Analysis of Intze Type Water Tank with Different Staging System & its Optimal Design

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Abstract

Water storage structures are used to store water to tide over the daily requirement of water by localities, industries, campuses, towns, cities, etc. Especially elevated water tanks are used to supply water to a particular area so that the water can reach to the users by gravity and pressure. These elevated structures have large mass concentrated at the top and are behaving like a slender supporting structure, as an inverted pendulum. Hence, these structures are vulnerable to horizontal forces due to earthquake. From the very upsetting experiences of few earthquakes, like the 2001 Bhuj earthquake in India (Durgesh C. Rai 2003), RCC Elevated water tanks were heavily damaged or collapsed. This might be due to the lack of knowledge regarding the proper behavior of the staging part of the tank and due to dynamic effect and improper geometrical selection of staging. This paper deals with the analysis of different fame type staging patterns for RCC elevated tank (Intze type) with the help of STAAD Pro Vi8 (series 6) by using response spectrum method. In this paper, at first by studying the losses occurred in water tanks during past earthquakes and the reasons for these occurred damages, the analysis was done for different staging patterns to overcome these damages in these structure in coming future. It was determined while comparing different staging patterns that X type of frame staging have shown better seismic behavior to the resistance against lateral loads as they reduces most of displacement and time period but it increases the base shear due to the increase in volume of concrete.

Keyword- Intze Tank, Staging, Frame Staging, STAAD Pro Vi8 (series 6), Seismic Analysis, Response Spectrum Method, Base Shear, Nodal Displacement, Time Period

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I. INTRODUCTION

Water is lifeline for every kind of creature in this world. Municipalities and industries all around the world uses liquid storage tanks extensively for water supply, firefighting systems, storage of inflammable liquids and other chemicals etc. 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. India is the country, which consist the 2nd highest population of the world and with the rapid increase of human population, demand for drinking water, has increased by many folds. Also due to shortage of electricity at many places in India and around the developing nations all around the world, it is not possible to supply water through pumps at peak hours. In such situations, elevated water tanks become an important part of life. Further Indian sub-continent is vulnerable to natural disasters like earthquakes, cyclones etc. Some natural calamities especially like earthquake is causing many casualties and innumerable property loss every year. Hence, it is necessary to learn to live with these events. According to seismic code IS:1893(Part I):2016 more than 60% of India is prone to earthquakes. Elevated tank structures are normally used to store water for domestic activities and firefighting purposes. Their safety performance is a critical concern during strong earthquakes. The failure of these structures may cause serious hazards for citizens due to the shortage of water or difficulty in putting out fires during earthquakes.

Based on the material of tanks, storage tanks are classified as; 1) Steel Tanks, 2) RCC Tanks. Further RCC tanks are classified as; 1) Tanks Resting on the Ground, 2) Underground Tanks, 3) Elevated or Overhead Tanks. Further Elevated tanks are classified as; 1) Square/Rectangular Tanks, 2) Circular Tanks, 3) Intze Tanks, 4) Conical/Funnel Tanks. This research paper deals with the study of Intze Tank only.

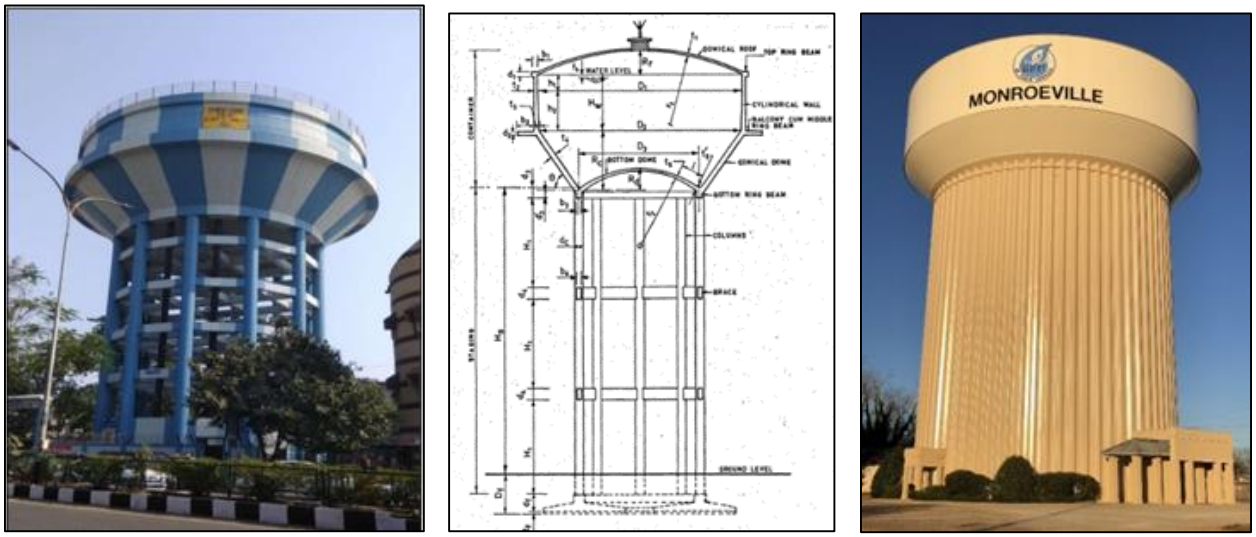

Fig. 1: Intze Tank

II. STAGING

Staging, an important part of Structure of overhead tank is responsible to provide a safe working to the water tower. Staging is formed by a group of vertical Columns and Horizontal or Inclined Braces provided at an intermediate levels to reduce the effective length of Column. Apart from Vertical Column, Tapered (Inclined) Columns are also used to support the Tank Container. Further, it may be as a shaft type circular hollow supporting shear wall instead of column and bracing. Based on structure, the staging is classified as; 1) Shaft Type (Shell) Staging, 2) Column-Brace (Frame) Staging. This research paper deals with the study of Column-Brace Staging only. Further Column-Brace Staging is classified as; 1) Normal Staging, 2) Radial Staging, 3) Cross Staging.

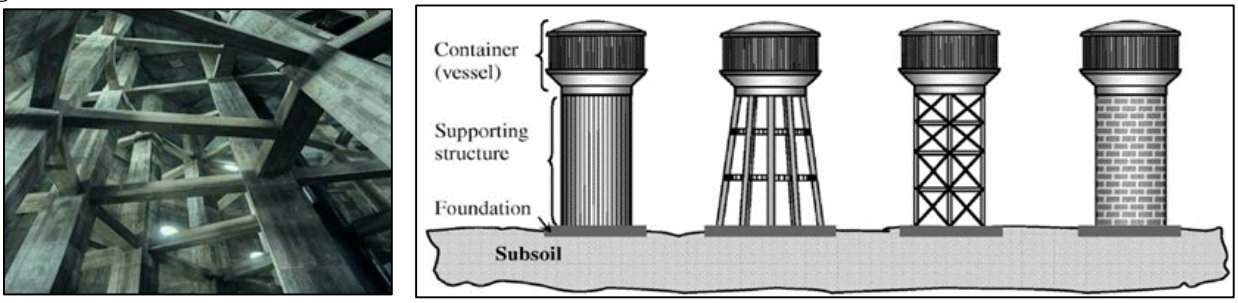

Fig. 2: Staging (Supporting Structures)

III. APPROACHES FOR FRAME STAGING

As experiences from Chile 1960; (1978 Izu-Oshima and Miyagi), 1971 San Fernando, and 1987 Whittier earthquakes; (Steinbrugge and Rodrigo 1963, Minowa 1980, Knoy 1995), Further (Wilson and John 1983, Olson and Bathe 1983, Dogangun et al. 1996, Dogangun and Livaoglu 2004, Livaoglu and Dogangun 2005, Livaoglu 2005, Livaoglu and Dogangun 2006, Livaoglu and Dogangun 2007, Sezen et al 2008), the major of these studies have focused on the ground level cylindrical tanks. However, very few studies have concentrated upon the dynamic behavior of liquid storage elevated tanks. Summary of all these studies states that focus must be placed on supporting structure of elevated water tank, which is called Staging because this part is highly vulnerable under seismic forces and is of huge importance. According to Durgesh C. Rai 2003 from the experiences of 2001 Bhuj earthquake in India, the design of RC shaft type staging is extremely vulnerable to lateral loads caused by earthquakes. Thus instead of shaft type staging RC frame type staging must be used which are less vulnerable to lateral loads caused by earthquake. Further, it states that proper seismic analysis must be considered while designing a water tank.

IV. CONCEPT OF FRAME STAGING

The frame type is the most commonly used staging in practice. The main components of frame type of staging are columns and braces. In frame staging, columns are arranged on the periphery and it is connected internally and externally by bracing at various levels. Staging is acting like a bridge between container and foundation for the transfer of loads acting on the tank. In elevated water tanks, head requirement for distribution of water is satisfied by adjusting the height of the staging portion. A reinforced

elevated Intze type water tank having different staging arrangements and staging levels has been considered for the present study. In staging, there are two types of braces as internal and external bracing. In this paper analysis is done by assuming different types of staging in which internal braces kept as it is currently used in market, but the changes will be done to external braces by applying new concepts and analyzing their models. After analyzing all models, comparisons of all results are done and the optimum best result is computed.

The general basic types of internal staging used currently in market are as follows; 1) Normal Bracing, 2) Radial Bracing, 3) Cross Bracing.

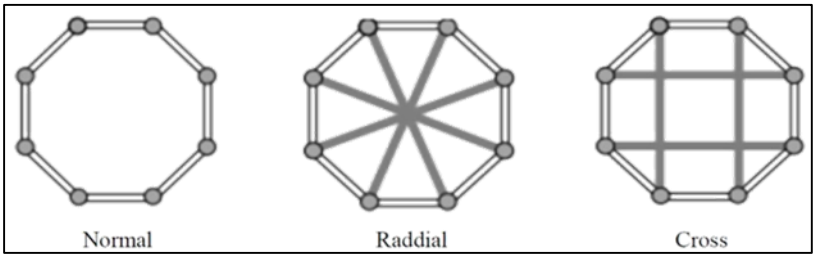

Fig. 3: Internal Bracing

The external staging to be used in our study are as follows; 1) Without External Bracing, 2) "X" type Bracing, 3) Diagonal Bracing, 4) Chevron Bracing, 5) Global Bracing, 6) "K" Type Bracing, 7) "V" Type Bracing.

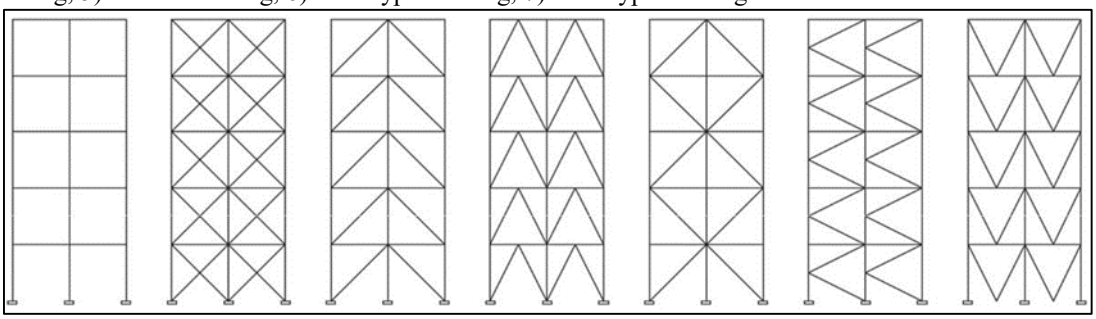

Fig. 4: External Bracing

In this paper analysis of two types of model are considered as per number of storey or level; 1) 5-storey, 2) 6-storey. For each single type of model, analysis will be done for all seven types of staging patterns. Further analysis can be done with different water level conditions as full water, half-filled water level and empty (no water) or for different seismic zones of earthquake. In this paper, analysis for full water condition and seismic zone is III is considered only.

V. CODE BASED PROCEDURE FOR SEISMIC ANALYSIS

Main features of seismic method of analysis based on IS: 1893(Part 1):2016 are described as follows:

A. Equivalent Lateral Force

Seismic analysis of most of the structures are still carried out on the basis of lateral (horizontal) force assumed to be equivalent to the actual (dynamic) loading. The base shear that is the total horizontal force on the structure is calculated based on structure mass and fundamental period of vibration and corresponding mode shape. The base shear is distributed along the height of structures in terms of lateral forces according to Code formula. This method is usually conservative for low to medium height buildings with a regular conformation.

B. Response Spectrum Analysis

This method is applicable for those structures, where modes other than the fundamental one affect significantly to the response of the structure. In this method, the response of Multi-Degree-of-Freedom (MDOF) system is expressed as the superposition of modal response. Each modal response being determined from the spectral analysis of single-degree-of-freedom (SDOF) system, which is then combined to compute the total response. Modal analysis leads to the response history of the structure to a specified ground motion; however, the method is usually used in conjunction with a response spectrum.

C. Elastic Time History Analysis

A linear time history analysis overcomes all the disadvantages of modal response spectrum analysis, provided non-linear behavior is not involved. This method requires greater computational efforts for calculating the response at discrete times. One interesting advantage of such procedure is that the relative signs of response quantities are preserved in the response histories. This is important when interaction effects are considered in design among stress resultants.

VI. PROBLEM DESCRIPTION

For finding the best staging system in Intze water tank, live model for comparison of different parameters are taken. The tank is considered having a capacity of 24 lakh liters, 12 columns supported having a beam and column staging of 5 and 6 stories both individually for each model. This paper studies about 7 different types of staging with external bracing for each 3 types of staging with internal bracing patterns with 5 and 6 story staging, to reaches the conclusion. Analysis is done for full water condition of water tank only. Thus, there are total different 42 models analyzed in STAAD Pro Vi8 software.

Dia. of Column	*1000*	*Top Dome*	*125 thick*
Tie Beam Internal Bracing	*750 x 650*		*23644 radius*
Bottom Ring Beam	*1000 x 2000*	*Internal Circular Wall*	*200 thick*
Ring Beam at Top of Conical	*1350 x 1000*	*Outer Circular Wall*	*475 to 200*
Top Ring Beam	*600 x 825*	*Conical Dome*	*800 thick*
Top and Bottom Beam for Cabin	*200 x 200*	*Inspection Slab*	*100*
Bottom Dome	*250 thick*	*Cabin Top Slab*	*100*
	10901 radius	*Radius at Bottom*	*15600*
Radius of Stair Wall	*2890*	*Radius for Outer Wall*	*22600*
Height of Stair Wall	*5500*	*Height of Outer Wall*	*4900*
Cabin Column	*200 x 200*	*Height of Top Cabin*	*2100*
Braces	*350 x 450*	*No. of Columns for Top Cabin*	*6*

Table 1: Data of Intze Tank from Live Structure (All dimensions are in mm.)

All external bracing beams is taken as 450 x 350 mm. In this model inlet pipe, outlet pipe, overhead pipe, staircase are not taken as a structural member; hence, those are not added in models.

The height of tank is 36.194 m at the top slab, in which frame staging are made up to 24.5 m and rest 11.694 m are the height of container. The seismic load factors such as zone factor, importance factor and response reduction factors are used for response spectrum analysis as per IS:1893(Part I):2016 and IS:1893(Part 2)-2016 draft code. Earthquake data are taken for Surat city in Gujarat, which are, R=5, Soil type is medium, Important factor is 1.5, zone is III, time period is manually calculated, which is 1.15 sec. and damping is 5% taken.

Tie beam for 6 storey are created (from bottom) 0.987 m, 5.237 m, 9.237 m, 13.237 m, 17.237 m, 21.237 m and at 24.5 m bottom ring beam is there. Tie beam for 5 storey are created at (from bottom) 0.987 m, 5.697 m, 10.397 m, 15.097 m, 19.797 m and at 24.5 m bottom ring beam is there.

From the available data there are total different 42 models prepared and analyzed in STAAD Pro Vi8 software. The different models are formed for 6-storey and 5-storey tanks.

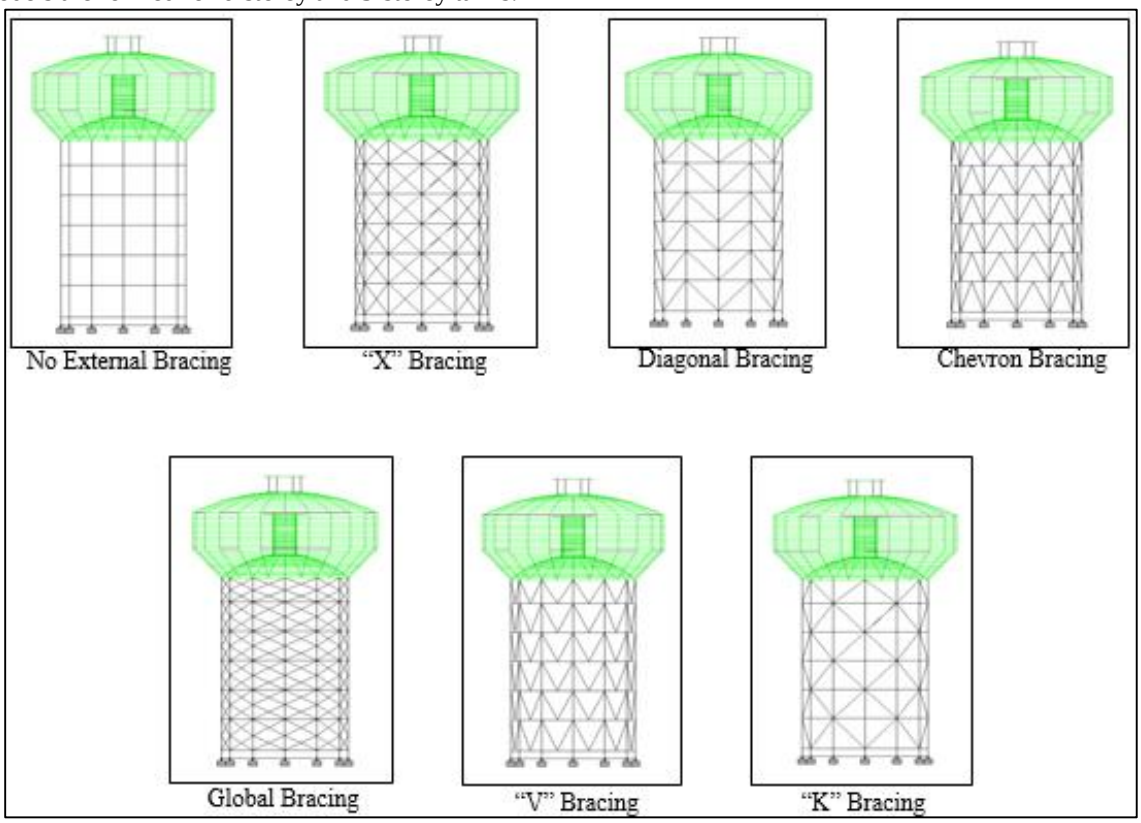

Fig. 5: Models of 6-Storey Water Tank with Different Staging Systems

The applied loads are Dead load, Self-weight and Water load as Live load, DL is 0.5 kN/m^2 on top dome in gravity direction and the LL are as per under table.

Plate Strip	*Load in kN/m^2*	*Plate Strip*	*Load in kN/m^2*
1 (outer most)	*99.0225*	*6*	*44.82*
2	*85.86*	*7*	*36.75*
3	*74.05*	*8*	*29.22*
4	*63.41*	*9*	*22.19*
5	*53.67*	*10 (inner most)*	*15.53*

Table 2: Hydrostatic Load (LL) on Bottom Dome (Divide in 10 equal divisions along Length)

Plate strip	*Load in kN/m^2*	*Plate strip*	*Load in kN/m^2*
1 (outer most)	*44.40*	*7*	*51.18*
2	*45.89*	*8*	*51.82*
3	*47.23*	*9*	*52.32*
4	*48.42*	*10*	*52.66*
5	*49.49*	*11*	*52.85*
6	*50.41*	*12 (inner most)*	*52.92*

Table 3: Hydrostatic Load on Conical Dome (Divide in 12 equal divisions along Length)

Plate strip	*Load in kN/m^2*	*Plate strip*	*Load in kN/m^2*
1 (bottom most)	*47.17 to 51.66*	*7*	*20.21 to 24.70*
2	*42.67 to 47.17*	*8*	*15.72 to 20.21*
3	*38.18 to 42.67*	*9*	*11.22 to 15.72*
4	*33.69 to 38.69*	*10*	*6.72 to 11.22*
5	*29.2 to 33.69*	*11*	*2.24 to 6.72*
6	*24.70 to 29.2*	*12 (top most)*	*0 to 2.24*

Table 4: Trapezoidal Load on Inner Wall (Divide in 12 equal divisions along Height)

Plate strip	*Load in kN/m^2*	*Plate strip*	*Load in kN/m^2*
1 (bottom most)	*42.02 to 46.02*	*7*	*18.00 to 22.01*
2	*38.02 to 42.02*	*8*	*14 to 18*
3	*34.01 to 28.02*	*9*	*10 to 14*
4	*30.01 to 34.01*	*10*	*6 to 10*
5	*26.01 to 30.01*	*11*	*2 to 6*
6	*22.01 to 26.01*	*12 (top most)*	*0 to 2*

Table 5: Trapezoidal Load on Outer Wall (Divide in 12 equal divisions along Height)

VII. ANALYSIS AND RESULTS

The maximum responses are determined for different parameters of elevated water tanks. These responses are shown in the form of Base Shear, Top Story Displacement (Nodal Displacement), and Time Period. As per IS:1893-2016 the maximum nodal displacement allowed against the earthquake is height/250, as the height of our structure is 36.194 m; the allowable displacement is 145 mm. For seismic analysis response-spectra method is used for the full water condition and as a comparison parameter, time period for 1st mode is taken. Further dead load, water load, seismic load is applied before analysis of each model.

Types of Bracing		*Top Story Displacement (mm)*	*Base Shear (KN)*	*Time Period (Seconds)*
External	*Internal*			
No External Bracing	*Normal*	*87.08*	*1572.66*	*2.97*
	Radial	*69.87*	*1699.49*	*2.59*
	Cross	*75.12*	*1716.56*	*2.59*
"X" Bracing	*Normal*	*11*	*1689.36*	*0.84*
	Radial	*10.40*	*1872.56*	*0.85*
	Cross	*10.52*	*1897.22*	*0.69*
Diagonal Bracing	*Normal*	*14.19*	*1651.01*	*1.07*
	Radial	*14.37*	*1818.40*	*1.08*
	Cross	*14.82*	*1799.54*	*1.07*
Chevron Bracing	*Normal*	*13.01*	*1671.73*	*1.02*
	Radial	*13.21*	*1854.93*	*1.03*
	Cross	*18.82*	*1879.59*	*0.76*
Global Bracing	*Normal*	*13.81*	*1610.64*	*1.04*
	Radial	*13.22*	*1737.47*	*1.04*

	Cross	*16.87*	*1752.42*	*1.02*
"V" Bracing	*Normal*	*13.94*	*1632.16*	*1.07*
	Radial	*14.58*	*1759.00*	*1.06*
	Cross	*14.69*	*1776.05*	*1.03*
"K" Bracing	*Normal*	*14.09*	*1633.62*	*1.04*
	Radial	*15.07*	*1730.69*	*1.08*
	Cross	*16.76*	*1776.50*	*1.02*

Table 6: 6-Storey Model Analysis (Full water condition)

From the above table it is found that 'X' type of bracing system is the most effective to reduce top storey displacement while the Chevron type is least effective.

Types of Bracing		*Top Story Displacement (mm)*	*Base Shear (KN)*	*Time Period (Seconds)*
External	*Internal*			
No External Bracing	*Normal*	*49.44*	*1540.05*	*2.15*
	Radial	*49.48*	*1643.30*	*2.11*
	Cross	*42.41*	*1657.94*	*1.94*
"X" Bracing	*Normal*	*8.71*	*1619.26*	*0.79*
	Radial	*8.77*	*1721.69*	*0.79*
	Cross	*9.05*	*1736.32*	*0.80*
Diagonal Bracing	*Normal*	*12.70*	*1579.24*	*1.00*
	Radial	*12.78*	*1682.50*	*1.00*
	Cross	*14.19*	*1697.13*	*1.03*
Chevron Bracing	*Normal*	*12.30*	*1604.79*	*0.98*
	Radial	*12.37*	*1708.04*	*0.99*
	Cross	*12.75*	*1722.68*	*0.98*
Global Bracing	*Normal*	*11.58*	*1579.26*	*0.98*
	Radial	*12.61*	*1682.50*	*0.97*
	Cross	*13.17*	*1696.47*	*0.97*
"V" Bracing	*Normal*	*13.56*	*1604.77*	*1.03*
	Radial	*14.15*	*1708.03*	*1.03*
	Cross	*14.06*	*1722.66*	*1.02*
"K" Bracing	*Normal*	*11.90*	*1599.14*	*0.96*
	Radial	*12.16*	*1702.4*	*0.94*
	Cross	*11.74*	*1717.82*	*0.93*

Table 7: 5-Storey Model Analysis (Full water condition)

VIII. CONCLUSIONS

After analyzing 42 different models of different bracing patterns and comparing all results it is concluded as follows:

- The parametric study shows that 'X' type of bracing system is most effective to reduce top storey displacement, where Chevron type is least effective for same parameters, in case of 6-storey tank.
- Similarly, in case of 5-storey tank, 'X' type is most effective and 'V' type is least effective to reduce top storey displacement.
- Study of time period parameters shows that 'X' type is most effective to reduce time period and 'V' type is least effective to reduce time period in case of 6-storey tank and 5-storey tank.
- 'K' & 'V' type of patterns, shows almost same behaviors for all parameters in case of 6-storey tank and 5-storey tank.
- For study of all parameters, Diagonal and Global type of patterns have a good effect.
- As per the formula of base shear from IS:456-2000; $V_b = A_h$ x W. Thus, more the weight of structure, the more will be the base shear. Hence as per Table 6 and 7, 'X' type have higher base shear and Global type of bracing have least base shear as compared to all other type of bracings.
- In parametric study for three different plane based internal patterns, cross type of patterns has most effective behaviors for seismic resistance in compares to Radial and Normal.
- In parametric study for 6-storey & 5-storey structure, both type of structure shows the same behaviors for increasing base shear and decreasing top storey displacement and time periods, from that study it is advisable to make 5-storey structure with suitable bracing patterns.

IX. FUTURE WORK

In this paper, I have studied and analyzed all models for full water tank condition only. But to study actual conditions and proper detailed analysis, water tank in half filled water condition and empty tank condition must also be analyzed. Thus, all these 42 models will also be analyzed similarly for these two conditions in near future. Further, there is a huge scope to work on material optimization also as compared to design optimization because these structures are too costly. Thus, material consumption of all these models will also be worked out in near future.

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