank for TH case

TABLE: Joint Displacements										
Joint	OutputCase	CaseType	StepType	StepNum	U1	U2	U3	R1	R2	R3
Text	Text	Text	Text	Unitless	m	m	m	Radians	Radians	Radians
35	DEAD	LinStatic			-1.9E-14	-1E-14	-0.00239	-9.6E-17	-6E-17	-2.2E-11
35	MODAL	LinModal	Mode	1	-0.03733	-0.00498	-1.4E-12	0.000027	-0.0002	3.66E-09
35	MODAL	LinModal	Mode	2	-0.00498	0.037334	-5.2E-13	-0.0002	-2.7E-05	2.49E-09
35	MODAL	LinModal	Mode	3	2.85E-08	-1.4E-08	2.12E-13	7.75E-11	1.56E-10	0.005227
35	MODAL	LinModal	Mode	4	0.015667	-0.02997	3.29E-09	0.004663	0.002438	1.49E-13
35	MODAL	LinModal	Mode	5	0.02997	0.015667	9.44E-10	-0.00244	0.004663	-2.5E-11
35	MODAL	LinModal	Mode	6	3.09E-09	-3.5E-10	1.95E-09	2.95E-10	-1.1E-08	-7.3E-11
35	MODAL	LinModal	Mode	7	-1.3E-09	3.59E-09	5.13E-09	8.05E-09	7.29E-09	8.01E-11
35	MODAL	LinModal	Mode	8	0.021239	0.000231	7.22E-09	-5.9E-05	0.005392	2.27E-11
35	MODAL	LinModal	Mode	9	0.000231	-0.02124	-3.2E-09	0.005392	0.000059	-2E-11
35	MODAL	LinModal	Mode	10	2.53E-10	-2.7E-09	9.31E-09	-6.9E-09	-4E-09	-0.00089
35	MODAL	LinModal	Mode	11	-3.2E-07	5.44E-07	1.78E-08	2.43E-06	1.38E-06	-4.3E-12
35	MODAL	LinModal	Mode	12	-5.4E-07	-3.1E-07	-1.1E-07	-1.4E-06	2.43E-06	2.74E-11
35	EQX	LinStatic			0.008666	1.21E-14	6.79E-16	-1.2E-12	0.000051	-5.5E-14
35	EQY	LinStatic			2.29E-14	0.008666	3.63E-16	-5.1E-05	-1.2E-12	2.75E-14
35	THX	NonModH	Max		0.004194	3.01E-12	3.9E-12	8.96E-12	0.000023	1.01E-13
35	THX	NonModH	Min		-0.00856	-2.2E-12	-5.8E-12	-5.8E-12	-5.4E-05	-1.3E-13
35	THY	NonModH	Max		9.53E-13	0.004194	2.6E-12	0.000054	1.02E-12	6.74E-14
35	THY	NonModH	Min		-6.9E-13	-0.00856	-3.3E-12	-2.3E-05	-1.8E-12	-5.1E-14

4.2 Full tank condition for fixed base model.

For tank full condition water pressure is applied on the tank wall. Here both impulsive and convective hydrodynamic pressures are calculated and are applied on the wall and base slab of the tank. Proper freeboard should be provided while applying these pressures. Then both response spectrum and time history analysis is carried out for water load and its combinations.

The following results are obtained from the analysis of the various models in Sap 2000

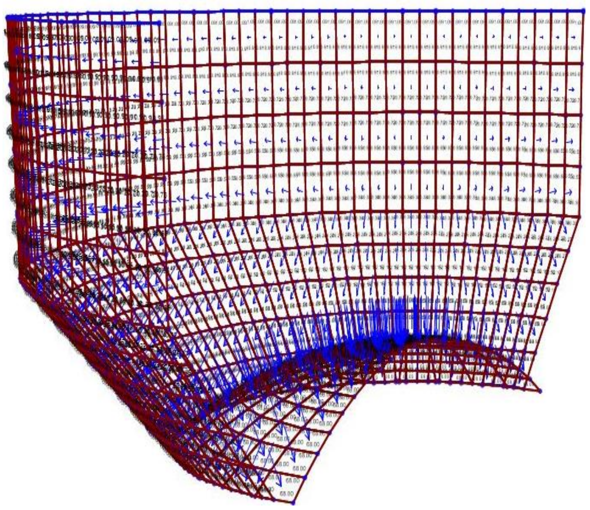

Fig -2: Sectional view of the tank subjected to water pressure

Table-10: Modal time period and frequencies obtained for full tank case

TABLE: Modal Periods And Frequencies						
OutputCase	StepType	StepNum	Period	Frequency	CircFreq	Eigenvalue
Text	Text	Unitless	Sec	Cyc/sec	rad/sec	rad2/sec2
MODAL	Mode	1	1.548771	0.645673081	4.056883615	16.45830467
MODAL	Mode	2	1.548771	0.645673081	4.056883615	16.45830467
MODAL	Mode	3	1.372201	0.728756285	4.578910781	20.96642394
MODAL	Mode	4	0.169713	5.892302659	37.02242949	1370.660286
MODAL	Mode	5	0.169713	5.892302659	37.02242949	1370.660286
MODAL	Mode	6	0.131567	7.600662071	47.75636825	2280.670708
MODAL	Mode	7	0.116743	8.565824576	53.82066312	2896.663779
MODAL	Mode	8	0.116743	8.565824576	53.82066312	2896.663779
MODAL	Mode	9	0.116612	8.575424154	53.88097905	2903.159903
MODAL	Mode	10	0.11654	8.580776059	53.91460606	2906.784746
MODAL	Mode	11	0.103067	9.702417052	60.96208426	3716.375718
MODAL	Mode	12	0.089573	11.16407549	70.14595506	4920.455011

Table-11: Base shear and base moments obtained for full tank for RS (Response spectrum) case

TABLE: Base Reactions									
OutputCase	CaseType	StepType	StepNum	GlobalFX	GlobalFY	GlobalFZ	GlobalMX	GlobalMY	GlobalMZ
Text	Text	Text	Unitless	KN	KN	KN	KN-m	KN-m	KN-m
DEAD	LinStatic			-7.134E-10	-2.13E-10	8551.183	45321.2691	-45321.2691	2.395E-09
MODAL	LinModal	Mode	1	-747.943	122.385	0.00001236	-2158.8335	-13193.4331	4612.7413
MODAL	LinModal	Mode	2	-122.385	-747.943	3.165E-08	13193.433	-2158.8336	-3315.4552
MODAL	LinModal	Mode	3	-1.304E-07	1.096E-07	-1.574E-07	-7.314E-07	5.922E-07	-5908.5515
MODAL	LinModal	Mode	4	-2.05	3525.431	-0.003278	260261.6687	151.3234	18695.6359
MODAL	LinModal	Mode	5	-3525.452	-2.045	-0.001341	-151.3252	260261.5903	18674.0343
MODAL	LinModal	Mode	6	0.006695	0.005807	104776.278	555314.2718	-555314.19	0.0575
MODAL	LinModal	Mode	7	-8556.391	-13370.053	-0.017	115553.3813	-73950.3374	-25512.4049
MODAL	LinModal	Mode	8	13370.047	-8556.404	0.009085	73950.4603	115553.4065	-116210.261
MODAL	LinModal	Mode	9	-0.001806	-0.003466	-0.002809	-0.0222	-0.0396	-0.0258
MODAL	LinModal	Mode	10	-0.004554	-0.004447	0.003376	-0.0192	-0.0645	-0.0652
MODAL	LinModal	Mode	11	-0.004124	0.001322	-0.009694	-0.074	-0.0559	115060.6957
MODAL	LinModal	Mode	12	-7.88	-1.923	0.037	-74.972	307.0679	31.6349
HYDRO STATIC PRESSURE	LinStatic			-1.287E-09	-3.304E-10	12876.829	68247.1961	-68247.1961	4.679E-09
EQX	LinStatic			-353.353	1.866E-09	5.977E-09	-1.481E-08	-7818.1304	2291.9636
EQY	LinStatic			1.874E-09	-353.353	1.635E-09	7818.1304	3.682E-08	-2291.9636
RSX	LinRespSpec	Max		351.271	0.00001403	0.00002185	0.00009171	7624.6153	2291.035
RSY	LinRespSpec	Max		0.000004378	351.271	0.00001252	7624.6153	0.00009132	2291.035

Table-12: Displacement of crown point for full tank for RS case

TABLE: Joint Displacements - Absolute										
Joint	OutputCa	CaseType	StepType	StepNum	U1	U2	U3	R1	R2	R3
Text	Text	Text	Text	Unitless	m	m	m	Radians	Radians	Radians
35	DEAD	LinStatic			2.29E-14	6.3E-15	-0.00254	-4.5E-16	-3.4E-17	-2.3E-11
35	MODAL	LinModal	Mode	1	0.022507	-0.00368	-7.7E-12	0.000018	0.000113	4.98E-14
35	MODAL	LinModal	Mode	2	0.003683	0.022507	6.06E-14	-0.00011	0.000018	3.93E-16
35	MODAL	LinModal	Mode	3	7.37E-14	-5.4E-14	6.63E-14	-5.2E-14	6.89E-15	0.003585
35	MODAL	LinModal	Mode	4	-0.00002	0.034302	-1E-08	-0.00501	-2.9E-06	5.86E-12
35	MODAL	LinModal	Mode	5	-0.0343	-0.00002	-2.8E-08	2.91E-06	-0.00501	-3.7E-12
35	MODAL	LinModal	Mode	6	6.2E-09	1.17E-11	-0.02661	-4.1E-10	-2.6E-09	-1.9E-10
35	MODAL	LinModal	Mode	7	0.003754	0.005866	-1.1E-09	-0.00131	0.000839	6.61E-11
35	MODAL	LinModal	Mode	8	-0.00587	0.003754	8.05E-09	-0.00084	-0.00131	2.84E-11
35	MODAL	LinModal	Mode	9	-3.1E-09	3.65E-10	-2.1E-08	-2.1E-09	-3.1E-09	5.95E-12
35	MODAL	LinModal	Mode	10	-2.3E-09	2.43E-09	5.71E-09	-2.1E-09	-4.7E-09	3.66E-11
35	MODAL	LinModal	Mode	11	-5.5E-09	3.51E-10	-1.8E-08	-1.2E-09	2.48E-09	0.000421
35	MODAL	LinModal	Mode	12	-4.8E-05	-1.2E-05	8.95E-09	2.11E-06	-8.7E-06	1.69E-12
35	HYDRO ST.	LinStatic			4.11E-14	9.73E-15	-0.00276	-4.9E-16	7.81E-17	-1.2E-13
35	EQX	LinStatic			0.013156	-6.4E-14	-1.2E-15	-7.7E-13	0.000068	-1.8E-15
35	EQY	LinStatic			-5.7E-14	0.013156	-3.5E-16	-6.8E-05	-7.7E-13	3.69E-16
35	RSX	LinRespSp	Max		0.013	2.88E-11	2.58E-11	5.52E-12	0.000065	3.5E-14
35	RSY	LinRespSp	Max		2.8E-11	0.013	1.01E-11	0.000065	5.16E-12	6.16E-14

Table-13: Base shear and base moments obtained for full tank for TH (Time History) case

TABLE: Base Reactions

OutputCase	CaseType	StepType	StepNum	GlobalFX	GlobalFY	GlobalFZ	GlobalMX	GlobalMY	GlobalMZ
Text	Text	Text	Unitless	KN	KN	KN	KN-m	KN-m	KN-m
DEAD	LinStatic			-7.134E-10	-2.13E-10	8551.183	45321.2691	-45321.2691	2.395E-09
MODAL	LinModal	Mode	1	-747.943	122.385	0.00001236	-2158.8335	-13193.4331	4612.7413
MODAL	LinModal	Mode	2	-122.385	-747.943	3.165E-08	13193.433	-2158.8336	-3315.4552
MODAL	LinModal	Mode	3	-1.304E-07	1.096E-07	-1.574E-07	-7.314E-07	5.922E-07	-5908.5515
MODAL	LinModal	Mode	4	-2.05	3525.431	-0.003278	260261.6687	151.3234	18695.6359
MODAL	LinModal	Mode	5	-3525.452	-2.045	-0.001341	-151.3252	260261.5903	18674.0343
MODAL	LinModal	Mode	6	0.006695	0.005807	104776.278	555314.2718	-555314.19	0.0575
MODAL	LinModal	Mode	7	-8556.391	-13370.053	-0.017	115553.3813	-73950.3374	-25512.4049
MODAL	LinModal	Mode	8	13370.047	-8556.404	0.009085	73950.4603	115553.4065	-116210.261
MODAL	LinModal	Mode	9	-0.001806	-0.003466	-0.002809	-0.0222	-0.0396	-0.0258
MODAL	LinModal	Mode	10	-0.004554	-0.004447	0.003376	-0.0192	-0.0645	-0.0652
MODAL	LinModal	Mode	11	-0.004124	0.001322	-0.009694	-0.074	-0.0559	115060.6957
MODAL	LinModal	Mode	12	-7.88	-1.923	0.037	-74.972	307.0679	31.6349
HYDRO STATIC PRESSURE	LinStatic			-1.287E-09	-3.304E-10	12876.829	68247.1961	-68247.1961	4.679E-09
EQX	LinStatic			-365.35	1.866E-09	5.977E-09	-1.481E-08	-7818.1304	2291.9636
EQY	LinStatic			1.874E-09	-365.35	1.635E-09	7818.1304	3.682E-08	-2291.9636
THX	NonModHist	Max		364.444	0.000009787	0.0000352	0.0001546	7855.5541	1371.9744
THX	NonModHist	Min		-258.863	-0.000008836	-0.00003554	-0.0001363	-4787.2677	-2291.9524
THY	NonModHist	Max		0.000004852	364.444	0.00002072	4787.2676	0.0001868	2291.9524
THY	NonModHist	Min		-0.00000419	-258.863	-0.00002393	-7855.5539	-0.0001896	-1371.9744

Table-14: Displacement of crown point for full tank for TH case

TABLE: Joint Displacements

Joint	OutputCase	CaseType	StepType	StepNum	U1	U2	U3	R1	R2	R3
Text	Text	Text	Text	Unitless	m	m	m	Radians	Radians	Radians
35	MODAL	LinModal	Mode	1	0.022507	-0.00368	-7.7E-12	0.000018	0.000113	4.98E-14
35	MODAL	LinModal	Mode	2	0.003683	0.022507	6.06E-14	-0.00011	0.000018	3.93E-16
35	MODAL	LinModal	Mode	3	7.37E-14	-5.4E-14	6.63E-14	-5.2E-14	6.89E-15	0.003585
35	MODAL	LinModal	Mode	4	-0.00002	0.034302	-1E-08	-0.00501	-2.9E-06	5.86E-12
35	MODAL	LinModal	Mode	5	-0.0343	-0.00002	-2.8E-08	2.91E-06	-0.00501	-3.7E-12
35	MODAL	LinModal	Mode	6	6.2E-09	1.17E-11	-0.02661	-4.1E-10	-2.6E-09	-1.9E-10
35	MODAL	LinModal	Mode	7	0.003754	0.005866	-1.1E-09	-0.00131	0.000839	6.61E-11
35	MODAL	LinModal	Mode	8	-0.00587	0.003754	8.05E-09	-0.00084	-0.00131	2.84E-11
35	MODAL	LinModal	Mode	9	-3.1E-09	3.65E-10	-2.1E-08	-2.1E-09	-3.1E-09	5.95E-12
35	MODAL	LinModal	Mode	10	-2.3E-09	2.43E-09	5.71E-09	-2.1E-09	-4.7E-09	3.66E-11
35	MODAL	LinModal	Mode	11	-5.5E-09	3.51E-10	-1.8E-08	-1.2E-09	2.48E-09	0.000421
35	MODAL	LinModal	Mode	12	-4.8E-05	-1.2E-05	8.95E-09	2.11E-06	-8.7E-06	1.69E-12
35	HYDRO ST.	LinStatic			4.11E-14	9.73E-15	-0.00276	-4.9E-16	7.81E-17	-1.2E-13
35	EQX	LinStatic			0.013156	-6.4E-14	-1.2E-15	-7.7E-13	0.000068	-1.8E-15
35	EQY	LinStatic			-5.7E-14	0.013156	-3.5E-16	-6.8E-05	-7.7E-13	3.69E-16
35	THX	NonModH	Max		0.008047	9.46E-12	2.68E-11	4.96E-12	0.000042	1.99E-14
35	THX	NonModH	Min		-0.01341	-6.4E-12	-3.1E-11	-5.6E-12	-6.8E-05	-4E-14
35	THY	NonModH	Max		9.36E-12	0.008047	1.03E-11	0.000068	9.21E-12	1.19E-13
35	THY	NonModH	Min		-7E-12	-0.01341	-1.4E-11	-4.2E-05	-7.7E-12	-1E-13

4.3 Soil structure interaction

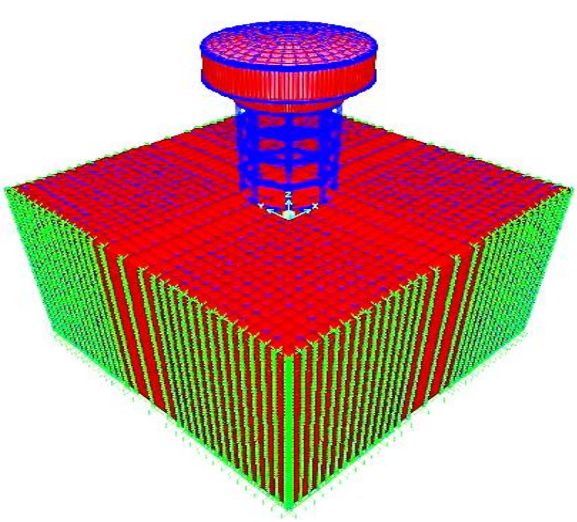

Fig -3: Intze tank with soil model

Soil is modelled by considering the soft clay with the unit weight 16 kN/m³ and modulus of elasticity E = 15000 kN/m² with Poisson ratio ν = 0.4.

Here the raft footing is provided at the depth of 1.2m from the ground level, thickness of the raft is 0.6m.

Here also response spectrum and time history analysis is carried out for both empty and full tank condition and the results obtained are as below.

Table-15: Modal period and frequencies for empty tank during SSI analysis

TABLE: Modal Periods And Frequencies

OutputCase	StepType	StepNum	Period	Frequency	CircFreq	Eigenvalue
Text	Text	Unitless	Sec	Cyc/sec	rad/sec	rad2/sec2
MODAL	Mode	1	1.588786	0.629411391	3.954708404	15.63971856
MODAL	Mode	2	1.588786	0.629411391	3.954708404	15.63971856
MODAL	Mode	3	1.07345	0.931575633	5.853262332	34.26067993
MODAL	Mode	4	1.07345	0.931575633	5.853262333	34.26067993
MODAL	Mode	5	1.053626	0.949103388	5.963392464	35.56204967
MODAL	Mode	6	0.978775	1.021684805	6.419434957	41.20914517
MODAL	Mode	7	0.976605	1.023955917	6.433704772	41.39255709
MODAL	Mode	8	0.900771	1.110160286	6.975342797	48.65540713
MODAL	Mode	9	0.801996	1.24688842	7.834431	61.3783091
MODAL	Mode	10	0.784991	1.273899899	8.004149125	64.06640322
MODAL	Mode	11	0.768372	1.301453129	8.17727118	66.86776395
MODAL	Mode	12	0.768372	1.301453129	8.177271181	66.86776396

Table-16: Base shear and Base moment for empty tank for SSI analysis

TABLE: Base Reactions

OutputCase	CaseType	StepType	StepNum	GlobalFX	GlobalFY	GlobalFZ	GlobalMX	GlobalMY	GlobalMZ
Text	Text	Text	Unitless	KN	KN	KN	KN-m	KN-m	KN-m
DEAD	LinStatic			1.477E-07	1.301E-07	1064770.79	56432.18	-56432.2	2.891E-07
MODAL	LinModal	Mode	1	-226.234	-44.945	-2.516E-05	4610.673	-23206.835	960.8227
MODAL	LinModal	Mode	2	44.947	-226.233	-1.357E-05	23206.8486	4610.6374	-1437.2598
MODAL	LinModal	Mode	3	-420.085	-1759.357	0.0003789	-69826.573	1669.4556	1297.8933
MODAL	LinModal	Mode	4	-1759.366	420.094	-0.001083	166973.508	6982.9003	3162.1112
MODAL	LinModal	Mode	5	0.032	-0.034	0.0002358	-0.3199	-0.4434	11390.6377
MODAL	LinModal	Mode	6	0.007051	0.015	0.014	0.4037	-0.4466	0.2805
MODAL	LinModal	Mode	7	-0.004864	-0.006529	-0.007987	-0.2516	0.2223	-15711.089
MODAL	LinModal	Mode	8	-0.005216	0.03	14280.312	75685.8899	-7568.5295	0.0057
MODAL	LinModal	Mode	9	0.075	-0.082	-2527.22	-13394.986	1339.3647	-0.8679
MODAL	LinModal	Mode	10	-0.005718	0.008318	-0.011	0.0847	0.1426	-1.0209
MODAL	LinModal	Mode	11	-1203.299	-3359.698	-0.0004993	-294.5223	1054.5292	4600.1805
MODAL	LinModal	Mode	12	-3359.658	1203.224	-0.01	1053.4927	293.6312	8161.3037
RSX	LinRespSpec	Max		309.102	0.071	0.029	1.2112	5675.2202	18207.3227
RSY	LinRespSpec	Max		0.083	309.921	0.028	453753.019	1.7768	18207.4544
EQX	LinStatic			-317.744	-1.31E-08	-9.363E-08	4.331E-08	5692.913	22110.3451
EQY	LinStatic			-1.89E-08	-317.744	-8.709E-08	-5692.913	3.366E-08	-22110.345
THX	NonModHist	Max		320.671	0.074	0.022	1.2016	5377.4103	15363.3498
THX	NonModHist	Min		-289.67	-0.075	-0.042	-1.2964	-5056.83	-29161.603
THY	NonModHist	Max		0.097	320.419	0.028	5056.6686	1.8664	29161.8078
THY	NonModHist	Min		-0.083	-289.526	-0.016	-5377.34	-1.6072	-15363.466

Table-17: Displacement of crown point for empty tank for SSI case

TABLE: Joint Displacements										
Joint	OutputCa:	CaseType	StepType	StepNum	U1	U2	U3	R1	R2	R3
Text	Text	Text	Text	Unitless	m	m	m	Radians	Radians	Radians
35	DEAD	LinStatic			-1.3E-11	-1.2E-11	-0.27321	3.02E-13	-3.3E-13	-2.2E-11
35	MODAL	LinModal	Mode	1	0.04008	0.007963	-1.4E-10	-0.00021	0.001049	6.24E-12
35	MODAL	LinModal	Mode	2	-0.00796	0.04008	-8E-11	-0.00105	-0.00021	1.51E-12
35	MODAL	LinModal	Mode	3	0.006771	0.002832	-3.2E-09	-3.2E-05	0.000077	7.83E-11
35	MODAL	LinModal	Mode	4	0.002832	-0.00677	-3.9E-09	0.000077	0.000032	1.62E-10
35	MODAL	LinModal	Mode	5	1.31E-09	9.11E-09	1.93E-09	-1.2E-09	-8.7E-10	-0.00402
35	MODAL	LinModal	Mode	6	4.69E-09	7.07E-09	5.45E-09	-4E-10	-6.7E-10	-3.8E-10
35	MODAL	LinModal	Mode	7	-1.3E-10	-7.8E-10	-7.1E-09	-3.1E-10	5.78E-10	-0.00327
35	MODAL	LinModal	Mode	8	-1.6E-09	-4.5E-09	-0.0057	2.53E-10	7.77E-10	3.18E-10
35	MODAL	LinModal	Mode	9	-1.8E-09	6.15E-09	-0.00674	-1.7E-09	-1.7E-09	-5.4E-10
35	MODAL	LinModal	Mode	10	-2.9E-09	-7.5E-09	-5.3E-09	1.97E-09	6.48E-10	1.99E-09
35	MODAL	LinModal	Mode	11	-0.0031	-0.00087	1.76E-09	0.000088	-0.00031	-5.5E-11
35	MODAL	LinModal	Mode	12	-0.00087	0.003101	-3.7E-10	-0.00031	-8.8E-05	-2.7E-09
35	RSX	LinRespSp	Max		0.026295	1.36E-08	4.62E-08	2.49E-09	0.00094	1.61E-08
35	RSY	LinRespSp	Max		1.36E-08	0.026295	3.95E-08	0.00094	6.6E-09	1.68E-08
35	EQX	LinStatic			0.210008	2.14E-12	2.86E-13	-7E-12	0.004818	-1.2E-12
35	EQY	LinStatic			2.07E-12	0.210008	2.6E-13	-0.00482	-6.9E-12	5.11E-13
35	THX	NonModH	Max		0.016658	2.21E-08	4.29E-08	2.3E-09	0.000964	1.31E-08
35	THX	NonModH	Min		-0.02934	-1.1E-08	-5E-08	-3.3E-09	-0.00119	-1.7E-08
35	THY	NonModH	Max		6.86E-09	0.016658	4.51E-08	0.00119	7.08E-09	1.54E-08

Table-18: Modal period and frequencies for full tank during SSI analysis

TABLE: Modal Periods And Frequencies						
OutputCase	StepType	StepNum	Period	Frequency	CircFreq	Eigenvalue
Text	Text	Unitless	Sec	Cyc/sec	rad/sec	rad2/sec2
MODAL	Mode	1	1.891714	0.528621134	3.321424543	11.031861
MODAL	Mode	2	1.888605	0.529491344	3.326892234	11.06821194
MODAL	Mode	3	1.373655	0.727984829	4.574063581	20.92205764
MODAL	Mode	4	1.373477	0.728079174	4.574656371	20.92748091
MODAL	Mode	5	1.351629	0.739847991	4.648602026	21.6095008
MODAL	Mode	6	1.078856	0.926907762	5.823933229	33.91819826
MODAL	Mode	7	1.075201	0.930058659	5.843730901	34.14919084
MODAL	Mode	8	0.970768	1.030112241	6.472386098	41.89178181
MODAL	Mode	9	0.862197	1.159827742	7.287412631	53.10638285
MODAL	Mode	10	0.825173	1.211867087	7.614385478	57.97886621
MODAL	Mode	11	0.808352	1.237084834	7.772833256	60.41693682
MODAL	Mode	12	0.808345	1.237095547	7.772900566	60.41798321

Table-19: Base shear and Base moment for full tank for SSI analysis

TABLE: Base Reactions									
OutputCase	CaseType	StepType	StepNum	GlobalFX	GlobalFY	GlobalFZ	GlobalMX	GlobalMY	GlobalMZ
Text	Text	Text	Unitless	KN	KN	KN	KN-m	KN-m	KN-m
DEAD	LinStatic			-6.347E-08	2.113E-08	106476.809	56431.61	-56432	4.39E-07
MODAL	LinModal	Mode	1	164.399	-164.401	0.29	1657.1325	1657.0666	-1742.6307
MODAL	LinModal	Mode	2	163.711	163.71	0.00009082	-1672.0277	16721.0212	-14.5001
MODAL	LinModal	Mode	3	-3221.861	3221.863	-1.495	12797.729	127989.497	3415.667
MODAL	LinModal	Mode	4	3224.495	3224.503	-7.734E-05	12797.9608	-127974.83	-470.3571
MODAL	LinModal	Mode	5	16.169	16.169	0.0006137	637.2829	-637.2632	11722.6136
MODAL	LinModal	Mode	6	-5.165	5.165	2.944	163.4765	132.4092	54.6674
MODAL	LinModal	Mode	7	1.561	1.571	0.003596	91.9069	-91.7829	-15466.352
MODAL	LinModal	Mode	8	-1.515	1.542	14279.698	7571.0573	-75646.483	16.1851
MODAL	LinModal	Mode	9	5.108	-5.126	2531.755	1331.4061	-13519.886	-53.8886
MODAL	LinModal	Mode	10	-28.316	-28.217	0.004597	18.501	-17.1782	9.1681
MODAL	LinModal	Mode	11	8840.551	-8840.492	0.424	-804.6099	-809.9075	-9370.08
MODAL	LinModal	Mode	12	8837.717	8837.731	0.004214	774.5428	-774.5021	-16.4042
HYDRO STATIC PRESSURE	LinStatic			-9.021E-09	3.031E-09	12876.829	68247.1961	-68247.196	6.134E-08
EQX	LinStatic			-417.396	1.055E-08	5.515E-08	-1.568E-07	12634.2846	22110.3332
EQY	LinStatic			1.109E-08	-417.396	-1.931E-08	-12634.285	5.596E-07	-22111.262
RSX	LinRespSpec	Max		405.44	20.943	7.648	652.3358	11352.0666	21481.7971
RSY	LinRespSpec	Max		20.965	405.348	7.635	11352.16	663.354	21480.6882
THX	NonModHist	Max		411.957	68.4	190.298	1689.3844	11384.52	69293.38
THX	NonModHist	Min		-393.309	-63.5	-191.029	-1772.4315	-11455.5	-61988.3
THY	NonModHist	Max		68.115	411.722	190.739	11656.6	1822.7603	62036.75
THY	NonModHist	Min		-63.401	-393.309	-189.803	-1438	-1673.1083	-69247.6

Table-20: Displacement of crown point for full tank for SSI case

TABLE: Joint Displacements										
Joint	OutputCas	CaseType	StepType	StepNum	U1	U2	U3	R1	R2	R3
Text	Text	Text	Text	Unitless	m	m	m	Radians	Radians	Radians
35	DEAD	LinStatic			-0.00019	0.000187	-0.27337	-6.7E-06	-6.7E-06	-2.3E-11
35	MODAL	LinModal	Mode	1	-0.02893	0.028926	-1.5E-05	-0.00076	-0.00076	3.64E-12
35	MODAL	LinModal	Mode	2	-0.02891	-0.02891	5.3E-10	0.000757	-0.00076	5.24E-06
35	MODAL	LinModal	Mode	3	0.00515	-0.00515	9.68E-06	0.000059	0.000059	1.75E-10
35	MODAL	LinModal	Mode	4	-0.00519	-0.00519	3.86E-09	0.000059	-5.9E-05	0.000022
35	MODAL	LinModal	Mode	5	-6.1E-05	-6.1E-05	4.21E-09	2.14E-06	-2.1E-06	-0.00396
35	MODAL	LinModal	Mode	6	0.000027	-2.7E-05	-8.9E-06	3.06E-07	3.07E-07	2.16E-10
35	MODAL	LinModal	Mode	7	-2.6E-05	-2.6E-05	5.86E-09	1.4E-06	-1.4E-06	-0.00337
35	MODAL	LinModal	Mode	8	6.72E-06	-6.7E-06	-0.00571	2.67E-08	2.74E-08	5.49E-11
35	MODAL	LinModal	Mode	9	-2.8E-05	0.000028	0.00675	-3.2E-08	-3.2E-08	-5E-10
35	MODAL	LinModal	Mode	10	-2.6E-05	-2.6E-05	1.46E-08	2.3E-06	-2.3E-06	9.68E-06
35	MODAL	LinModal	Mode	11	0.002281	-0.00228	3.02E-06	0.000231	0.000231	-5.9E-10
35	MODAL	LinModal	Mode	12	0.00229	0.00229	-4.7E-09	-0.00023	0.000231	-3.1E-06
35	HYDRO ST.	LinStatic			-0.00032	0.000321	-0.03924	-1.2E-05	-1.2E-05	-1.2E-13
35	EQX	LinStatic			0.210329	-0.00045	0.000045	0.000018	0.004835	-1.3E-05
35	EQY	LinStatic			-0.00045	0.210329	-4.5E-05	-0.00484	-1.8E-05	-1.3E-05
35	RSX	LinRespSp	Max		0.03108	0.000306	0.000025	7.93E-06	0.001112	0.000016
35	RSY	LinRespSp	Max		0.000306	0.03108	0.000025	0.001112	7.93E-06	0.000016
35	THX	NonModH	Max		0.771181	0.004948	0.000781	0.000122	0.030674	0.000489
35	THX	NonModH	Min		-0.73249	-0.00472	-0.0007	-0.00012	-0.02705	-0.00053

6. CONCLUSIONS

Base shear and base moment in full condition tank is slightly higher than empty tank due to absence of water pressure. By providing the free board height of 1.8m which is greater than the sloshing wave height of 0.386 m we can reduce the additional stresses coming on the top dome.Since total base shear (347.33 kN) and base moment (7354.75 kN-m) in tank full condition are more than that total base shear (234.592 kN) and base moment (4683.261 kN-m) in tank empty condition, design will be governed by tank full condition.

For the applied Bhuj earthquake data maximum displacement of the crown point in case of soil structure model is found to be around 770mm at 44.40 sec for tank full condition and around 650mm at 44.40 sec for empty condition. The additional deflection in tank full condition is due to hydrodynamic pressure induced in the structure due to sloshing effect.

The maximum hydrodynamic pressure obtained is 2.708 kN/m2 which is about 3 % of hydrostatic pressure at base ($\rho g h$ = 1,000 x 9.81 x 7.0 = 68 kN/m^2). In practice, container of tank is designed by working stress method. When earthquake forces are considered, permissible stresses are increased by 33%. Hence, hydrodynamic pressure in this case does not affect container design.

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