Dynamic Evaluation of a Circular and Rectangular Water Tanks with Non-Linear Time History Data

[1]Miss. Rutuja Vitthal Sabale, [2]Prof. Mr. Ravindra Desai

[1]Student, M.Tech Structural Engineering, [2]Professor
Dept. of Civil Engineering
Sanjay Ghodawat University, Kolhapur.

Abstract- **Elevated water tank is a water storage facility supported by a tower and constructed at an elevation to provide useful storage and pressure for a water distribution system. The height of the tower provides the pressure for the water supply system. During the high peak hours of the water system, the static potential reserved in the tank will be used to provide the pressure in the water pipes and helps the pumping systems by maintaining the necessary water pressure without increasing pumping capacity. They also present enough water pressure for firefighting when the pumping systems are not sufficient to provide large amount of water needed for fire extinguishing. In public water distribution system, Elevated water tanks are generally used being an important part of a lifeline system. Due to post earthquake functional needs, seismic safety of water tanks is of most important. Elevated water tanks also called as elevated service reservoirs (ESRs) typically consists of a container and a supporting tower. In major cities and also in rural areas elevated water tanks forms an Integral part of water supply system. The elevated water tanks must remain functional even after the earthquakes as water tanks are most essential to provide water for drinking purpose. These paper analysis and design of elevated water tank of different type such as rectangular and circular water tank by using software SAP2000 by using various bracing system.**

Keywords: **Elevated Water tank, SAP 2000, Bracing System, Circular, Rectangular.**

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.

A. Performance of elevated water tank

Geological and seismological discoveries during the 20thcentury have helped in initiating the development of seismic building codes and earthquake resistant buildings and structures. The improvement in seismic design requirements has led to more robust, safe and reliable buildings. Due to the earthquake many buildings collapsed killing thousands of people. Therefore, to protect the earthquake effects/earthquake damages to the buildings and to protect the life of people, it’s important to use seismic control techniques. The base isolators are provided at the basement level to absorb the earthquake energy or earthquake forces. Not only important buildings such as Museum, Shopping Mall, Hospital, Water tanks, Dams, and Airports etc. are provided with base isolator, but if the occurrence of the earthquake is more often it can be provided for all types of buildings.

B. Nonlinear Time History Analysis:

Nonlinear Time History Analysis can be used for all isolation systems regardless of height, size, geometry, location, and nonlinearity of the isolation system. Time-History analysis is a step-by-step procedure where the loading and the response history are evaluated at successive time increments. 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. Nonlinear 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, Response of base isolated structure on liquefiable soil. 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.

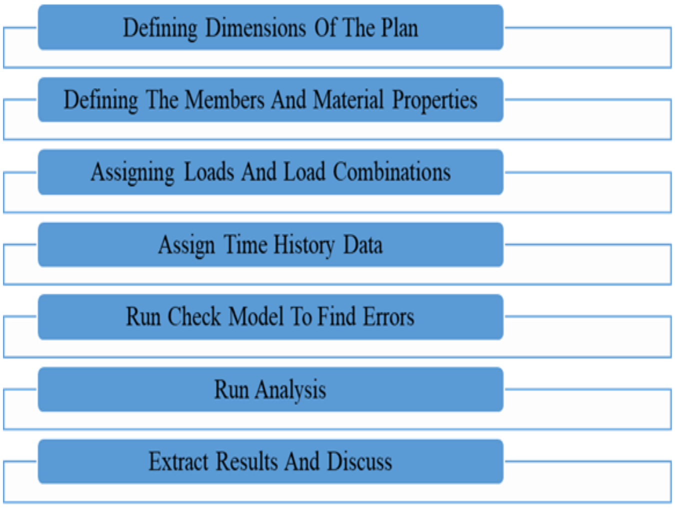
Table 1: Properties of Ground Motion

Earthquake Area	Magnitude	Record/ Component	PGA
EI-Centro (1940)	7.2	El-Centro 1940,	0.35 g
Bhuj (2001)	7.7	Bhuj (2001), India	0.38 g
Uttarkashi	6.6	Uttarkashi (2001), India	0.31 g

(2001)			
Koyna (1967)	6.5	Koyna(1967)	0.31g
Chamoli (1999)	6.8	Chamoli(1999)	0.31g

II. 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.



A. Types of bracing

- **Single diagonals**

Trussing, or triangulation, is formed by inserting diagonal structural members into rectangular areas of a structural frame, helping to stabilise the frame. If a single brace is used, it must be sufficiently resistant to tension and compression

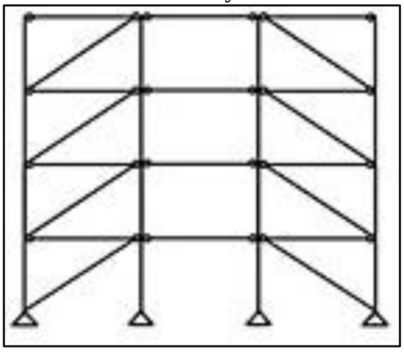


Fig 1. Single bracing

- **Cross-bracing**

Cross-bracing (or X-bracing) uses without diagonal members crossing each other. These only need to be resistant to tension, one brace acting to resist sideways forces at a time depending on the direction of loading. As a result, steel cables can also be used for cross-bracing.

Fig 2 Cross bracing

- **K-bracing**

Braces connect to the columns at mid-height. This frame has more flexibility for the provision of openings and results in the least bending in floor beams. K-bracing is generally discouraged in seismic regions because of the potential for column failure if the compression brace buckles

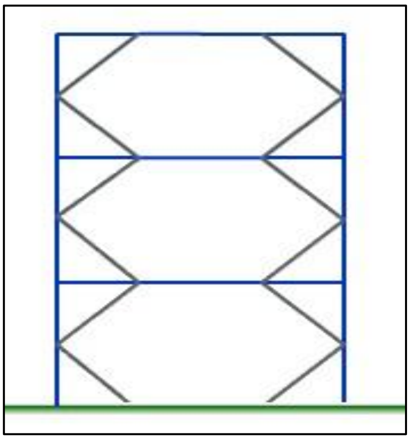


Fig 3 K-bracing

III. PROBLEM STATEMENT

A. Model input Data

- **Size of Rectangular Water Tank**
  - L = 9m
  - B = 4.5m
  - H= 4m
- **Size of Circular Water Tank**
  - Diameter - 7m
  - H= 4m
  - Staging Height=20m
  - Beam size - 230x600
  - Column size - 230x650
  - Earthquake zone - III
  - Time history – Bhuj
  - Soil – Medium stiff
  - Depth of Foundation - 1.5m
  - Concrete – M30
  - Bracing BRB- A buckling-restrained brace (BRB) is a structural brace, designed to allow the structure to withstand cyclical lateral loadings, typically earthquake-induced loading. It consists of a slender steel core, a concrete casing designed to continuously support the core and prevent buckling under axial compression, and an interface region that prevents undesired interactions between the two.

Table 2 Models

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

IV. MODEL DESCRIPTION

1) Rectangular Water Tank (Plain)

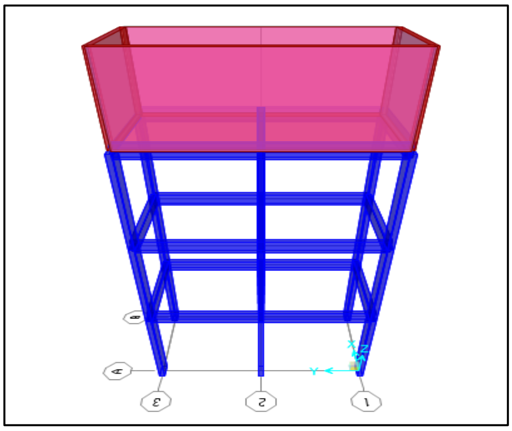


Fig 4 Rectangular water tank without Bracing

2) Rectangular Water Tank with Single Bracing

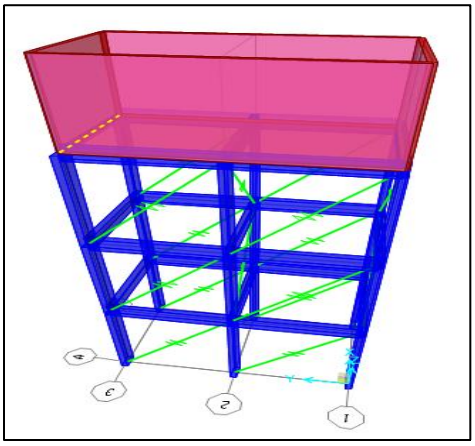


Fig 5 Rectangular water tank with Single Bracing

3) Rectangular Water Tank with Knee Bracing

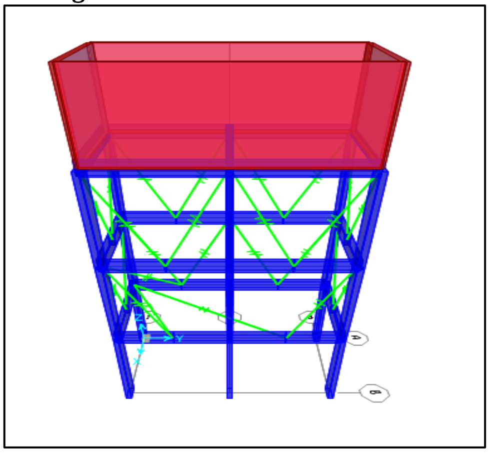


Fig 6 Rectangular water tank Knee Bracing

4) Rectangular Water Tank with Cross Bracing

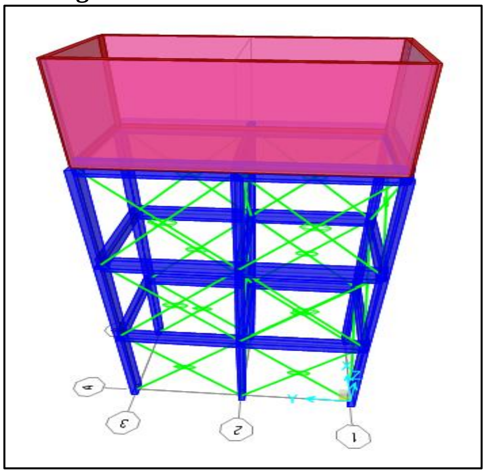


Fig 7 Rectangular water tank with Cross Bracing

5) Circular Water Tank (Plain)

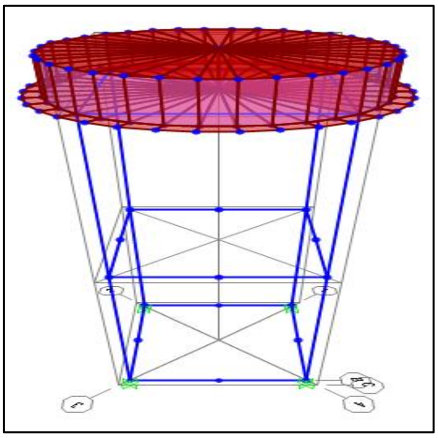


Fig 8 Circular water tank without Bracing

6) Circular Water Tank with Single Bracing

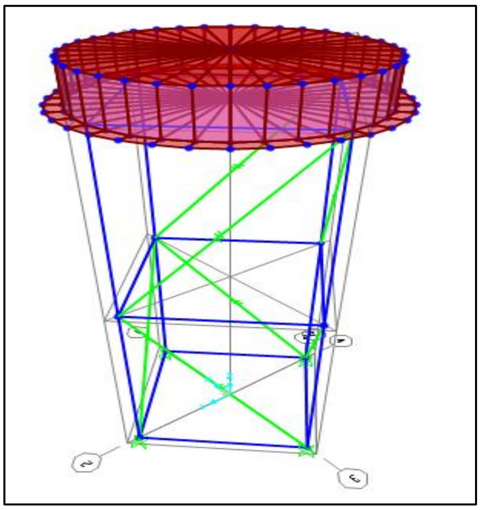


Fig 9 Circular water tank with Single Bracing

7) Circular Water Tank with Knee Bracing

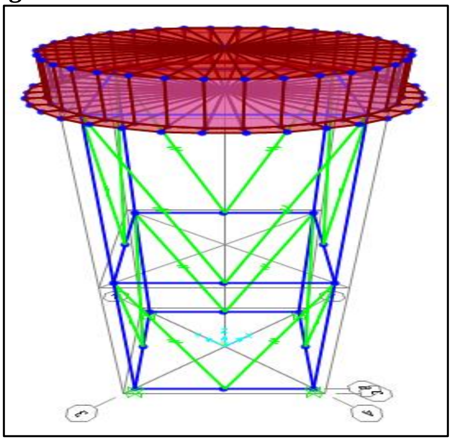


Fig 10 Circular water tank Knee Bracing

8) Circular Water Tank with Cross Bracing

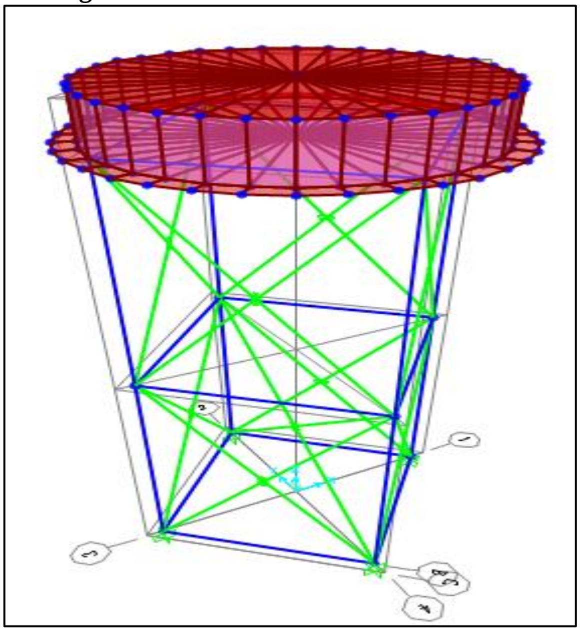


Fig 11 Circular water tank with Cross Bracing

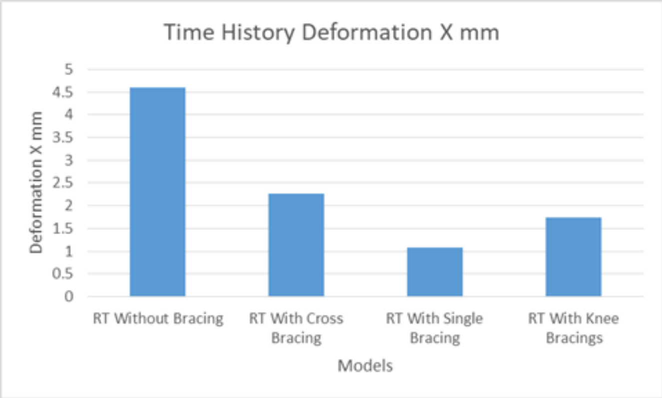
V. RESULT AND DISCUSSION

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.

A. Analysis Parameter for Rectangular Water Tank

Table 2 Time History Deformation

Time History Deformation-X mm			
RT Without Bracing	RT With Cross Bracing	RT With Single Bracing	RT With Knee Bracings
4.6	2.268	1.09	1.74

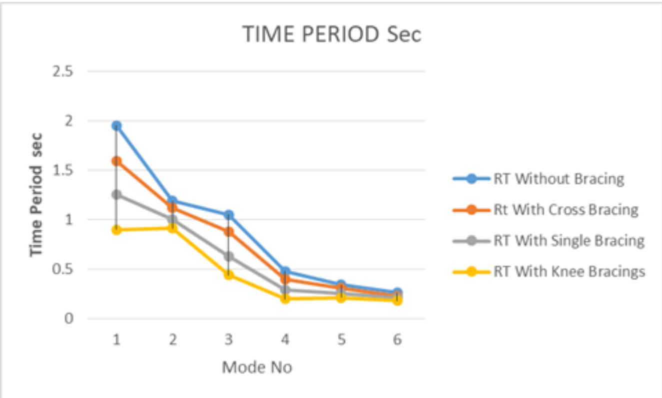


Graph 1 Time History Deformation X mm

In this graph maximum deformation is 4.6 mm rectangular tank without bracing difference between Rectangular Tank without Bracing and rectangular tank with Single Bracing is 30%.

Table 3 Time Period For RT

TIME PERIOD				
MODE NO	RT Without Bracing	RT With Cross Bracing	RT With Single Bracing	RT With Knee Bracings
1	1.95	1.59	1.25	0.90
2	1.19	1.12	1.00	0.91
3	1.05	0.88	0.63	0.44
4	0.48	0.40	0.29	0.20
5	0.34	0.31	0.25	0.21
6	0.26	0.23	0.21	0.18



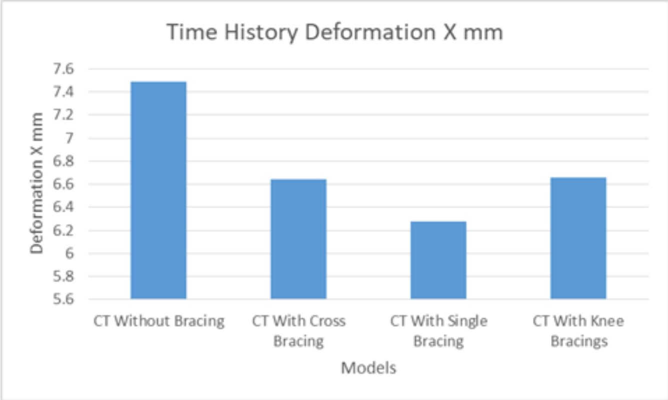
Graph 2 Time Period For RT

In this graph max Time Period is 1.95 sec. for rectangular tank without bracing. Difference between rectangular tank without bracing and rectangular with single bracing is 15%, the economic results given by model RT with Knee Bracings.

B. Analysis Parameter for Circular Water Tank

Table 4 Time History Deformation

Time History Deformation-X mm			
CT Without Bracing	CT With Cross Bracing	CT With Single Bracing	CT With Knee Bracings
7.49	6.64	6.28	6.66

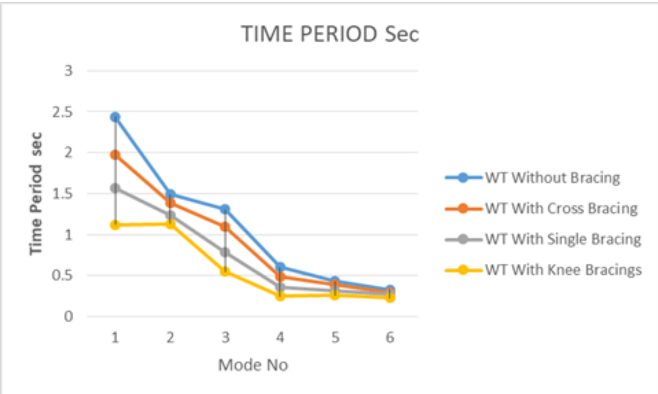


Graph 3 Time History Deformation

In this graph max deformation is 7.49 Circular tank without bracing. Difference between Circular tank without bracing and with single bracing is 15%.

Table 5 Time Period Sec CT

TIME PERIOD				
MODE NO	CT Without Bracing	CT With Cross Bracing	CT With Single Bracing	CT With Knee Bracings
1	2.44	1.98	1.57	1.12
2	1.49	1.39	1.24	1.13
3	1.31	1.10	0.79	0.55
4	0.60	0.49	0.36	0.25
5	0.43	0.39	0.32	0.26
6	0.33	0.29	0.27	0.23



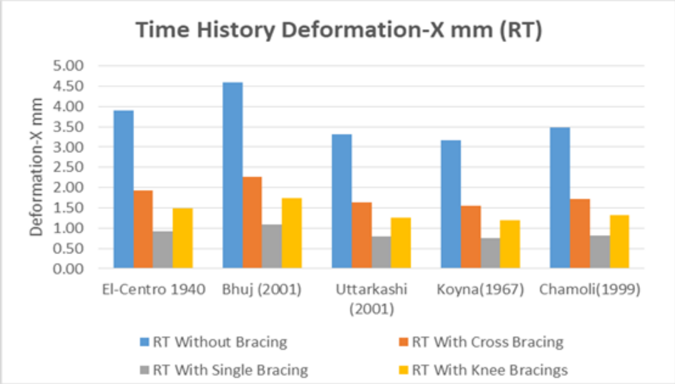
Graph 4Time Period Sec

In this graph max Time Period is 2.44 sec. for Circular tank without bracing. Difference between rectangular tank without racing and rectangular with single bracing is 20%, the economic results given by model RT with Knee Bracings.

C. Model Results For All Time History Data

Table 6 Time History Deformation-X mm (RT)

Time History Deformation-X mm				
Earthquake Area	RT Without Bracing	RT With Cross Bracing	RT With Single Bracing	RT With Knee Bracings
El-Centro 1940	3.91	1.93	0.93	1.48
Bhuj (2001)	4.60	2.27	1.09	1.74
Uttarkashi (2001)	3.32	1.64	0.79	1.26
Koyna(1967)	3.16	1.56	0.75	1.19
Chamoli(1999)	3.49	1.72	0.83	1.32

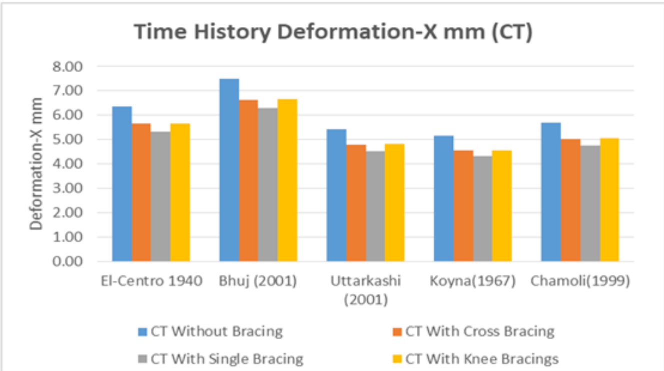


Graph 5 Time History Deformation-X mm (RT)

Above graph shows the deformation for the rectangular water tank with different Earthquake data, the continuously economic results given by model RT with Knee Bracings in every data.

Table 7 Time History Deformation-X mm (CT)

Time History Deformation-X mm				
Earthquake Area	CT Without Bracing	CT With Cross Bracing	CT With Single Bracing	CT With Knee Bracings
El-Centro 1940	6.37	5.64	5.34	5.66
Bhuj (2001)	7.49	6.64	6.28	6.66
Uttarkashi (2001)	5.41	4.80	4.54	4.81
Koyna(1967)	5.14	4.56	4.31	4.57
Chamoli(1999)	5.68	5.04	4.76	5.05



Graph 6 Time History Deformation-X mm (RT)

Above graph shows the deformation for the circular water tank with different Earthquake data, the continuously economic results given by model CT with Knee Bracings in every data.

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 150m3 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
- 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.

A. Future Scope

As known from very upsetting experiences, elevated water tanks were heavily damaged or collapsed during earthquake Hence different configurations of liquid storage tanks have been constructed. Water tanks are play an important role in municipal water supply and fire fighting systems. Due to post earthquake useful desires, seismic safety of water tanks is most important. In the current study time history analysis of rectangular and circular elevated water storage tank were analysed using SAP 2000 software. In further study the concrete baffle wall should use to reduce sloshing effect of the water tank. The tank responses such as maximum nodal displacement, base shear and result should compared for empty and full tank water fill condition.

REFERENCES:

1. 01 G. W. Housner (1963), “The dynamic behaviour of water tanks”, Bulletin of the Seismological Society of America, Vol.53, No.2, pp 381-387.
2. 02 B. Devadanam and M K Ratnam (2015), “Effect of staging height on the seismic performance of RC elevated water tank”,International Journal of Innovative Research in Science, Engineering and Technology (An ISO 3297: 2007 Certified Organization) Vol. 4, Issue 1, January 2015.
3. 03 S.C. Dutta, S.K. Jain, and C.V.R. Murty (2000), “Assessing the seismic torsional vulnerability of elevated tanks with RC frame-type staging”, Soil Dynamics and Earthquake Engineering, Vol.19 (2000) pp183–197.
4. 04 R. Livaoğlu andA. Doğangünk (2008), “Sloshing response of the cylindrical elevated tanks with frame staging system on different soil conditions”, Technical University, Department of Civil Engineering. 61080,Gumushane, Turkey. Institute of Thermo mechanics, Prague, 2008.
5. 05 S. M. Maidankar, G.D. Dhawale, and S.G. Makarande (2015), “Seismic analysis of elevated circular water tank using various bracing systems”, International Journal of Advanced Engineering Research and Science Vol-2, Issue-1, Jan.- 2015
6. 06 P. M.Vijay and A. Prakash (2014), “Analysis of sloshing impact on overhead liquid storage structures”, IMPACT: International Journal of Research in Engineering & Technology Vol. 2, Issue 8, Aug 2014, pp127-142
7. 07 M.M. Ranjbar and R. Madan (2013), “Seismic Behavior Assessment of Concrete Elevated Water Tanks”, Journal of Rehabilitation in Civil Engineering pp 69-79.
8. 08 K. J. Dona Rose, M. Sreekumar and A. S. Anumod (2015), “A Study of Overhead Water Tanks Subjected to Dynamic Loads”, International Journal of Engineering Trends and Technology (IJETT) – Volume 28 Number 7 - October 2015.
9. 09 S. A. Patil, A. H. Kumbhar, and T. F. Mujawar (2016), “Elevated Water Tank Under Sloshing Effect”, International Journal for Scientific Research & Development Vol. 4, Issue 05, 2016
10. 10 M. V. Waghmare and S. N. Madhekar (2013), “Behaviour of Elevated Water Tank Under Sloshing Effect”, International Journal of Advanced Technology in Civil Engineering, Vol.-2, Issue-1, 2013.
11. 11 M. R.Wakchaure and S. S. Besekar (2014), “Behaviour of Elevated Water Tank Under Sloshing Effect”, International Journal of Engineering Research & Technology (IJERT) Vol. 3 Issue 2, February – 2014.
12. 12 S. K. Jangave and P. B. Murnal (2014), “Structural Assessment of Circular Overhead Water Tank Based on Frame Staging Subjected to Seismic Loading”, International Journal of Emerging Technology and Advanced Engineering, Vol. 4, Issue 6, June 2014.
13. 13 D. Virkhare and L. Vairagade (2015), “Pushover Analysis of Water Tank Staging”, Civil Engineering Department, G.H.R.A.E.T N Structural Consultant, Techpro Consultancy, Nagpur, Maharashtra, India IRJET/July 2015.
14. 14 M. Masoudi, (2012), “Evaluation of Response Modification Factor (R) of Elevated Concrete Tanks”, Engineering Structures, Vol.39 (2012) pp199-209.
15. 15 F. Omidinasab and H. Shakib(2008), “Seismic Vulnerability of Elevated Water Tanks Using Performance Based-Design” The 14th Withoutrld Conference on Earthquake Engineering, October 12- 17, 2008, Beijing, China.
16. 16 A. M. Jabar and H. S. Patel (2012), “Seismic behaviour of RC elevated water tank under different staging pattern and earthquake characteristics”, International Journal of Advanced Engineering Research and Studies, Vol.1 April-June, 2012, pp293-296.
17. 17 S.C. Dutta, S.K. Jainb and C.V.R. Murty (2000), “Assessing the seismic torsional vulnerability of elevated tanks with RC frame-type staging”,Soil Dynamics and Earthquake Engineering , Vol.19 (2000) pp183–197.
18. 18 P. K.Malhotra, T.Wenk and M.Weiland , “Simple Procedure of Seismic Analysis of liquid-Storage Tanks”, Structural Engineering, Vol. 3, pp197–201.
19. 19 D.C. Rai (2001), “Performance Of Elevated Tanks In Mw 7.7 Bhuj Earthquake of January 26, 2001”,International Conference on Seismic Hazard With Particular Reference to Bhuj Earthquake of January 26, 2001, Oct. 3–5, New Delhi.

IS Codes

1. IS 456-2000 Indian Standard Code of Practice for Plain and Reinforced Concrete, Bureau of Indian Standards, New Delhi.
2. IS: 1893 (Part 1), (20016), Indian Standard Criteria for Earthquake Resistant Design of Structures, Bureau of Indian Standards, New Delhi.
3. IS: 875 (Part 2) – 1987: Imposed loads.
4. IS 3370- (2009) – Concrete Structures For Storage Of Liquids-Code Of Practice.