Dynamic Analysis of Elevated Water Tank with Different Staging Configurations

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Abstract— The report presents the static analysis and Time History Analysis of an elevated water tank using STAAD Pro V8i software. The design involves load calculations manually and analyzing the whole structure by STAAD Pro V8i. The design method used in STAAD Pro analysis is Limit State Design and the water tank is subjected to live load, dead load, self-weight and seismic loads. Seismic load calculations are done as per IS 1893-2000.Eigen solution so obtained helps in determining the base shear and various peak story shear values of the structure. Frequency analysis gives the natural frequency of the structure and time history, which defines the behaviour of the structure in certain interval of time against various functions like velocity, displacement and acceleration and hence the graphical solutions has been drawn for each analysis. In the present study, three earthquake ground motions selected are considered as an input motion for the time history analysis and applied at the base of the structure. The seismic performance of the elevated water tank under three different selected earthquake (Kakinada, Elcentro and Bhuj) records will be examined for different staging configurations. For time history analysis STAAD Pro v8i software is used for the structure. The output parameters Base Shear, Nodal Displacement at the top of tank, Mass Participation factor, Time period of Vibration in various structural elements of various cases of water tank has been investigated and also been compared with static analysis results.

Keywords: Time History Analysis, Static Analysis. STADD Pro V8i, Base Shear, Nodal Displacement, Mass Participation Factor, Time period of Vibration

I. INTRODUCTION

Storage tanks are built for storing water, liquid petroleum, petroleum products and other liquids. Analysis and design of such tanks is independent of chemical nature of product. They are designed as crack free structures to eliminate any leakage. Adequate cover to reinforcement is necessary to prevent corrosion. In order to avoid leakage and to provide higher strength concrete of grade M30 and above is recommended for liquid retaining structures. Elevated water tanks are somewhat critical and strategic structures; damage happening of these structures during earthquakes, endangers drinking water supply, cause to fail in preventing large fires and may cause substantial economic loss. Due to large mass of tank and water concentrated at an elevation from base, water tanks are sensitive to earthquake loading and it experiences a high damage due to shaking of ground during earthquake. Large amount of energy released during this phenomenon reaches to water tank from origin of occurrence in the form of seismic waves, this seismic wave has different features like Peak ground acceleration, frequency contents, and effective duration of the ground motion, which affects the performance of water tank.

The study of time history analysis is to understand the actual behaviour of a structure at every addition of time, when it is subjected to a ground motion. The technique of time history analysis represents the most sophisticated method of dynamic analysis for the structure. The mathematical model of the structure is subjected to acceleration from earthquake at the base of the structure. Time history analysis consists of a step by step direct integration over a time interval, the equation of motion is solved with the acceleration, velocities and displacements of the previous step serving as initial function. The three earthquake ground motions selected are considered as an input motion for the time history analysis and applied at the base of the structure. The seismic performance of the elevated water tank under three different selected earthquake records will be examined for different staging conditions. For time history analysis StaadPro v8i software is used for the structure.

II. LITERATURE REVIEW

Housner G.W (1963) accounted for the motion of water relative to tank and motion of tank relative to ground. He indicated a simplified dynamic analysis for the response of elevated water tanks to earthquake ground motion. In this study it has been pointed out that if a closed tank is completely full of water or completely empty, it is essentially a one-mass structure and if the tank has a free water surface there will be sloshing of the water during an earthquake and this makes the tank essentially a two-mass structure. In order to account for the motion of water relative to tank he considered two different tanks, one on the ground level and the other at an elevation. In case of tank on the ground level, he considered dynamic fluid force on the wall of the tank only and neglected the dynamic fluid force on the floor. He mentioned the amplitude of vibration (d) for both cylindrical and rectangular water tanks. In case of elevated water tank, he compared the case of a completely full tank with half-filled tank and he concluded that the maximum force to which the half-full tank is subjected may be significantly less than half the force to which the full tank is subjected.

Nitesh J, Mohammad Ishtiyaque (2003) studied Wind Forces and Seismic Forces acting on an Intze Type water tank for Indian conditions. They considered the design of various wind forces and checked with different seismic zones using Response Spectrum method. For the purpose of this analysis, elevated tanks were considered as systems with a single degree of freedom with their mass concentrated at their centres of gravity. They considered both cases when the tank was full and empty. They considered 4 different cases for analysis each being with different zones and different wind speeds. After comparing the analysis results of these cases they concluded that, as the wind speed and seismic zone increases for the same bearing capacity volume of concrete and quality of steel both were increased. They also found out that as the wind speed increases the wind force on staging goes on increasing for different cases. Later it has been found out that the seismic load in case with Zone V has been increased almost 3 times as compared to the case with Zone II full tank condition. Similarly the seismic load in case with Zone V has been increased 4 times in tank empty condition. From one of the charts provided in the paper they analysed that for different cases the moment at face of braces, from lowest braces to top outer braces has been increased almost 2 times in each cases. In each case, as the wind speed goes on changing or increasing the wind moment calculated manually and analyzed from Staad Pro software differ by 4-5 %.

Korkmaz K.A Et. Al (2005) evaluated the earthquake performance of storage tanks in terms of earthquake resistance in Turkish industrial facilities. They believed that modelling a typical storage tank of an industrial facility helps to understand the structure’s seismic response therefore he considered a model tank structure which has been modelled as a solid with lumped mass and spring systems. He collected 40 different earthquake data on which performance estimation was done through non-linear time history analysis. In this study finite element modelling has been used to investigate the seismic response of the tank structures through structural model with a diameter of 14.6 m and a height of 18 m. For the model structure, analysis results were evaluated and compared. In the study, vulnerability of storage tanks in Turkey was determined and the probabilistic risk was defined with the results of the analysis. The summary provided for the displacement results considered the system’s geometry, period, mass and rigidity which have significant effects on the calculated displacements and forces. The resultant displacements showed that earthquake loads are effective in structural design and the calculated displacements may also be used for the conceptual design of circular columns supporting similar types of tanks analyzed in this study.

Moslemi M Et. Al (2011) evaluated the performance of elevated tanks under seismic loading. He investigated the seismic response of liquid filled tank using Finite element technique. Effect of wall flexibility and sloshing of water free surface were accounted in Finite element analysis. In this study the performance of elevated tank supported on concrete shaft was evaluated by Finite element method. Two analyses were carried out in the elevated tank model. It was concluded from the free vibration analysis that both impulsive and convective behaviours of the considered model are practically dominated by its fundamental modes. And from the time history analyses it was concluded that the contribution of impulsive component in total seismic response of elevated tank model is much higher than that of the convective model. The studied responses were shear and overturning moment at the base of shaft structure. The values of impulsive and convective terms were determined separately. Both impulsive and convective terms of the response of the elevated tank model considered were mainly dominated with fundamental methods. The computed FE time history results were also compared with those obtained from current practice and a very good agreement was observed. This verifies the validity of the current practice in estimating the seismic response of liquid filled elevated water tanks

Moslemi M, Kianoush M.R (2012) investigated the dynamic behaviour of cylindrical open top ground-supported water tanks. They carried out a comprehensive research work on dynamic behaviour of liquid filled tanks, both theoretically and experimentally. The study has been mainly focused to investigate the effect of a wide range of parameters such as tank aspect ratio, vertical component of earthquake, sloshing of the liquid free surface, wall flexibility, damping characteristics of the liquid components, base fixity, and higher impulsive and convective modes in ground supported cylindrical tanks. In addition, to investigate the accuracy of current code provisions in seismic analysis and design of liquid containing structures, a comparison between the calculated numerical results and those proposed by current practice is made. They proposed a rigorous FE model to investigate the precise three-dimensional behaviour of cylindrical tanks involving sloshing behaviour of contained liquid. Two cylindrical concrete tank models with different aspect ratios, representative of two classes of tanks namely ‘‘Shallow’’ and ‘‘Tall’’ were considered. The considered tall tank model has an aspect ratio of about 3 times higher than that of shallow tank model. Dimensions of the models were considered in such a way that the volume of the water remains unchanged in both tanks. They compared the results of time history analysis and free vibration analysis of both shallow and tall tank, in addition of comparing these results to the standard specifications. They concluded that the current design procedure in estimating the hydrodynamic pressure is too conservative.

III. SCOPE OF THE STUDY

Time history analysis is used to determine the seismic response of a structure under dynamic loading of representative earthquake. Time history analysis is a step-by- step analysis of the dynamic response of a structure to a specified loading that may vary with time.

1) This Study focusses on the dynamic Analysis of elevated water tanks under three different earthquakes (Bhuj, El-Centro, Kakinada).
2) Further extending the dynamic analysis of elevated water tank by changing the number of columns and diameter of columns and compare all these results with static analysis results.

IV. OBJECTIVE OF THE STUDY

Following parameters will be compared to analyses the elevated water tank.

1) Validation of the tank model manually and to determine shear forces in tank wall.
2) Base Shear in water tank.
3) To determine the max. nodal displacement values at the top of tank.

4) Mass Participation factor and time period of vibration in various cases of tank

V. METHODOLOGY

In the Present study, three earthquake ground motions selected are considered as an input motion for the time history analysis and applied at the base of the Tank structure. The seismic performance of the elevated water tank under three different selected earthquake records will be examined for different staging conditions. For time history analysis StaadPro v8i software is used for the structure and have been compared with Static analysis.

Time-history earthquake analysis is conducted to avoid many limitations of the response spectrum method and to account for the time-dependent response of the structure and better representation of the foundation-structure and fluid-structure interaction effects. The earthquake input for time-history analysis is usually in the form of acceleration time-histories that more accurately characterize many aspects of earthquake ground motion such as duration, number of cycles, presence of high energy pulse and pulse sequencing. Time-history analysis is also the only appropriate method for estimation the level of damage in structures. Response history is computed in the time domain using a step by step numerical integration or in the frequency domain by applying Fourier transformation.

HEIGHT OF WATER TANK	5m
NUMBER OF COLUMNS	6 /8/10
HEIGHT OF STAGING	30m
GRADE OF CONCRETE	M30
GRADE OF STEEL	Fe-415
BASE DIA OF TOP SPHERICAL DOME	15m
DIA OF BOTTOM CIRCULAR RING	7m
SIZE OF TOP RING BEAM	300mm*600mm
SIZE OF BOTTOM RING BEAM	300mm*600mm
SIZE OF COLUMN	400mm dia and 500mm dia

Table 1.1: Data Used for Analysis

Name	Type	E (MPa)	Design Strength
M30	Concrete	27386.13	Fc = 30 MPa
HYSD 415	Steel	200000	Fy = 415 MPa

Table 1.2: Material Used for Analysis

Name	Size (mm x mm)	Shape	Material
Beam	300 x 600	Concrete Rectangular	M30
Column	500 x 500	Concrete Circular	M30
Column	600 x 600	Concrete Circular	M30
Plate	125 x 125	Concrete	M30

Table 1.3: Properties of Member

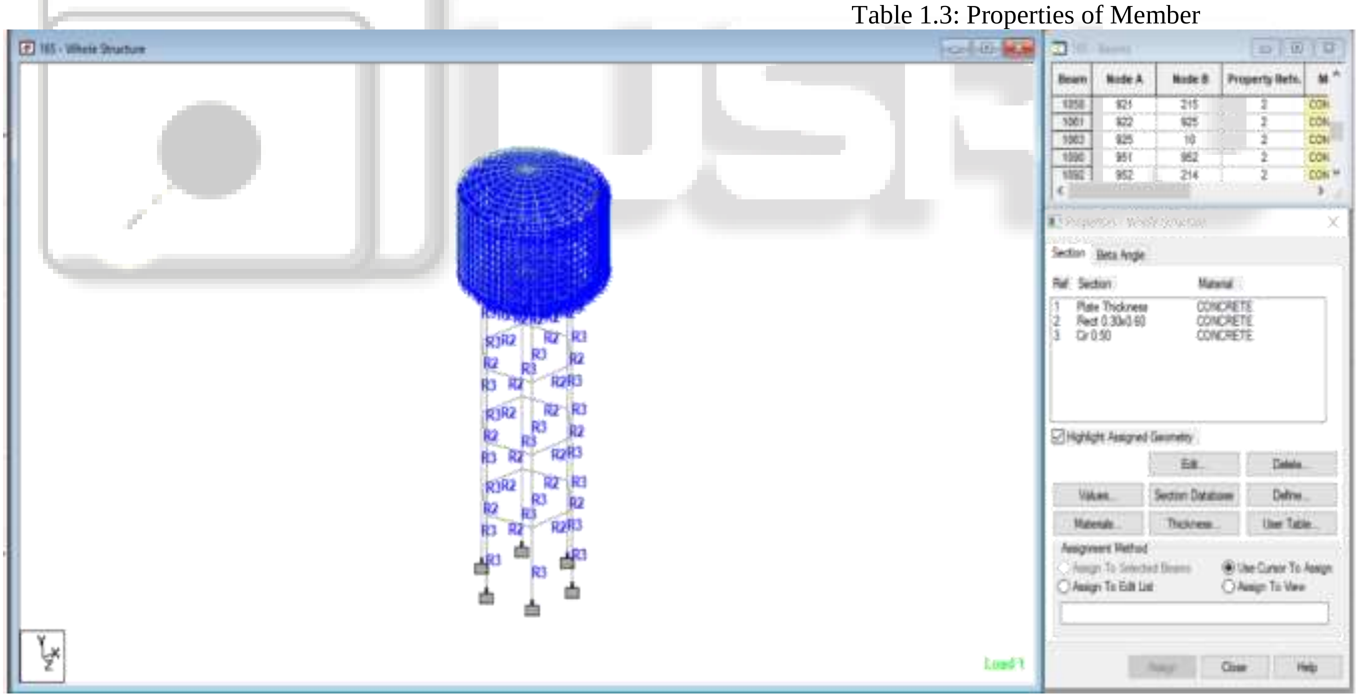


Fig. 1.1: Property of the Structure

VI. MANUAL VALIDATION OF TANK AND SHEAR STRESSES IN WALL OF TANK

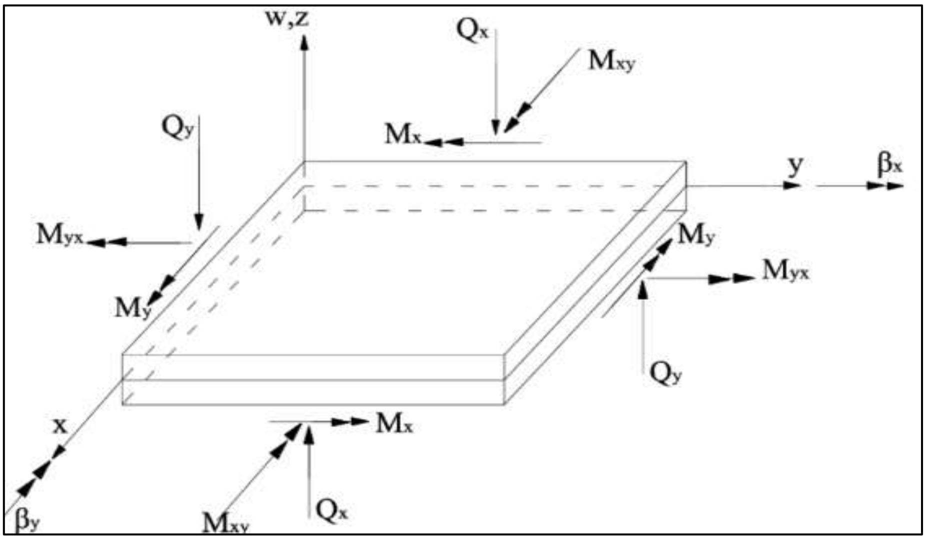


Fig. 1.2: Forces acting on Plates of wall

Hoop Tension acting on the wall = kWHR

T=k*10000*5*5

T=250000k

DEPTH FROM F.S.L(m)	VALUE OF K	HOOP TENSION T=250000k (N)	Q=T/150*100 (N/mm^2)
0.5	0.099	24750	$0.165<0.125$ N/mm^2
1.0	0.199	49750	$0.331<0.125$ N/mm^2
1.5	0.304	76000	$0.506<0.125$ N/mm^2
2.0	0.412	103000	$0.686<1.88$ N/mm^2
2.5	0.531	137250	$0.915<1.88$ N/mm^2
3.0	0.641	160250	$1.068<1.88$ N/mm^2
3.5	0.687	171750	$1.145<2.52$ N/mm^2
4.0	0.582	145600	$0.97<2.52$ N/mm^2
4.5	0.265	66250	$0.442<1.25$ N/mm^2
5	-	-	-

Table 1.4: Manual Values of Hoop Tension and Shear Stresses in Tank Wall

VII. DATA USED FOR TIME HISTORY ANALYSIS

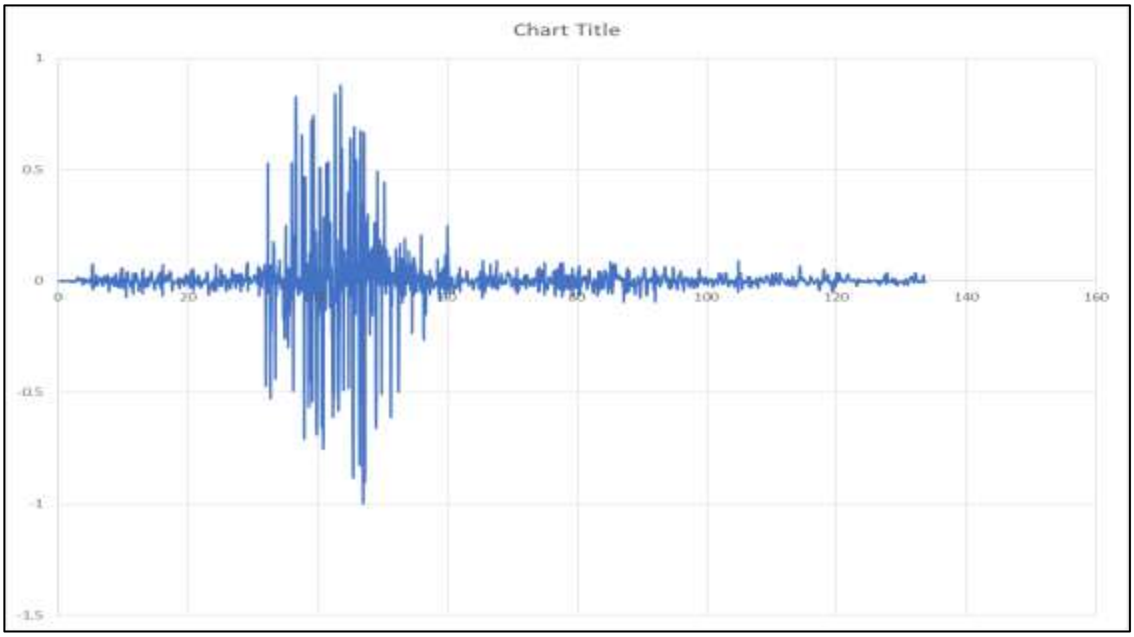


Fig. 1.3: Bhuj earthquake Time history data

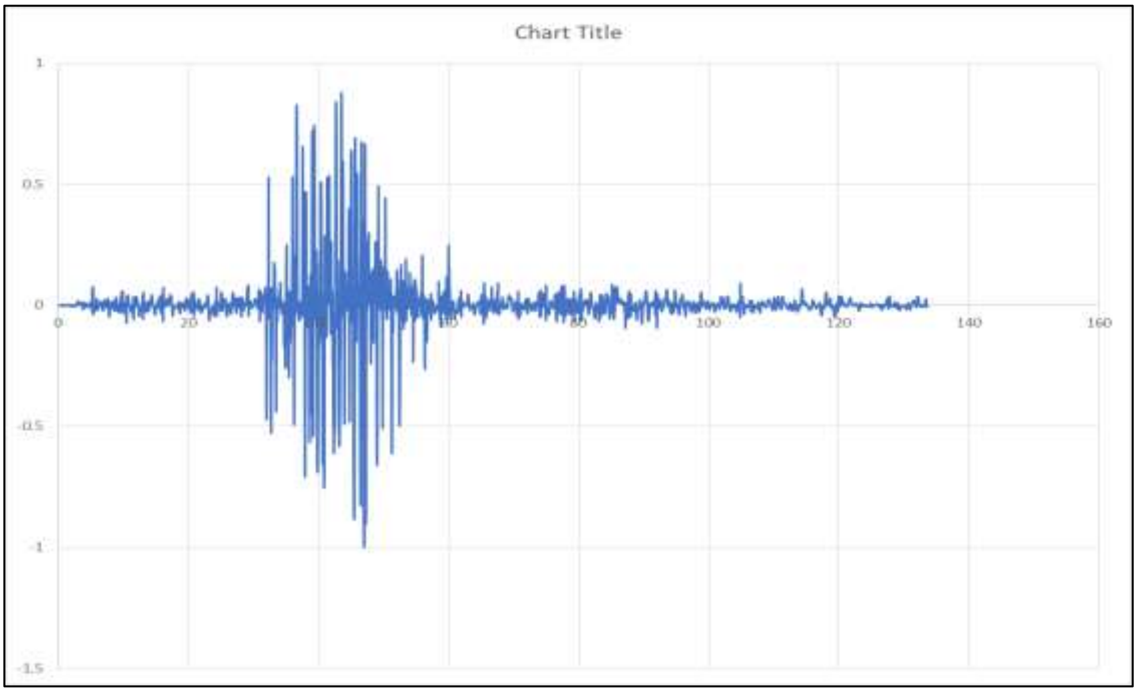


Fig. 1.4: Elcentro earthquake Time history data

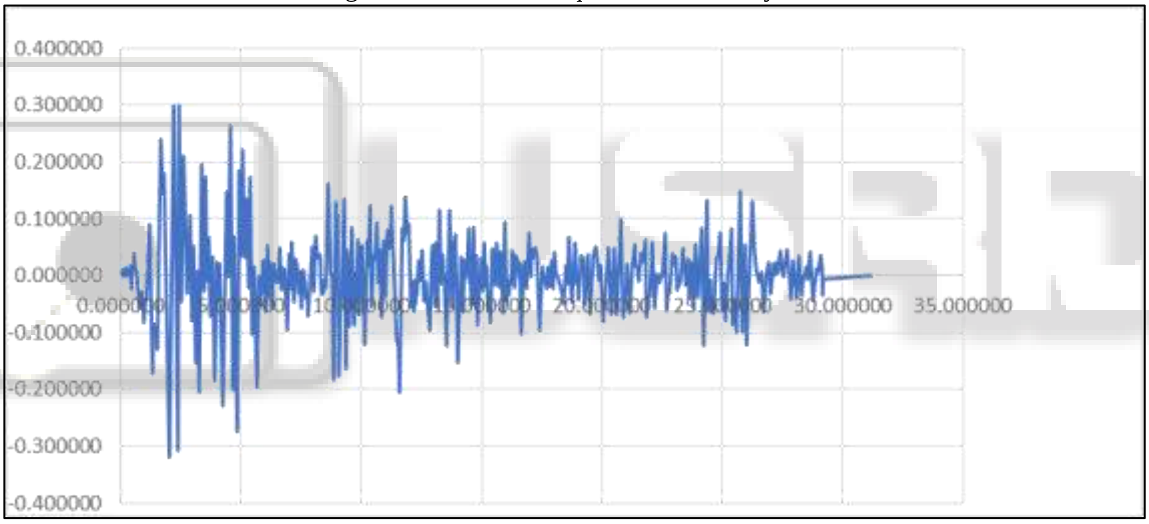
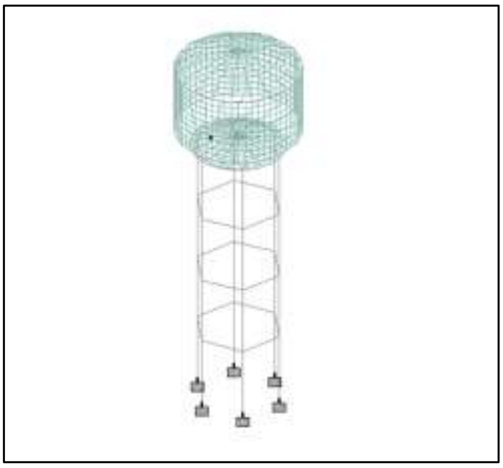
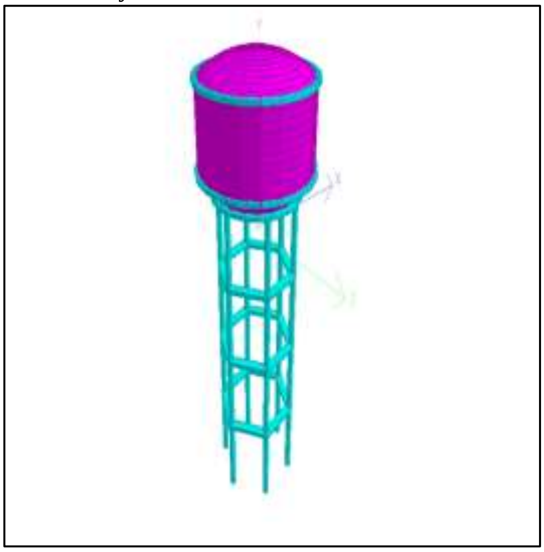


Fig. 1.5: Kakinada earthquake Time history data

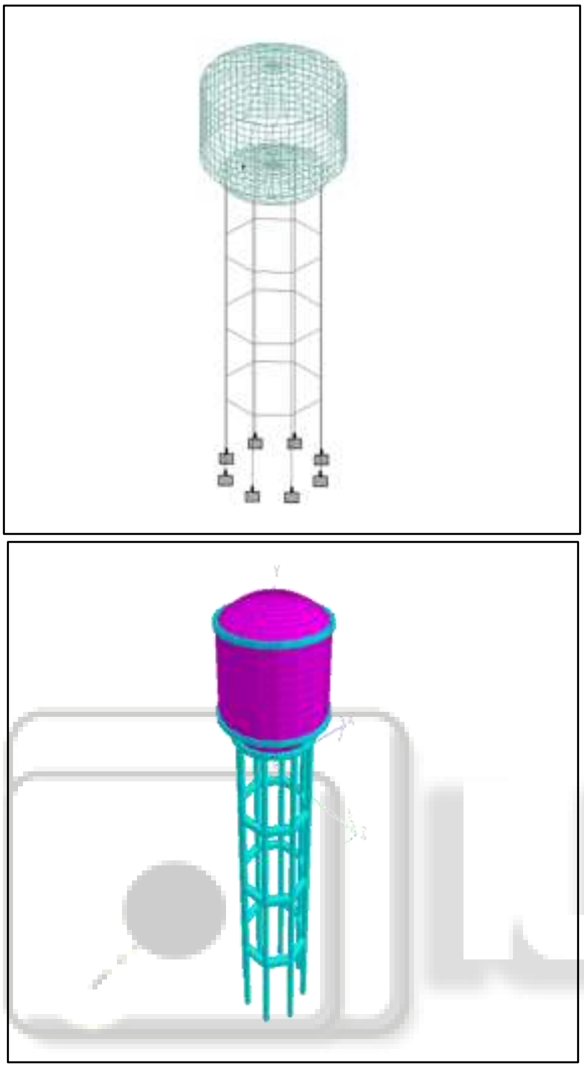
VIII. INTZ TANK MODELS

A. Tank Model Having 6 columns of 500mm and 600mm dia

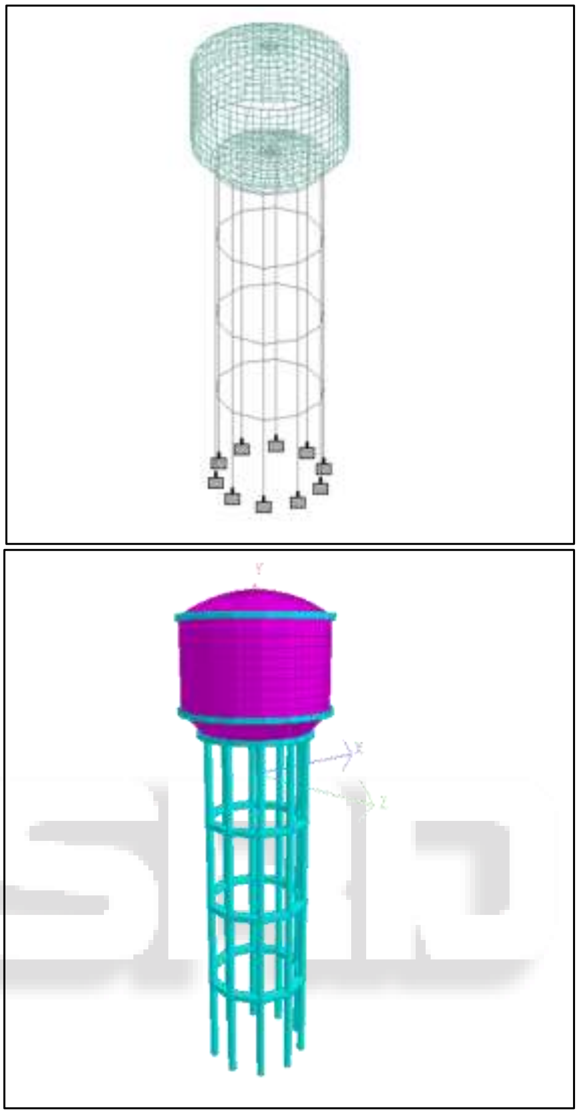




B. Tank Model Having 8 columns of 500mm and 600mm dia



C. Tank Model Having 10 columns of 500mm and 600mm dia



IX. RESULTS

	MAX. BASE SHEAR (N)			
TYPE OF WATER TANK	KAKINADA	ELCENTRO	BHUJ	STATIC ANALYSIS
Water Tank Consisting of 6 Columns of 500mm Dia	3010	5249	11591	6795
Water Tank Consisting of 6 Columns of 600mm Dia	4424	6732	14697	6755
Water Tank Consisting of 8 Columns of 500mm Dia	5967	6856	13117	7885
Water Tank Consisting of 8 Columns of 600mm Dia	7433	8300	15015	7975
Water Tank Consisting of 10 Columns of 500mm Dia	6403	7300	12320	7404
Water Tank Consisting of 10 Columns of 600mm Dia	7550	8340	16719	8742

Table 1.4: Comparison of Base shear between Time History Analysis and Static Analysis

	MAX. NODAL DISPLACEMENT (mm)			
TYPE OF WATER TANK	KAKINADA	ELCENTRO	BHUJ	STATIC ANALYSIS
Water Tank Consisting of 6 Columns of 500mm Dia	24.104	26.75	35.339	109.40
Water Tank Consisting of 6 Columns of 600mm Dia	22.15	24.347	32.19	95.62
Water Tank Consisting of 8 Columns of 500mm Dia	14.281	15.22	21.254	77.02
Water Tank Consisting of 8 Columns of 600mm Dia	12.331	13.062	16.386	61.99
Water Tank Consisting of 10 Columns of 500mm Dia	11.074	11.917	13.964	47.49
Water Tank Consisting of 10 Columns of 600mm Dia	8.75	9.213	10.506	37.80

Table 1.5: Comparison of Nodal Displacement between Time History Analysis and Static Analysis

TYPES OF WATER TANK	TIME PERIOD OF VIBRATION (Sec)
Water Tank Consisting of 6 Columns of 500mm Dia	0.320
Water Tank Consisting of 6 Columns of 600mm Dia	0.268
Water Tank Consisting of 8 Columns of 500mm Dia	0.229
Water Tank Consisting of 8 Columns of 600mm Dia	0.192
Water Tank Consisting of 10 Columns of 500mm Dia	0.179
Water Tank Consisting of 10 Columns of 600mm Dia	0.159

Table 1.6: Time Period of Vibration

X. DISCUSSION

By increasing the number and diameter of columns from Water Tank having 6 columns of 500mm dia to Water Tank having 10 columns of 600mm dia, Base Shear has been increased by:-

- 1.5% for Kakinada Earthquake
- 0.6% for Elcentro Earthquake
- 0.5% for Bhuj Earthquake

By increasing the number and diameter of columns from Water Tank having 6 columns of 500mm dia to Water Tank having 10 columns of 600mm dia, Nodal displacement has been decreased by:-

- 6.36% for Kakinada Earthquake
- 6.55% for Elcentro Earthquake
- 7.0% for Bhuj Earthquake
- It has been found that base shear values and nodal displacement values are also increased by increasing the magnitude of the Earthquake. As Bhuj Earthquake has highest magnitude among three earthquakes, so Max Base shear value and Nodal displacement has been found in the Bhuj Earthquake Case.
- Max Base shear value obtained from Time history Analysis for Kakinada Earthquake is 0.87 times the value obtained from Static Analysis.
- Max Base shear value obtained from Time history Analysis for Elcentro Earthquake is almost same as the value obtained from Static Analysis. Max Base shear value obtained from Time history Analysis is 0.96 times the value obtained from Static Analysis.
- Max Base shear value obtained from Time history Analysis for Bhuj Earthquake is 1.91 times the value obtained from Static Analysis
- In Static Analysis, percentage reduction in nodal displacement from Water Tank having 6 columns of 500mm dia to Water Tank having 10 columns of 600mm dia is 6.54% which almost same as Elcentro earthquake.
- The least value of Nodal displacement obtained from Time history Analysis for Kakinada Earthquake is 0.231 times the value obtained from Static Analysis
- The least value of Nodal displacement obtained from Time history Analysis for El centro Earthquake is 0.243 times the value obtained from Static Analysis
- The least value of Nodal displacement obtained from Time history Analysis for Bhuj Earthquake is 0.271 times the value obtained from Static Analysis
- Time History Analysis is realistic method used for seismic analysis. It provides a better check to the safety of the structure analysed and designed by method specified by code. Static Analysis always gives higher values of seismic responses such as base shear values, storey drift, nodal displacement, max axial forces, bending moments which is not as accurate as time history method for safety of the structure.
- Due to increase in stiffness of the Structure, Time period of vibration has been reduced by 0.5%. By increasing the dia and number of columns Time period of Vibration has been reduced from 0.32 sec to 0.159 sec
- Max Base Shear and minimum Nodal displacement is found in Water Tank having 10 columns of 600mm dia in all types of earthquake. Time period of vibration also found to be least for Water Tank having 10 columns of 600mm dia. so water Tank having 10 columns of 600mm dia is our most effective model for all the three Earthquake

XI. SCOPE OF FUTURE WORK

The present work is carried out to study the Time history analysis of elevated water tank. It has also scope to study seismic behaviour by changing shape of water tank i.e. Rectangular or Circular water tank. Depth of water in water tank can also be changed in future. In Future behaviour of water tank for different type of bracings in columns can also be studied.

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