IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)
e-ISSN: 2278-1684,p-ISSN: 2320-334X, Volume 14, Issue 4 Ver. VI (Jul. - Aug. 2017), PP 49-56
www.iosrjournals.org

A Comparative Study of Seismic Behaviour of R.C Elevated Water Tank, Chimney and Building Frame

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Abstract: *In event of severe earthquakes R.C structures are subjected to lateral jolts. The behaviour of the structures towards seismic forces is dependent on the structural composition. Elevated water tank is an inverted pendulum with heavy mass suspended at the top supported by a slender staging. While chimney is a stack like structure having a slender cantilever fixed at the base, and R.C building frame consists of floor diaphragms of very large moment of inertia in the lateral direction connected with parallel rows of vertical columns which actually behave as beam-columns under lateral seismic forces. In this paper an attempt has been made to critically compare between the lateral seismic behaviour of three different structures using dynamic analysis procedure.*

Keywords*: Building frame, elevated water tanks, inverted pendulum, seismic behaviour, slender chimney.*

Date of Submission: 27-07-2017 Date of acceptance: 25-08-2017

I. Introduction

The behaviour of a structural system to lateral seismic forces is dependent on the portion of the mass of the structural system which participates during the seismic jolts and also the lateral stiffness of the structural system. Due to variation in the structural configuration the portion of participating seismic mass and the lateral stiffness of the structural system varied for various class of structural composition. In this case Elevated water tanks, Chimney and Building frames all have different structural compositions to suit the functional utility. A comparative study shall be made in the paper that due to change in the structural composition that is due to variation in the seismic mass and the lateral stiffness of the structural system how the fundamental period of the system which is a basic dynamic property of the system is varied.

II. Literature Survey

Elevated water tanks fall in the category of “inverted pendulums”. The major mass which is affected by the lateral seismic forces is concentrated at the C.G of the tank container. The location of the C.G is affected with the depth of the water in the tank container. The Indian Earthquake code IS 1893-1984[1] recommended a single degree of freedom model (SDOF). However later after revision the two mass model for tank full condition has been the recommended model as per provisions of IS 1893 (part 2) 2014[2] version of the code. In the two mass model, the water contained in the tank container below the free board executes impulsive pressure and portion of the water near the free board executes convective pressure. This two different modes of vibration requires a two mass modeling to account for hydrodynamic pressure distribution in the tank container. Chimneys being slender stack like structures used for discharging industrial waste gases at high enough elevation so that after dilution due to atmospheric turbulence, their concentration and that of their entrained solid particulates is within acceptable limit on reaching the ground. A tall chimney achieves simultaneous reduction in concentration of number of pollutants including Sulphur dioxide, fly ash etc. chimneys being slender cantilever structures, their behaviour against lateral forces such as earthquakes requires elaborate study. Empirical expression for arriving at seismic base shear and earthquake induced bending Moment at the base of the chimney are obtained from the Indian earthquake code IS 1893-(Part -4) 2005 [3] .R.C buildings frames consists of floor diaphragms of very large moment of inertia in the lateral direction connected with parallel rows of vertical columns which actually behaves as beam-columns under lateral seismic forces. The Indian earthquake code IS 1893-(part 1) 2002[4] has been adopted for the purpose of determination of seismic base shear and moment in the building structure.

The necessary formulae as obtained from the various versions of the Indian earthquake code are reproduced later for ready reference.

III. Structures Studied

Three types of structures i.e elevated intze type water tank having both frame and shaft type of staging considered one at a time, chimney and symmetrical building have been studied. Three different heights of each of these structures have been subjected to response spectrum analysis in STAAD PRO to study the trend in the behavior of each type of structure with different heights as well as to point out the analogies and discrepancies between the three different types of structures having different configurations.

For tank, chimney and building, the expressions of horizontal acceleration coefficient (A_h), and base shear (V_B) as per the coda provisions of IS 1893-2002 (Part-1) is given by:

$$A_h = \frac{Z}{2} * \frac{I}{R} * \frac{S_a}{g}$$

(1)

Where

Z = Zone factor given in Table 2 of IS 1893 (Part 1): 2002,

I = Importance factor given in Table 1 of this standard,

R = Response reduction factor given in Table 2 of this standard, and

Sa/g = Average response acceleration coefficient as given by Fig. 2 and Table 3 of IS 1893(Part 1): 2002 and subject to Clauses 4.5.1 to 4.5.4 of this standard.

$$V_B = A_h W$$

(2)

where W=total weight of the structure

The bending moment of the building is calculated as by the formula:

M=V_Bh

(3)

Where h=height of the centre of gravity of the structure from its base

IV. Structural Modelling

All the three structures – elevated water tank, chimney and building have been modeled as cantilever beams fixed at the base using the finite element software STAAD PRO. For all the structures grade of the concrete is taken as M30 and are located in zone IV having hard rocky soil and damping ratio of 0.05. The support condition is considered to be fixed in all the cases.

Two types of intze type water tanks have been modeled-one with frame type of staging and another with shaft type of staging. Each type of tank with 15m, 20m and 25m staging height have been analyzed both in tank full and tank empty condition. The shaft of the tank has been modeled withuniformly thick plate elements which gives result for out of plane moment and shear and designs accordinglywhile the bracings of the frame type staging are modeled with beam element the details of which are given in Table 1.a and 1.b.The shell of the three chimneys of heights 30m, 45m and 60m have been modeled with uniformly thick plate elements as per the parameters of Table 2. On the other hand three symmetrical buildings of heights 18m,24m and 30m have been modeled with simple beam elements as per the data given in Table 2.

Capacity=250 cum
Thickness of Top Dome=100 mm
Top Ring Beam= 300x 200 mm
Thickness of Cylindrical Wall=200 mm
Height of Cylindrical Wall=5m
Bottom Ring Beam=400 x 300 mm
Circular Ring Beam=400 x 300 mm
Thickness of Bottom Dome=100 mm
Thickness of Conical Dome=250 mm
Dimension of Columns = 650mm diameter
Number of columns =8
Dimension of Bracing = 300 x 300 mm
Spacing between the bracings= 5m
Importance Factor=1.5
Response reduction factor=3

Table 1.a: Parameters of water tank having frame type of staging of heights 15m, 20m and 25m

Capacity=250 cum
Thickness of Top Dome=100 mm
Top Ring Beam= 300x 200 mm
Thickness of Cylindrical Wall=200 mm
Height of water containing portion=5m
Bottom Ring Beam=400 x 300 mm
Circular Ring Beam=400 x 300 mm
Thickness of Bottom Dome=100 mm
Thickness of Conical Dome=250 mm
Thickness of shaft= 150 mm
Importance Factor=1.5
Response reduction factor=2.5

Table 1.b: Parameters of water tank having shaft type of staging of heights 15m, 20m and 25m

Top diameter=2m
Bottom diameter=3m
Shell thickness=0.3m
Importance Factor=1.5
Response reduction factor=3

Table 2: Parameters of chimney of height 30m,45m 60m

Number of bays in X direction=4
Number of bays in Z direction=4
Spacing between the bays= 3m c/c
Beam dimension=650x650 mm
Column dimension=650x650 mm
Slab thickness=0.15m
Wall thickness=250mm
Height of parapet wall=1.5m
Floor to floor height=3m
Live load = 3 KN/m^2
Importance Factor=1
Response reduction factor=3

Table 3: Parameters of symmetrical building of height 18m, 24mand 30m

V. Results And Discussion:

height of tank(m)	time period (sec)
20.000	0.942
25.000	1.290
30.000	1.622

Table 4.a: Variation of time period of water tank with frame type staging with height in tank empty condition

height of frame(m)	time period (sec)
20.000	1.443
25.000	1.962
30.000	2.441

Table 4.b: Variation of time period of water tank with frame type staging with height in tank full condition

height ofshaft(m)	time period (sec)
20.000	0.222
25.000	0.320
30.000	0.438

Table 5.a: Variation of time period of water tank with shaft type staging with height in tank empty condition

height of shaft(m)	time period (sec)
20.000	0.405
25.000	0.568
30.000	0.751

Table 5.b: Variation of time period of water tank with shaft type staging with height in tank empty condition

5.1 Observation

1) As evident from table 4.a, 4.b, 5.a and 5.b, the time period of the structure increases with increase in height.
2) For each of frame and shaft type of staging the time period is more in tank full condition compared to tank empty condition.
3) When the time periods of tanks with frame type of staging are compared with tank with shaft type of staging, in each case the time period of tank with shaft type of staging is more. Thus it can be concluded that shaft is a more rigid structure compared to frame of the same height.

Height(m)	Time Period (sec)
30	0.458
45	1.026
60	1.821

Table 6: Variation of time period of chimney with height

From the results obtained from table 6, as the height of the chimney increases its stiffness reduces resulting in lengthening of time period.

Height(m)	Time Period (sec)
18	0.65
24	0.813
30	0.68

Table 7: Variation of time period of chimney with height

It can be concluded from Table 7 that with the increase in height of the building its time period increases leading it more vulnerable to earthquake forces.

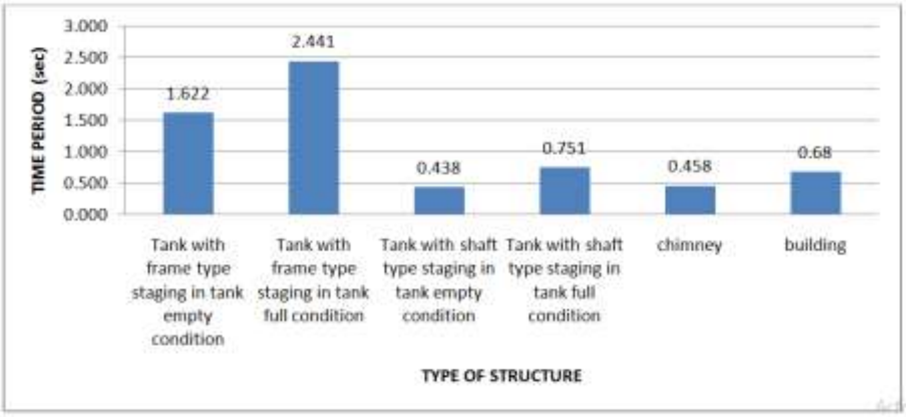

Table 8: Variation of time period of water tank, chimney and building of height 30m each

From the above graph, time period of chimney obtained is very less. But chimney being a very slender structure should have more time period than water tank or building which are comparatively stiffer. Thus earthquake force is not the critical force for the failure of any chimney rather other major forces like wind force should be taken into consideration while designing it. Thus if only earthquake forces are considered the water tank with frame type of staging in tank full condition is the most flexible structure of all having the least stiffness and highest time period.

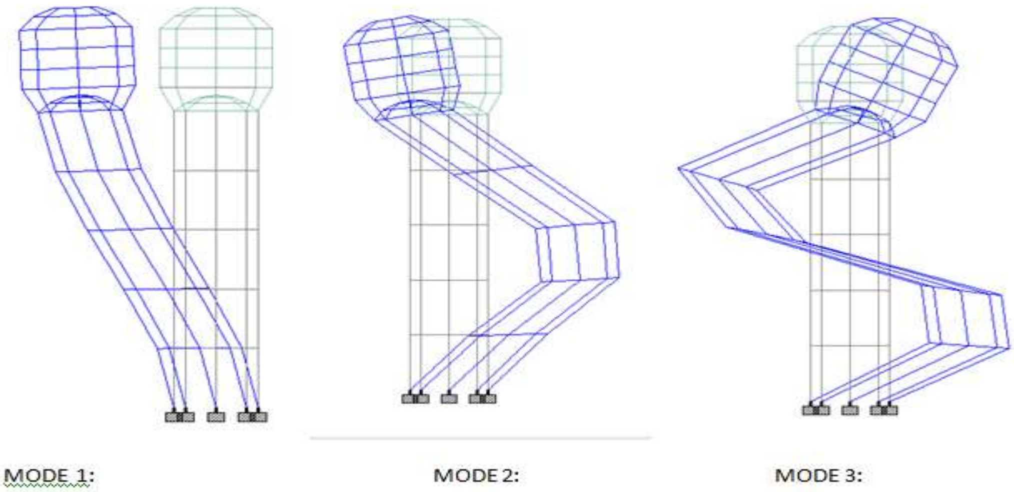

Fig 1: Mode shapes of water tank of height 30m with frame type staging

Capacity of Tank (cum)	Staging Type	Height of tank (m)	Tank Condition	Time Period (sec) FEA Model Mode 1	Mode 2	Mode 3	FEA modal participation
250	Frame	20	Tank Full	1.443	0.472	0.148	96.023 (1st mode)
			Tank Empty	0.942	0.488	0.152	97.625(3rd mode)
		25	Tank Full	1.962	0.594	0.238	94.224(2nd mode)
			Tank Empty	1.290	0.606	0.240	95.573(3rd mode)
		30	Tank Full	2.441	0.704	0.343	92.641(3rd mode)
			Tank Empty	1.622	0.713	0.337	94.012(3rd mode)

Table 9: Time period of water tank with frame type staging at different modes along with modal participation.

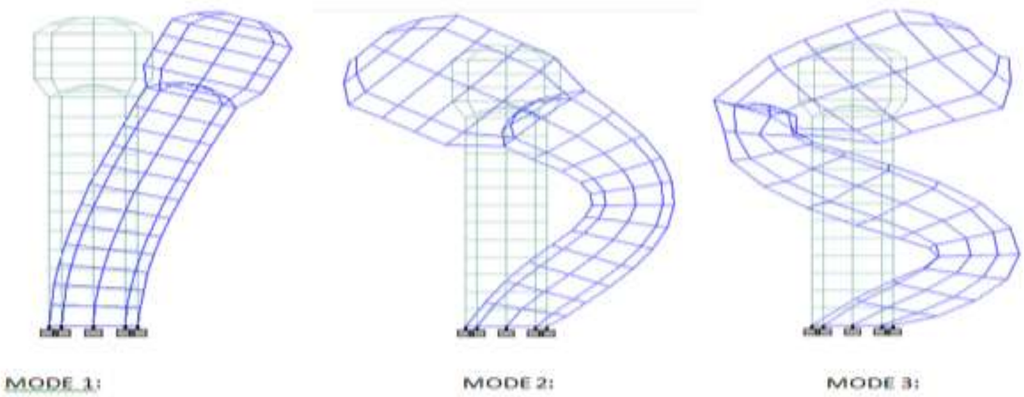

Fig 2: Mode shapes of water tank of height 30m with shaft type staging

Capacity of Tank (cum)	Staging Type	Height of tank (m)	Tank Condition	Time Period (sec) FEA Model Mode 1	Mode 2	Mode 3	FEA modal participation
250	Shaft	20	Tank Full	0.405	0.055	0.038	90.537 (1st mode)
			Tank Empty	0.222	0.058	0.040	90.66(3rd mode)
		25	Tank Full	0.568	0.066	0.050	94.210(3rd mode)
			Tank Empty	0.320	0.069	0.050	94.713(10th mode)
		30	Tank Full	0.751	0.077	0.064	94.303(3rd mode)
			Tank Empty	0.438	0.080	0.063	94.283(11th mode)

Table 10: Time period of water tank with shaft type staging at different modes along with modal participation.

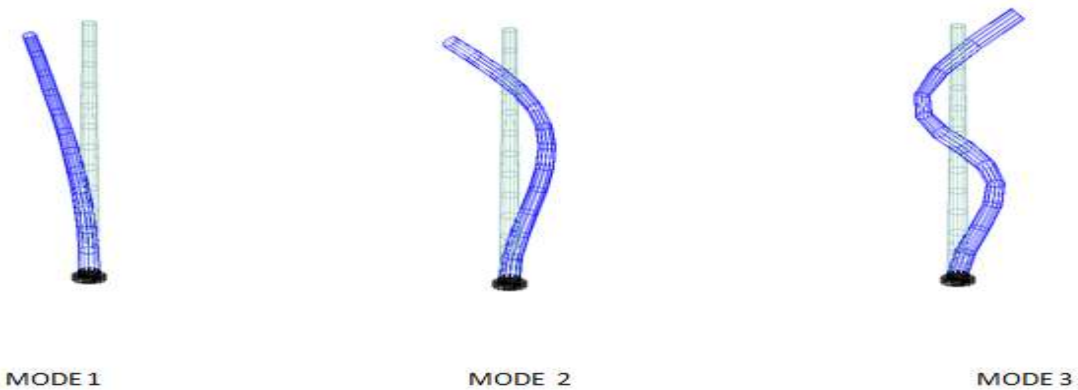

Fig 3: Mode shapes of chimney of height 30m

Structure	Height (m)	Mode 1	Mode 2	Mode 3	FEA modal participation
Chimney	30	0.458	0.091	0.036	93.821(5th Mode)
	45	1.026	0.197	0.076	92.548(5th Mode)
	60	1.821	0.347	0.132	91.941(4th Mode)

Table 11: Time period (in sec)of chimney at different modes along with modal participation.

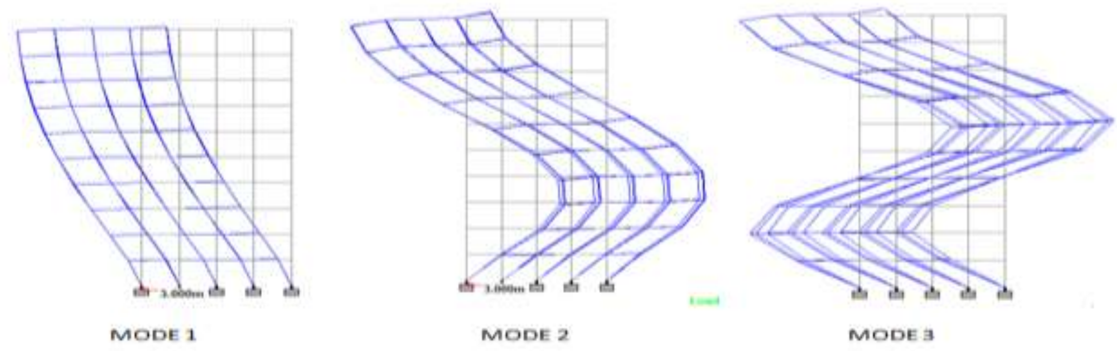

Fig 3: Mode shapes of building of height 30m

Structure	Height (m)	Mode 1	Mode 2	Mode 3	FEA modal participation
Building	18	0.41	0.26	0.13	93.538(3rd mode)
	24	0.55	0.34	0.18	92.373(3rd mode)
	30	0.68	0.42	0.22	91.54(3rd mode)

Table 12: Time period (in sec) of building at different modes along with modal participation.

5.2 Observation:

1) The modal participation of frame type water tank increases with increase in height for tank full condition while it remains the same for with increment in height for tank empty condition.
2) In water tank with shaft type staging the modal participation increases with height at a moderate rate for tank full condition. But the participation of modes is very high with increase in height for tank empty condition.
3) In case of chimney the modal participation decreases with increase in height.
4) The modal participation of building remains the same with variation in height.

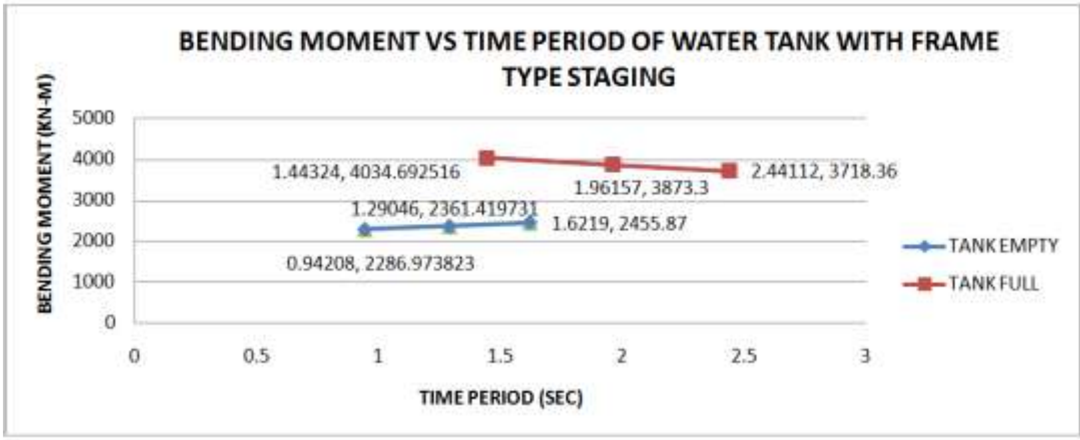

Fig 4: Variation of bending moment with varying time period for water tank with frame type staging

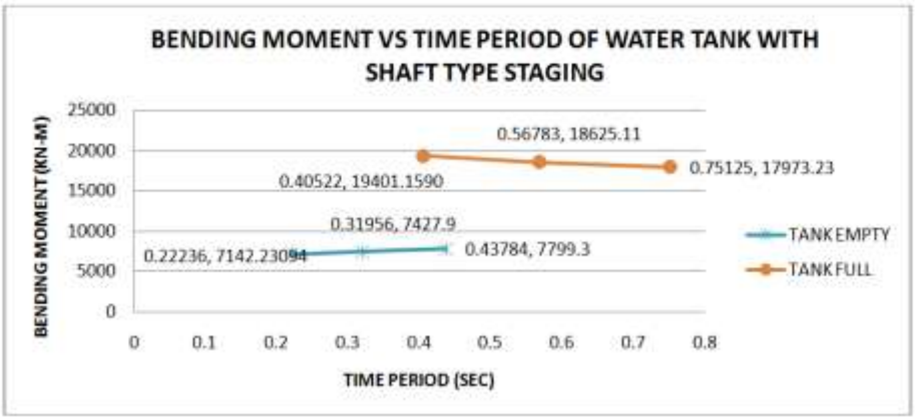

Fig 5: Variation of bending moment with varying time period for water tank with shaft type staging

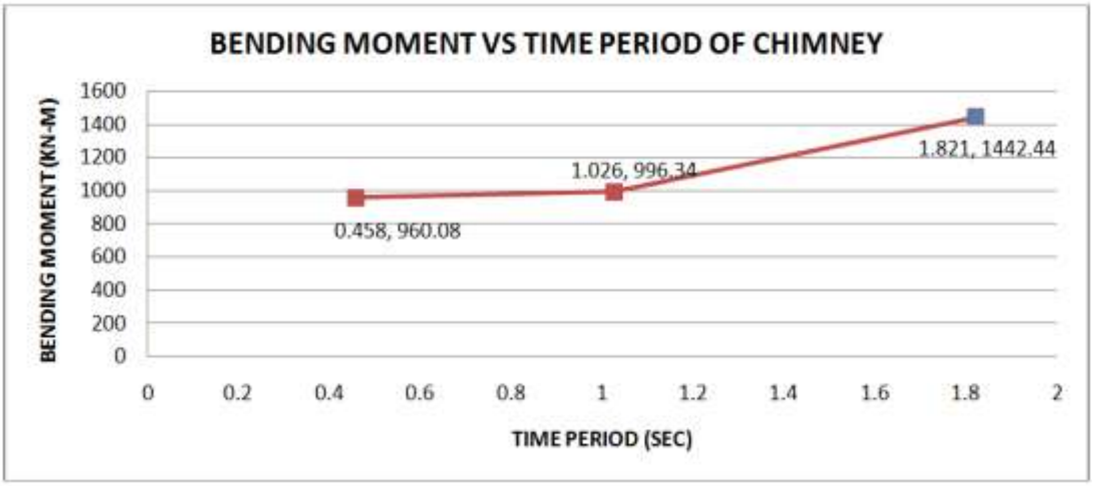

Fig 6: Variation of bending moment with varying time period for chimney

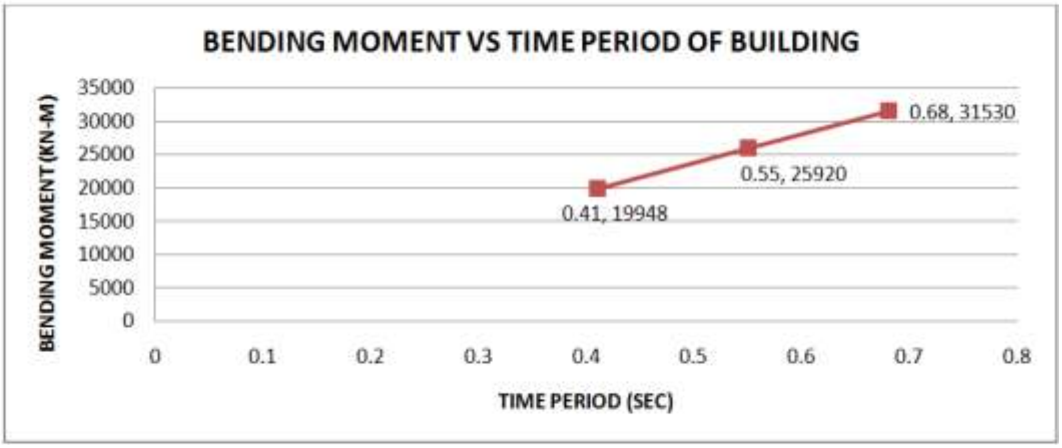

Fig 7: Variation of bending moment with varying time period for building

5.3. Observation:

Some general observations are made from the study of the graphs made in this paper.

1) It is observed that the highest values of bending moment were seen at the base of the shaft type elevated tank in tank full condition while much lesser bending moments are observed at the base of a chimney. This indicates an interesting trend that may be for chimney seismic force is not the critical lateral force. Hence of course chimneys must be checked both for seismic and wind forces to determining to determine the dominating lateral force.
2) It is also observed that bending moment at the base of the tank is much more with shaft type of staging than frame type of staging. Thus shaft type of staging is a much more rigid structure than frame type of staging and hence attracts more seismic forces.
3) It is also seen that for building structures bending moment values induced due to earthquake forces lies intermediate in comparison to those obtained in elevated water tank with shaft and chimney structure
4) In tank full condition of both frame and shaft type of staging, bending moment gradually decreases with increase in time period while for tank empty condition bending moment increases with increase in time period. This shows that for tank full condition the tank falls under displacement sensitive zone while for tank empty condition it lies in acceleration sensitive zone of the response spectrum.
5) For the variation of heights considered in all the cases of both chimney and building the graph of increasing bending moment with increase in time period shows that these two structures lie in the acceleration sensitive zone of the response spectrum for that range of height.

VI. Conclusion

Three structures of three different structural configurations have been studied. But the height of the structures is kept in comparable ranges, to make a comparative evaluation of the seismic behavior. Within the limited scope of the study we have found that among all the various structures studied chimney is relatively less vulnerable to seismic forces for low to moderate height. Therefore its behavior with respect to wind forces should be more critically studied when comparison is made as to which lateral force shall be more critical for such type of structure. Tank on shaft in the tank full condition is the most vulnerable to seismic forces than tank on frame staging system. Building structures in comparable range of vertical height exhibits much greater bending moment at base than chimney. For a vertical height between 20 to 30 m for both frame and shaft type staging, the water tank falls under displacement sensitive zone in tank full condition and lies in acceleration sensitive zone in tank empty condition while for comparable heights of building and chimney the structures lie in the acceleration sensitive zone of response spectrum. Thus it is evident that structural configuration has definite impact on the seismic behaviour of the structure.

References

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Priyosmita Das. "A Comparative Study of Seismic Behaviour of R.C Elevated Water Tanks, Chimney and Building Frames." IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE) , vol. 14, no. 4, 2017, pp. 49–56.