Non-Linear Time History Analysis of An Elevated Water Tank

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Abstract- *It was discovered that reinforced concrete elevated water tanks with frame staging outperformed reinforced concrete elevated water tanks with shaft staging in terms of seismic resistance. These can be due to the frame staging's seismic energy absorption capability. As a result, the primary goal of this research is to better understand the seismic behaviour and performance characteristics of elevated water tanks with frame staging. Furthermore, when compared to other shapes, circular tanks have the smallest surface area for a given tank size. As a result, the amount of material needed for a circular water tank is less than for other shapes. As a result, a circular water tank was chosen, and seismic analysis of elevated RC circular water tanks was carried out according to IITK-GSDMA guidelines, with the behaviour of the water tank analysed for various parameters such as zone factor, soil condition, and different staging heights. SAP 2000 was used to determine the structure's modal characteristics (mode shapes and modal participation mass ratio).*

Keywords- SAP2000, Elevated water tank, Rectangular water tank, Circular water tank, Time history Analysis

I. INTRODUCTION

Elevated water tanks are commonly used in public water distribution system. Being an important part of lifeline system, and due to post earthquake functional needs, seismic safety of water tanks is of considerable importance. Elevated water tanks also called as elevated service reservoirs (ESRs) typically comprises of a container and a supporting tower (also called as staging). Staging in the form of reinforced concrete shaft and in the form of reinforced concrete column-brace frame are commonly deployed. The column-brace frame type of staging is essentially a 3D reinforced concrete frame which supports the container and resists the lateral loads induced due to earthquake or wind.

Aim of the present study is to bring out the differences in seismic behavior of column beam (Building) frame and column-brace (staging) frame in the post-elastic region and to quantify their ductility. In addition, nonlinear dynamic analysis is also performed to bring out the differences in the nonlinear dynamic behavior of twithout types of frames. Pushover analysis is an approximate analysis method in which the structure is subjected to monotonically increasing lateral forces with an invariant height-wise distribution until a target displacement is reached. Pushover analysis consists of a series of sequential elastic analysis, superimposed to approximate a force-displacement curve of the overall structure. A twithout or three dimensional model which includes bilinear or tri-linear load-deformation diagrams of all lateral force resisting elements is first created and gravity loads are applied initially.

II. LITRATURE REVIEW

G. W. Housner et. al. [1] Studied simplified formulae to calculate earthquake forces for a water tank considering it as a twithout-mass system is given. A dynamic analysis of tanks should take into account the motion of water relative to the tank as well as motion of the tank relative to the ground. If a closed tank is completely filled with water or completely empty, it is essentially a one-mass structure. Usually, the tanks have free water surfaces and therefore, there will be sloshing of water during an earthquake and this makes the tank essentially a twithout-mass structure. In this case, the dynamic behaviour of elevated water tank may be quite different. For some cases, the sloshing effect might be predominant whereas for some it might not be dominating. Therefore, A detailed understanding of dynamic behaviour of tanks is required. As the fluid containers are important in nuclear reactor installation, a detailed presentation of without rk able method for predicting the dynamic behaviour of the fluid is given by author. The impulsive pressure is not impulses in the usual sense but is associated with inertia forces produced by accelerations of wall of the container and are directly proportional to these accelerations. The convective pressures are those produced by the oscillations of the fluid and are therefore the consequences of the impulsive pressure. In the analysis the impulsive and convective pressures are examined separately.

S.C. Dutta et al [2] Studied elevated water tanks in past earthquakes (including 1952 Kern County and recent 1993 Killari earthquakes) has highlighted the importance of this problem. It is established that these structures may have amplified torsion-induced rotation if their torsional-to-lateral natural period ratio t is close to 1 and amplified displacement of structural elements due to the coupled lateral torsional vibration if t is within the critical range 0:7,t, 1:25: one reinforced concrete elevated water tank collapsed vertically downwards, burying the six supporting columns directly underneath the bottom slab of its container during the 1993 Killari, India. Elevated water tanks, with their broadly axi-symmetric geometry and mass distribution, should have no considerable eccentricity between centre of mass and centre of stiffness

B.Devadanam et al [3] Found that reinforced concrete elevated water tanks with frame staging, has shown better seismic resistance than reinforced concrete elevated water tanks with shaft staging. These can be attributed to the seismic energy absorption capacity of the frame staging. Hence this study is primarily focused on understanding the seismic behaviour and performance characteristics of elevated water tank with frame type staging. Moreover, circular tanks have minimum surface area when compared to other shapes for a given capacity of the tank. Hence the quantity of material required for circular water tank is less than that required for other shapes. Hence, a circular water tank has been adopted and seismic analysis of elevated RC circular water tanks has been performed as per IITK-GSDMA guidelines and behaviour of the water tank for various parameters viz., zone factor, soil condition, different staging heights have been analyzed. The modal characteristics (mode shapes and the modal participation mass ratio) of the structure were ascertained using SAP2000.

S. M. Maidankar et al [4] From the very upsetting experiences of few earthquakes, like Bhuj earthquake (2001) in India, R.C.C. elevated water tanks were heavily damaged or collapsed. The main finding of this study is to understand the behavior of different staging, under different loading conditions and strengthening the conventional type of staging, to give better performance during earthquake for three different types of bracing systems, applied to the staging of elevated circular water tank for earthquake zones. Analysis is carried out using SAP2000 v15. Twenty-seven models are used for calculating base shear and nodal displacements for staging with normal bracing, cross bracing, and radial bracing in staging. Variation in staging height is 12m, 16m, and 20 m at 4m eachIn the analysis response spectrum method has been used for seismic analysis of structures by using software. Sloshing forces and base shear was calculated from IITK guideline, the results obtain from software was compared with manual calculation. Hydrodynamic pressure for impulsive and convective mode was calculated.

Sadik Can Girginaet al [5] studied the seismic performance factors for precast buildings with hybrid beam-column connections. Hybrid connections were constructed by welding of corbel plates to beam end plates where beam longitudinal re bars were welded, and casting of concrete through the designated gaps in beam tops and column elements at site. Their study presents the development of a numerical model for hybrid connections to be used to assess seismic performance of multi-storey precast concrete structures. The numerical model included truss-based elements for beam-column connections and fiber-based elements for beams and columns. Lateral load-drift ratio relations for the measured and computed cyclic responses of a precast connection were compared. In addition, two-dimensional three- and five- storey precast concrete frames were designed for seismic performance evaluation. Frame models were analyzed by performing nonlinear static pushover analyses and incremental dynamic analyses with representative ground motions. Response modification factors were obtained and evaluated for seismic design of precast concrete buildings.

R.Livaoglu et al [6] The aim of this paper is to investigate how the soil structure interaction affects sloshing response of the elevated tanks with frame staging system on different soil conditions. For this purpose, the elevated tanks with frame staging system which are built on six different soil profiles are analyzed for both embedded and surface foundation cases. Thus, considering these six different profiles described in well-known earthquake codes as supporting medium, a series of transient analysis have been performed to assess the effect of both fluid sloshing and soil-structure interactionFinally results from analyses showed that the soil-structure interaction for the elevated tanks affected the sloshing response of the fluid inside the vessel. The other conclusion can be drawn from the study is that the sloshing response is affected from the embedment more in case of soft soil than the stiff soil. In other withoutrds, when the soil gets softer, the effect of the embedment on sloshing response becomes more visible.

Amlan K. Sengupta et al [7] After the tremor in Bhuj, Gujarat, in 2001, there has been a purposeful exertion to address the seismic helplessness of existing structures in India. This paper is a piece of an undertaking, whose point is to advance techniques to evaluate the seismic weakness of fortified solid three-to ten-storeyed, private and business structures and to propose retrofit measures for the basically inadequate structures. For the structures tended to in the task, the basic component insufficiencies are lacking shear limit, center restriction and rebar grafting of sections; deficient shear limit, rebar safe haven and plastic pivot turn capacity of shafts and insufficient control of pillar to-segment joints.. Without authority components in the piece and legitimate enumerating of the associations with the structure outline, there is absence of necessary activity of the horizontal burden opposing components. The neighborhood retrofit procedures of section, shaft, pillar to-segment joint, divider and establishment fortifying are inspected. Under worldwide retrofit techniques, the expansion of infill dividers, shear dividers and steel supports, and the decrease of the structure inconsistencies are referenced. A point by point contextual analysis is accounted for. In the end, issues relevant to retrofit are talked about.

P.V. Muthu et al [8] This paper presents analysis to study the effects of sloshing in overhead liquid storage tank. In such structure a large mass concentrated at the top of slender supporting structure makes the structure vulnerable to horizontal forces e.g. due to earthquakes. This study focuses mainly on the response of the elevated Intze type water tank to dynamic forces by both equivalents static method and finite element analysis using commercial software. To find out the design parameters for seismic analysis and also the importance in the sloshing effect consideration during the design. Here an elevated Intze type water tank is Analyzed and designed. The analysis is carried out for twithout cases namely, tank full condition considering only the hydrostatic effects and tank full condition considering the sloshing effect using STAAD pro. From the analysis it is concluded that, to consider the sloshing effect along with the effect of hydrodynamic pressure on container wall of the tank during the design is very important in earthquake prone regions. The results obtained from analyses are discussed considering the importance of the structure during seismic activity. There is almost 40% increase of time period for first and second mode on comparing hydrostatic case and sloshing case which indicates more consideration should be given to sloshing case rather than hydrostatic case. On examining the critical elements of staging, the maximum axial force in sloshing case increases 56% more than in hydrostatic case, 56% in shear force and 45% increase of bending moment in x-direction, while 40% in y-direction and 59% in z-direction.

S. Bozorgmehrnia et al [9] In this research, a sample of reinforced concrete elevated water tank, with 900 cubic meters capacity, exposed to three pair of earthquake records have been studied and analyzed in time history using mechanical and finite-element modeling technique. The liquid mass of tank is modeled as lumped masses known as sloshing mass, or impulsive mass. The corresponding stiffness constants associated with these lumped masses have been withoutrked out depending upon the properties of the tank wall and liquid mass. Tank responses including base shear, overturning moment, tank displacement, and sloshing displacement have been calculated. Results reveal that the system responses are highly influenced by the structural parameters and the earthquake characteristics such as frequency content. Based on this study the researcher concluded that in this study, an elevated 900 m3 water tank which was supported by moment resisting frame was considered. Using Housner twithout mass models, dynamic responses including base shear, overturning moment, roof and floor displacement, and sloshing displacement were assessed under three earthquake records. The dynamic responses of tank have been determined using time history analysis in three cases, i.e. empty, half-full and full.

K. J. Dona Rose et al [10] Studied tanks of various capacities with different staging height is Modeled using ANSYS software. The analysis is carried out for twithout cases namely, tank full and half level condition considering the sloshing effect along with hydrostatic effect. The time history analysis of the water tank is carried out by using earthquake acceleration records of EL CENTRO. The tanks withstood the acceleration with the displacements within the permissible limits. The peak displacements and base shear obtained from the analysis were also compared. The methodology includes fixing the dimensions of components for the selected water tank and performing nonlinear dynamic analysis (time history analysis) by: 1893-2002 (part 2) draft code. This withoutrk proposes to study circular tanks of different capacity and staging height and column configuration. The analysis is carried out for tank with full capacity and half capacity and considering the sloshing effect along with hydrostatic effects. Finite Element Model (FEM) issued to model the elevated water tank using ANSYS software.

III. METHODOLOGY

The main objective of this study is to examine the behaviour of overhead circular water tank supported on frame staging considering different modelling systems. All the above cases are analysed for five different earthquake records i.e. time history analysis. The analysis is carried out using SAP 2000 software.

Time History Analysis

It is an analysis of the dynamic response of the structures at each increment of time, when its base is subjected to a specific ground motion time history. In this method, the structure is subjected to real ground motion records. This makes this analysis method quite different from all of the other approximate analysis methods as the inertial forces are directly determined from these ground motions or in forces are calculated as function of time, considering dynamic properties of building structures.

Non-linear Time History Analysis

Time-History analysis is a step-by-step procedure where the loading and the response history are evaluated at successive time increments, Δt– steps. During each step the response is evaluated from the initial conditions existing at the beginning of the step (displacements and velocities) and the loading history in the interval. Non linear time history analysis is the dynamic analysis in which the loading causes significant changes in stiffness. With this method the non-linear behaviour may be easily considered by changing the structural properties (e.g. stiffness, *k*) from one step to the next. Therefore, this method is one of the most effective for the solution of non-linear response. Non-linear time history analysis utilizes the combination of ground motion records with a detailed structural model therefore is capable of producing results with relatively low uncertainty. In nonlinear dynamic analyses, the detailed structural model subjected to a ground-motion record produces estimates of component deformations for each degree of freedom in the model and the modal responses are combined using schemes such as the square-root-sum-of-squares.

IV. PROBLEM STATEMENT

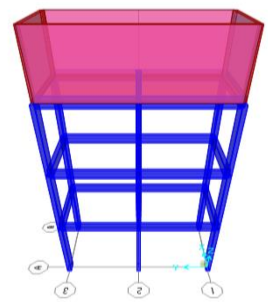
Design Data –

Total Structure=200
Minimum water capacity required=200 X 5 X 135=135000 lit.
Considering 10% commercial use extra.
Total Capacity=150000 lit. =150m^3
Staging Height=20m
Assume height of tank=4m (Ref.IS 3370)
Thickness of CROSS BRACING wall=180mm
Thickness of base slab=200mm
For rectangular water tank:
Capacity=L*B*H
For circular water tank:
Capacity=3.14*r^2*h

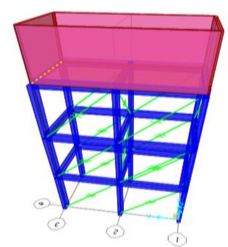
Model No.1	Rectangular water tank without bracing
Model No.2	Rectangular water tank with single bracing
Model No.3	Rectangular water tank double bracing
Model No.4	Rectangular water tank knee bracing
Model No.5	Circular water tank without bracing
Model No.6	Circular water tank with single bracing
Model No.7	Circular water tank double bracing
Model No.8	Circular water tank knee bracing

MODELING IN SAP2000

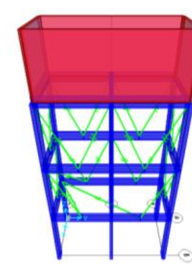
Rectangular Water Tank (Plain)



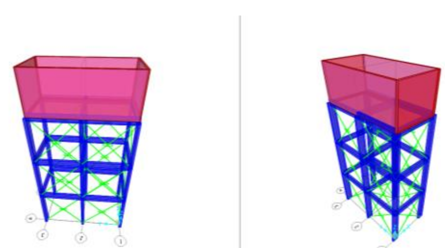
Rectangular Water Tank with Single Bracing



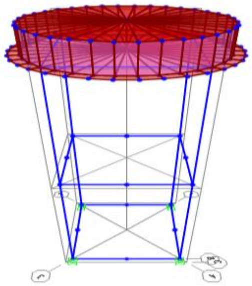
Rectangular Water Tank with Knee Bracing



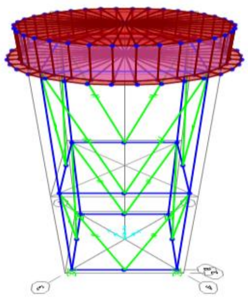
Rectangular Water Tank with Cross Bracing



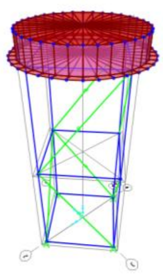
Circular Water Tank Without Bracing (Plain)



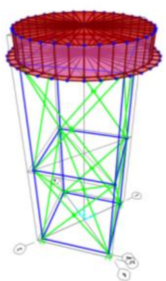
Circular Water Tank with Knee Bracing



Circular Water Tank with Single Bracing



Circular Water Tank with Cross Bracing



V. RESULTS AND DISCUSSION

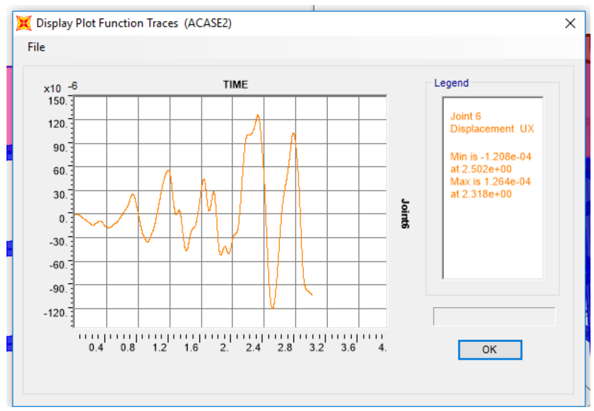
General-

The result of analytical parameter such as story drift, base shear, and time history analysis of Composite frame are carried out. These results are shown in tabular form. The interpretations of this result are compared graphically. Also soil structure interaction comparison of composite element with element are done by tabular form

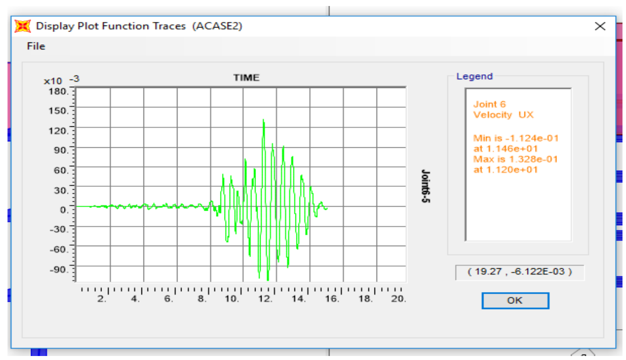
Following graphs are obtained from SAP-2000:

For Rectangular Water Tank:-

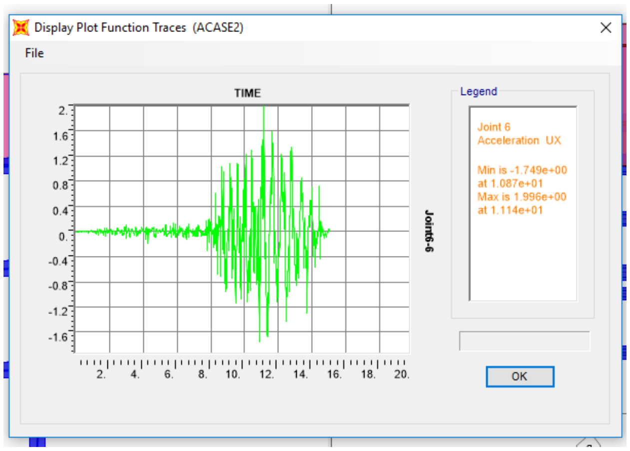
1. Displacement (Ux):



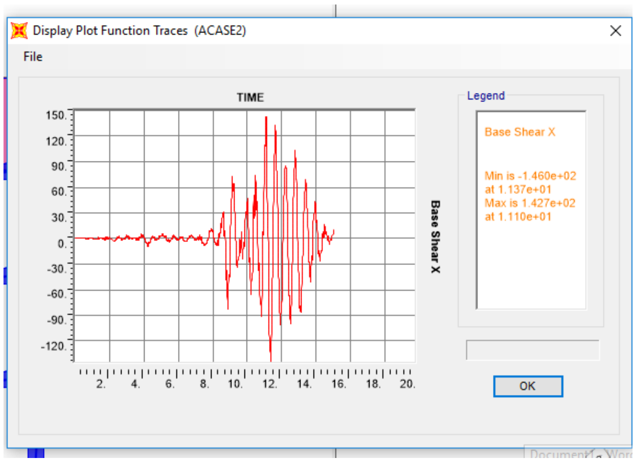
2. Velocity:



3. Acceleration:



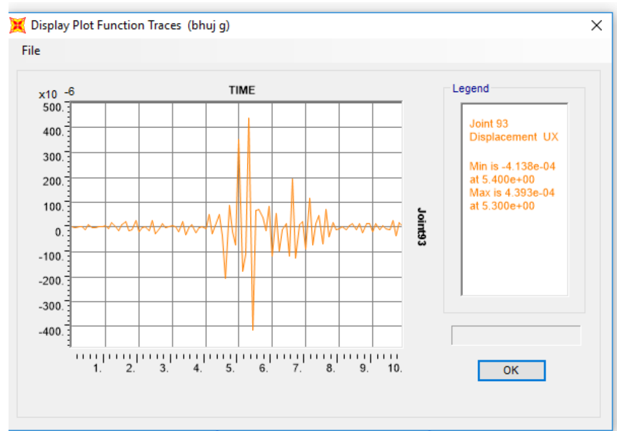
4. Base Shear



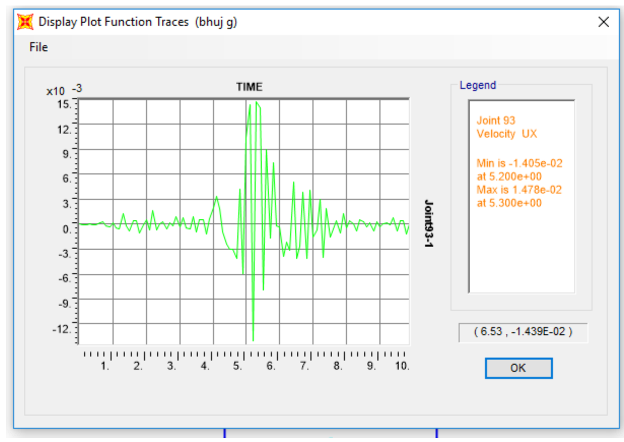
Analysis Parameter for Rectangular Water Tank			
Sr. No.	Name	Type	Max Value
1	Without Bracing	Displacement (Ux)	4.6mm
		Velocity	45.9mm/s
		Acceleration	6.5mm/s^2
		base shear	1.43x10^{2}kn
2	Single Bracing	Displacement (Ux)	2.26mm
		Velocity	41.31 mm/s
		Acceleration	5.85 mm/s^2
		base shear	6.45x10^{2}kn
3	Knee Bracing	Displacement (Ux)	1.09mm
		Velocity	26.85 mm/s
		Acceleration	3.8025 mm/s^2
		base shear	3.36x10^{2}kn
4	Cross Bracing	Displacement (Ux)	1.74mm
		Velocity	32.2218mm/s
		Acceleration	4.563 mm/s^2
		base shear	3.74x10^{2}kn

For Circular Water Tank:-

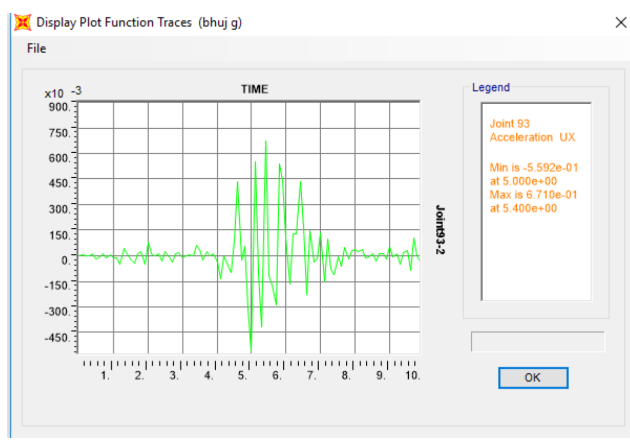
Displacement:



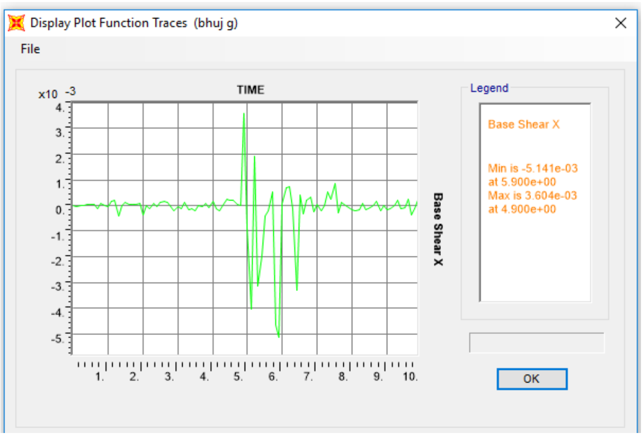
Velocity:



Acceleration



Base Shear



Analysis Parameter for Circular Water Tank			
Sr No	Name	Type	Max Value
1	Knee Bracing	Displacement(Ux)	6.66mm
		Velocity	$2.24x10^{-2}$mm/s
		Acceleration	1.02 mm/s^2
		Base Shear	$6.15x10^{3}$kn
2	Single Bracing	Displacement(Ux)	6.28mm
		Velocity	$2.22x10^{-2}$ mm/s
		Acceleration	$9.82x10^{-1}$ mm/s^2
		Base Shear	$8.83x10^{3}$kn
3	Double Bracing	Displacement(Ux)	6.64mm
		Velocity	2.24 $x10^{-2}$ mm/s
		Acceleration	1.01 mm/s^2
		Base Shear	$6.15x10^{3}$kn
4	Without Bracing	Displacement(Ux)	7.49mm
		Velocity	$2.70x10^{-2}$ mm/s
		Acceleration	1.09 mm/s^2
		Base Shear	$5.26x10^{3}$kn

VI. CONCLUSION

In the given study the elevated water tank with various bracing systems are studied for staging height 20m.Firstly water tank model is designed for 150m^3 capacity and for time history analysis bhuj earthquake is considered. Various models of bracing systems are proposed and following conclusions are made.

- For the time-displacement results in SAP 2000,difference between rectangular water tank without bracing and rectangular water tank with single bracing is 42%,because the diagonal bracings increase resistance to lateral bracings
- For the time-velocity results in SAP 2000Difference between rectangular water tank without bracing and rectangular water tank with single bracing is 30% because the diagonal bracings increase resistance to lateral bracings
- For the time-acceleration results in SAP 2000Difference between circular water tank without bracing and rectangular water tank with single bracing is 5% because the diagonal bracings increase resistance to lateral bracings
- For circular water tank without bracing max deformation is 7.49 mm. Difference between circular water tank without bracing and circular water tank with single bracing is up to 15-20%
- By performing the analysis of circular and rectangular water tanks with different bracing systems we came to the conclusion that rectangular water tank is more sustainable as compared to circular water tank in accordance to displacement. And the displacement of circular and rectangular water tank is 6.28mm and 2.26mm respectively.
- In accordance to velocity and acceleration parameter circular water tank gives better results than rectangular water tank.
- The bhuj intensity is considered in zone IV which has time period of 132 sec and for this non linear dynamic analysis the circular water tank with bracings is observed to be most effective as its stiffness is observed more than rectangular water tank

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