International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 8 Issue 09, September-2019

A Study of Hydrodynamic Behaviour of Liquid in Overhead Tank As Per Is 1893-Part Ii (2014)

[1]Vinod Sharma, Aamir Mirza Biag[2]
[2] Guide Name
Al-Falah School of Engineering And Technology
Department of Civil Engineering
Al-Falah University
Dhauj, Faridabad, Haryana, (India)

***Abstract*:- This paper presents dynamic analysis of elevated water tanks supported on RC framed structure with water storage capacity. Effects of hydrodynamic forces on tank walls are calculated. History of earthquake reveals that it have caused numerous losses to the life of people in its active time, and also post-earthquake time have let people suffer due to damages caused to the public utility services. Either in urban or rural areas elevated water tanks forms integral part of water supply scheme, so its functionality pre and post-earthquake remains equally important. These structures have heavy mass concentrated at the top of slender supporting structure hence these structures are especially vulnerable to horizontal forces due to earthquakes. Objective paper is to understand the dynamic behavior of elevated water tanks under earthquake loading using latest Indian code IS 1893(part 2):2014. Parameters from seismic analysis of elevated water tanks including sloshing effects are calculated, lateral stiffness of frame staging is calculated using latest STAAD Pro Connect edition software.**

Keywords : Convective Hydrodynamic Pressure, Elevated Water Tank, Impulsive Hydrodynamic Pressure, Sloshing Wave Height, STAAD Pro connect edition.

I INTRODUCTION

1.1 General

Indian sub-continent is highly vulnerable to natural disasters like earthquake, draughts, floods, cyclones etc. According to IS code 1893 (Part 1):2016, more than 60% of India is prone to earthquakes. The earthquake of 26 January 2010 in Gujarat was unprecedented for the entire country, then public learnt first time that the scale of disaster could have been far lower had the construction in the region compiled with codes of practice for earthquake prone regions. These natural calamities are causing many casualties and innumerable property loss every year. After an earthquake the loss which cannot be recovered are the life loss. Collapse of structure causes people to life loss. Hence badly constructed structures kill people more than earthquake itself. Hence it becomes important to analyze the structures properly.

Seismic safety of liquid storage tanks is of considerable importance, as tanks storing highly concentrated liquids in industries, or in transporting vehicles, ships can cause considerable harm for human society if damaged. Water supply being the lifeline facility must remain functional following disaster to carter the need of drinking and firefighting. These structures have large mass concentrated at the top of slender supporting structure hence these structure are especially vulnerable to horizontal forces due to earthquake as they act as the inverted pendulum like structure.

Keeping these problems in consideration 'Bureau of Indian Standards' have published code especially for liquid retaining structures, 'Criteria for earthquake resistant design of structures' IS 1893(Part 2) : 2014 based on the guidelines and suggestions by IITK-GSDMA for seismic design of liquid storage tanks. This paper evaluates all the seismic analysis parameters using the recommended procedure in latest code as well as in IIT-GSDMA guidelines, and is concentrated mainly to the Sloshing effect that is happening in the water during earthquake. Sloshing is defined as the periodic motion of the free liquid surface in partially filled container. It is caused by any disturbance to partially filled containers. If the liquid is allowed to slosh freely, it can produce additional hydrodynamic pressure in case of storage tanks. Hence considerations of these forces are necessary, during analysis.

1.2 Literature Review

A Much of literature has been presented in the form of technical papers till date on dynamic analysis of elevated water tanks RC framed supported and concrete shaft supported. Different points are covered in that relevance
i.e. dynamic analysis, sloshing effect on tank, dynamic response of framed staging etc. Some of them are listed below.

George W. Housner [1]: Chilean earthquake that took place in 1960 was the main plot behind this paper. He stated about the relation between motion of water w.r.t tank and whole structure w.r.t ground. Fully filled tank, empty tank, partially filled tank, were the three cases considered by him. Sloshing effect was neglected in first two cases as there is no free board in first case and other no water to cause sloshing motion. Here the whole structure behaves as one-mass structure. But in the third case sloshing effect must be considered, because here the structure behaves as two-mass structure. Concluding he stated that the maximum force to which a half-filled tank can be subjected is less than that of totally filled tank.

Dr. Suchita Hirde & Manoj Hedaoo [2]: Hydrodynamic analysis of elevated water tanks for various heights, capacity and soil conditions. The effect of height of water tank, earthquake zones and soil conditions on earthquake forces have been presented in this paper. They considered RCC circular tank with M-20 grade of concrete and Fe-415 grade of steel for analysis. Capacity of 50,000 lit and 100.000 with staging height of 12m, 16m, 20m, 28m with 4m height of panel are considered for analysis. Following were the conclusions made in the paper (1) Seismic forces are directly proportional to the seismic zones. (2) Seismic forces are inversely proportional to the height of the supporting system. (3) Seismic forces increase with increase in capacity of tank. (4) Seismic forces are higher in soft soil than that of medium and higher in medium soil than that of hard.

R Livaoglu & Dogangun [3]: This paper presents the response of the supporting system of water towers. Here they have considered frame staging as well as concrete shaft as supporting system for elevated water tanks. In this paper they concluded that where there is high risk of seismic force, the cylindrical shaft support system may be used because of having important advantages than the common used frame type system. They also found that roof displacement response for frame support is higher than that of concrete shaft support system.

Sudhir K Jain, O.R. Jaiswal [4]: Recognizing the limitations and shot comings in the provision of IS code 1893- 1984, this paper recommends the changes, (1) Different spring-mass model for tanks with rigid & flexible wall are done away with instead, a single spring-mass model for both types of tank is proposed. (2) Simple expression for sloshing height is given (3) Design horizontal seismic coefficient given in revised IS: 1893 (Part- I)-2002 is used and values of response reduction factor for different types of tanks are proposed.

1.3 Objective

The main objective of this paper is to study the hydrodynamic effect on elevated water tank, with h/d ratio of the tank constant for different capacities. Here 'h' is the maximum height of water in tank and 'D' is the internal diameter of tank

2. SYSTEM DEVELOPMENT

2.1 Impulsive and Convective mass

During an earthquake, elevated water tank with free liquid surface is subjected to horizontal ground motion, and liquid in tank as well as tank wall are subjected to horizontal acceleration. Here the liquid in the lower region of the tank behaves like a mass that is rigidly connected to tank wall. This mass is stated as impulsive liquid mass (m_i), which accelerates along with the wall and induces impulsive hydrodynamic pressure on tank wall as well as base. Liquid mass in the upper region on the tank undergoes sloshing motion. This mass is stated as convective liquid mass (m_c) and it exerts convective hydrodynamic pressure on tank wall and base. Thus the total liquid mass gets divided into two parts i.e. impulsive mass and convective mass. These mass are suitably represented in spring mass model.

A qualitative description of impulsive and convective hydrodynamic pressure distribution on tank wall is given in Figure 1

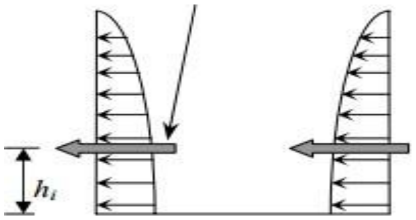


Fig.1a) Impulsive pressure on wall

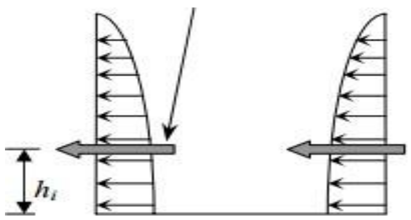


Fig.1b) Impulsive pressure on wall and base

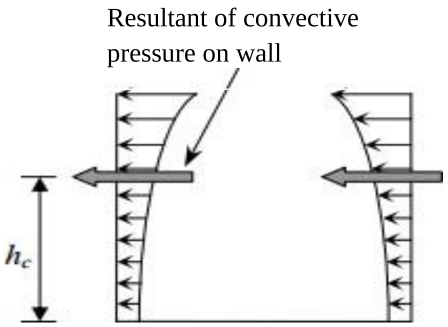


Fig.1c) Convective pressure on wall

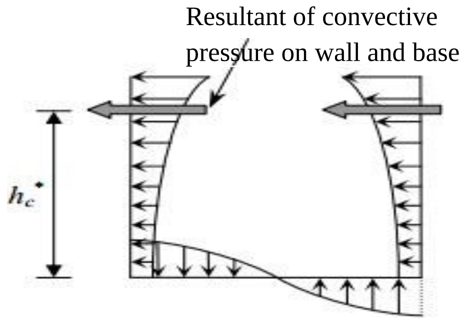


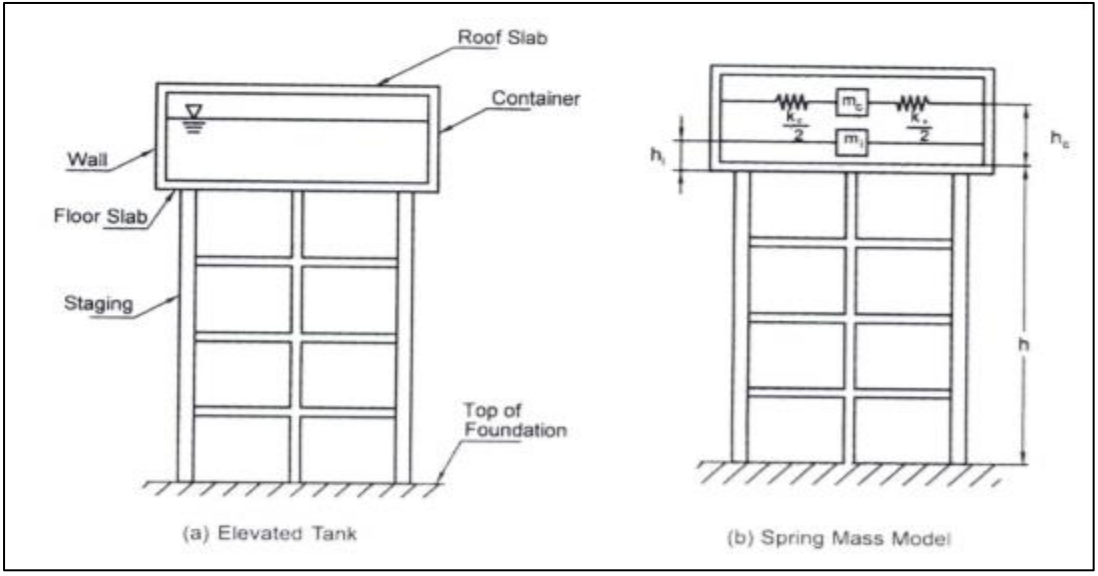
Fig.1d) Convective pressure on wall and base

Resultant of impulsive pressure on wall and base

Resultant of impulsive pressure on wall

2.2 *Spring mass model for seismic analysis of elevated tank*

Most of the elevated tanks are partially filled. Hence two-mass idealization of the tank is more appropriate than one-mass model. It is also being commonly used in international codes. The response of two-degree of freedom system can be obtained by elementary structural dynamics. However, two periods are well separated for most of the tanks. Hence, system can be considered as two uncoupled single degree of freedom system. This two uncoupled single degree of freedom systems, one representing impulsive plus structural mass behaving as an inverted pendulum with lateral stiffness equal to the stiffness of staging, (k_s) and the other convective mass with spring of stiffness, (k_c).



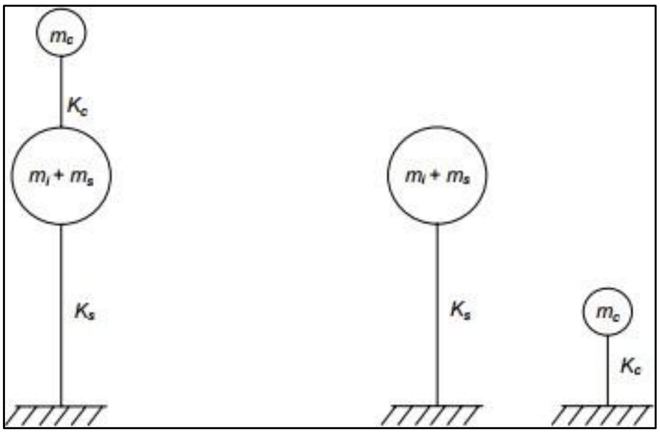


Fig.2a) Two-mass idealization of elevated tank

Fig.2b) Equivalent uncoupled system

2.3 *Lateral stiffness of staging*

Lateral stiffness of staging is defined as the force required to be applied at the CG of tank so as to get a corresponding unit deflection. From the deflection of CG of tank due to an arbitrary lateral force one can get stiffness of staging. STAAD pro software is used to model the staging.

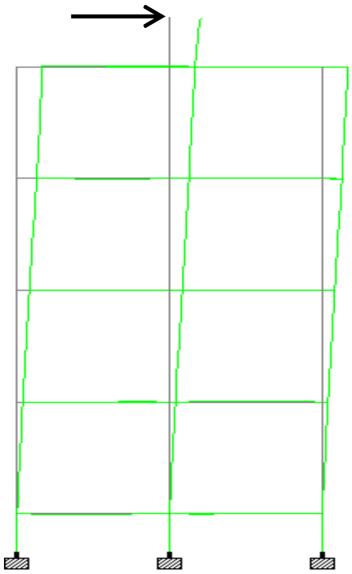


Fig.3 Deflected shape of tank staging

2.4 Numerical problem considered

Dynamic analysis of Circular elevated water tanks, supported on RC frame staging and following specifications are performed with respect to the procedure recommended in IS 1893 (Part 2): 2014 for zone III.As the capacity increases the number of columns supporting are increased. A 1.0 m wide gallery is considered around the periphery of all tanks for access. Grade of concrete, grade of steel and soil condition for circular elevated tanks are M-30, Fe500 and medium soil respectively. Tank is provided a free board of 500mm.

Here, H = Lowest supply level from ground, D= Internal diameter of tank, h= Height of water in tank from bottom of wall, N= Number of columns, where as, the ratio of H/D and h/D is kept constant for all capacities of tank.

Table 1: Geometrical Specifications.

Capacity	**H**	**D**	**h**	**D/h**	**h/D**
(m^3)	(m)	(m)	(m)	-	-
1050	13	18	4.13	4.36	0.23

Table 2: Constants.

Sr No.	**Constant**	**Values**
1	Seismic intensity (Zone III)	0.16 (as per IS code 1893 Part 1)
2	Importance factor (I)	1.5
3	Response reduction factor (R)	2.5 (as per IS code 1893 Part 2)

Table 3: Components Sizes.

Sr No.	**Component**	**Sizes (mm)**
1	Roof Dom	150
2	Cylindrical wall	200
3	Base slab	200
4	Roof beams	400 x 450
5	Floor beams	400 x 600
6	Braces	300 x 500
7	Gallery	150
8	Columns	500
9	Main beams	500 x 1000
10	Conical dome	375
11	Bottom Raft	750

3.0 ANALYSIS PARAMETERS

3.1 Time period

Time period in impulsive mode (T_i) and time period in convective mode of vibration (T_c) is calculated and compared with capacities of tank. Since the tank is analyzed for both tank full and tank empty condition the values of time period in tank empty condition is also stated below.

Time period in Impulsive mode Ti

$$T_i = 2\pi\sqrt{\frac{m_i + m_s}{K_s}}$$

Where mi = Mass of impulsive liquid.
ms = Mass of empty container and 1/3 rd mass of staging.
Ks = Lateral stiffness of staging.

Time period in convective mode Tc

$$T_c = C_c\sqrt{\frac{D}{\rho}}$$

3.2 Design Horizontal Seismic Coefficient

Design Horizontal Seismic coefficient is given by :

$$A_h = \frac{Z}{2}\frac{I}{R}\left(\frac{S_a}{g}\right)$$

Z	=	Zone Factor	0.16 for Zone III.
I	=	Importance factor	1.5
R	=	Response reduction factor	2.5

3.3 Base shear

Total base shear (V), the horizontal force which acts at the bottom at the staging is resultant of two different case base shears, one for impulsive mode (V_i) and for convective mode (V_c). It represents the increase in base shear with increase in capacity of tank. Base shear in tank empty case is mostly less than that of tank full condition

Base Shear in impulsive mode Vi = (A_h)i $(m_i$ + ms) g

Base Shear in convective mode Vc = $(A_h)_c\, m_c\, g$

Total base shear V = SQRT(Vi2 + Vc2)

3.4 Base Moment:

Since the large mass accumulation at the top of slender supporting system, the overturning moment is the important parameter at the time of designing elevated water tank.

Overturning moment in impulsive mode at base of staging is given by

M_i = $(A_h)_i\, [\, m_i\, (h_i + h_s) + m_s h_{cg}\,]\, g$

Overturning moment in convective mode

Mc = $(A_h)_c\, m_c\, (h_{cg} + h_s)\, g$

Where

hs = Structural height of staging, measured from top of footing of staging to the bottom of tank wall.
h_{cg} = Height of c.g of the empty container of elevated tank, measured from Top of footing.
Total moment M = SQRT ($M_i^2 + M_c^2$)

3.5 Hydrodynamic force

Maximum hydrodynamic force per unit circumferential length for impulsive (qi) and convective mode (qc) is given below. This force in actual is non-linearly distributed on tank wall. For uniform distribution, equivalent pressure distribution can be considered. Further these forces will be actually applied in software for designing the elevated tank.

3.5.1 Impulsive Hydrodynamic Pressure on wall

$$p_{iw}(y) = Q_{iw}(y)(A_h)_i \rho g h \cos \varnothing$$

$$Q_{tw}(y) = 0.866[1 - (y/h)^2]\tanh\ (0.866\ D/h)$$

No.	y/h	Y	Qiw	Piw
1	0	0.00	0.865	1.64
3	0.2	0.83	0.830	1.57
4	0.3	1.24	0.787	1.49
5	0.4	1.65	0.727	1.38
6	0.5	2.07	0.649	1.23
7	0.6	2.48	0.554	1.05
8	0.7	2.89	0.441	0.84
9	0.8	3.30	0.311	0.59
10	0.9	3.72	0.164	0.31
11	1	4.13	0.000	0.00

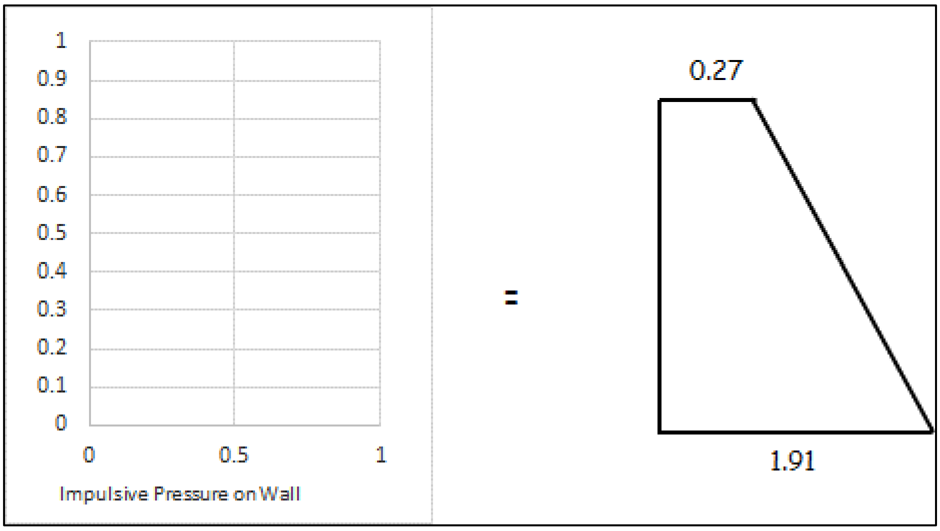
Base shear due to impulsive liquid mass per unit circumferential length, q_i

$$q_i = \frac{(A_h)_i m_i g}{\pi D/2}$$

Pressure at Bottom and Top is given by:

$$a_i = \frac{q_i}{h^2}(4h - 6h_i)$$

$$b_i = \frac{q_i}{h^2}(6h_i - 2h)$$



Impulsive hydrodynamic pressure on the base slab (y=0)

$$P_{ib} = 0.866(A_h)_i \rho g h \sinh(1.732\, x/h)\, /\cosh(0.866\; l'/h)$$

3.5.2 <u>Convective hydrodynamic pressure on wall</u>

$$p_{cw}(y) = Q_{cw}(y)(A_h)_c\, \rho\, g\, D\, [1 - 1/3\, cos^2 Ø] \cos Ø$$

$$Q_{cw}(y) = 0.5625 \cosh(3.674\; y/D) \cosh(3.674h/D)$$

No.	y	y/D	Qcw	Pcw
1	0.00	0.000	0.409	1.009962
2	0.41	0.023	0.410	1.013552
3	0.83	0.046	0.414	1.024349
4	1.24	0.069	0.422	1.04243
5	1.65	0.092	0.432	1.067923
6	2.07	0.115	0.445	1.101009
7	2.48	0.138	0.462	1.141924
8	2.89	0.161	0.482	1.190958
9	3.30	0.184	0.505	1.24846
10	3.72	0.207	0.532	1.314839
11	4.13	0.229	0.563	1.390568

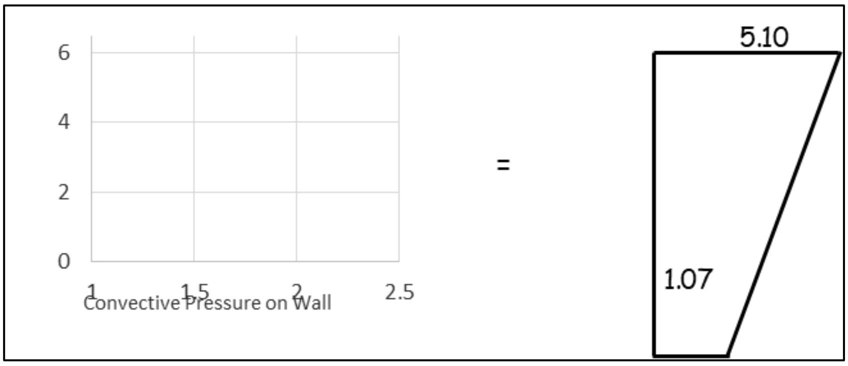
Base shear due to impulsive liquid mass per unit circumferential length

$$q_c = \frac{(A_h)_c m_c g}{\pi D/2}$$

Pressure at Bottom and Top is given by

$$a_c = \frac{q_c}{h^2}(4h - 6h_c)$$

$$b_c = \frac{q_c}{h^2}(6h_c - 2h)$$



Convective hydrodynamic pressure on the base slab (y = 0)

$$p_{cb} = Q_{cb}(x)(A_h)_c \, \rho \, g \, D$$
$$Q_{cb}(x) = 1.125[x/D - 4/3\,(x/D)^3]\,\mathrm{sech}(3.674\ h/D)$$

3.5.3 Pressure Due to wall Inertia

$$p_{ww} = (A_h)_i \, t \, \rho_m \, g$$

This pressure is uniformly distributed along the wall height.

3.5.4 Pressure Due to Vertical Excitation

Hydrodynamic pressure on tank wall due to vertical ground acceleration.

$$p_v = (A_v)[\rho \, g \, h \, (1 - \ y/h)]$$

$$A_v = \frac{2}{3}\left(\frac{Z}{2}\frac{I}{R}\frac{S_a}{g}\right)$$

3.5.5 Maximum Hydrodynamic Pressure on wall

$$P = \sqrt{\left(P_{iw} + P_{ww}\right)^2 + P_{cw}^2 + P_v^2}$$

3.5.6 Sloshing Wave Height

Free Board to be provided in tank based on the maximum value of sloshing wave height. This is particularly for the important tanks containing toxic liquids, where loss of liquid needs to be prevented. Or if required free board is not provided, roof structure of tank should be designed for resisting uplift pressure due to sloshing liquid.
Maximum Sloshing height
dmax = $(A_h)_c$ R D/2

4. RESULT AND DISCUSSION

For all the above stated Circular elevated tanks, RC frame staging system was modeled in STAAD Pro and arbitrary load was applied at the center of gravity of the tank. Following are the values of deflections and stiffness calculated.

Table 4: Deflection and stiffness

Tank	**Deflection (mm)**	**Stiffness (N/m)**
T1	60	1.90E+07

5. CONCLUSION

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

1) Time period in convective mode is greater than that of impulsive mode and both the time periods increases with increase of capacity/ structural mass of the tank.
2) The horizontal force which is acting at the staging of the structure increases with increase in capacity of tank.
3) The deflection of staging is found to be decreasing with increase of capacity and change in staging pattern, further causing increase in its stiffness.
4) The risk of overturning moment is more at the tanks with higher capacity and the same must be accounted well while designing the structure.
5) Sloshing wave height result represents that, it's necessary to provide free board for partially filled tanks or else the roof of tanks should be designed to resist the uplift pressure of liquid.

These results can be accounted as reference for the detailed study of dynamic analysis of elevated tanks in different zone and also to compare the different supporting systems for the same capacity of tanks.

6. REFERENCES

[1] George W. Housner, 1963 *"The Dynamic Behaviour of Water Tank" Bulletin of the Seismological Society of America. Vol.53, No.2,* pp. 381-387. February 1963.
[2] Dr Suchita Hirde, Dr Manoj Hedaoo, *"Seismic Performance of Elevated Water Tank", International Journal of Advanced Engineering Research and Studies/ Vol.I/2011.*
[3] Mangulkar Madhuri N, Gaikwad Madhukar V, *Review On Seismic Analysis of Elevated Water Tank.*
[4] *International Journal of Civil Engineering and Technology (IJCIET), Volume 4, Issue 2,* March-April 2013
[5] Soheil Soroushnia, Sh Tavousi Tafreshi, F. Omidinasab, *"Seismic Performance of RC Elevated Water Tanks with Frame Staging and Exhibition Damage Pattern" Science Direct ELSEVIER* Procedia Engineering 14 (2011) 3076-3087
[6] Sudhir K Jain and M. S. Mdhekar, October-1993, *"Proposed provisions for aseismic design of liquid storage tanks" Journals of Structural Engineering Vol-20, No-03.*
[7] Sudhir K Jain, O.R. Jaiswal, Spetember-2005, *Journal of Structural Engineering, Vol-32, No03.*
[8] Bureau of Indian Standards *"Criteria For Earthquake Resistant Design Of Structures" IS Code 1893 (Part2):2014, August 2014*
[9] IITK-GSDMA guidelines for seismic design of liquid storage tank.