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Seismic Response of an Elevated Water Tank for different Bracing Systems

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Abstract—*The paper entitled "***Seismic response of an elevated water type tank for different bracing systems"** *involves a 1000m^3 capacity RC elevated intze type tank supported on frame staging of 20m height. The modeling of the the elevated tank as mechanical spring mass analogue as per IITK-GSDMA (2007) which is based on the concept of George W. Housner (1963), where the water inside the tank can be idealized as two mass model namely convective mass and impulsive mass respectively. Under dynamic loading, the water inside the tank exerts hydrodynamic pressure on the tank wall and tank base which can be classified as convective hydrodynamic pressure and impulsive hydrodynamic pressure and hence the fluid masses can be classified as convective mass and impulsive mass. FEM software SAP2000 is used in modeling the tank, convective mass is connected to the tank wall by spring elements and impulsive mass is connected to the tank wall with rigid link elements axisymmetrically. Parametric study is done where two types of bracing patterns, namely diagonal bracing and chevron bracing and a fluid viscous damper system were applied on the tank in addition to the conventional bracing system. Three different fluid level conditions such as tank empty, tank half and full tank conditions have been studied. Time history analysis is done for all the bracing systems done where the tank is subjected to three time history functions of Imperial Valley earthquake, Loma Prieta earthquake and Northridge earthquake at Elcentro, Hollister and Santa Monica stations respectively. Seismic response of tank is expressed in terms of tank roof displacement and base shear.*

1. INTRODUCTION

All around the world water storage tanks are used extensively by municipalities and industries for water supply, firefighting systems etc. Elevated water tanks are considered as an important city services in many flat areas and accordingly, their serviceability performance during and after strong earthquakes is of crucial concern. These structures has large mass concentrated at the top of slender supporting structure thus making them vulnerable to horizontal forces during earthquakes. Many of the elevated water tanks have suffered extensive damage during past earthquakes. The staging is the most critical part of an elevated water tank as failure in staging results in the failure of the whole tank. Failure in the staging occurs in the form of shear failure in beams, combined bending and shear failure in beams and axial failure in columns. North Eastern region of India falls under the category of most severe seismic zone (Zone –V), which is the most vulnerable region prone to earthquakes. Thus a study dynamic behavior of such tanks must be taken into account considering their vulnerability to earthquakes in highly seismic zones.

2. LITERATURE REVIEW

Patel et al. 2012[1]; *Sloshing response of elevated water tank over alternate column proportionality*; It involves study of the seismic behavior of elevated water tank under alternate column proportionality under different earthquake records. It aims at checking the adequacy of water tank for seismic excitations. The response includes sloshing displacement under four different earthquake records and compared. The results show that the structural responses are exceedingly influenced by different column proportionality.

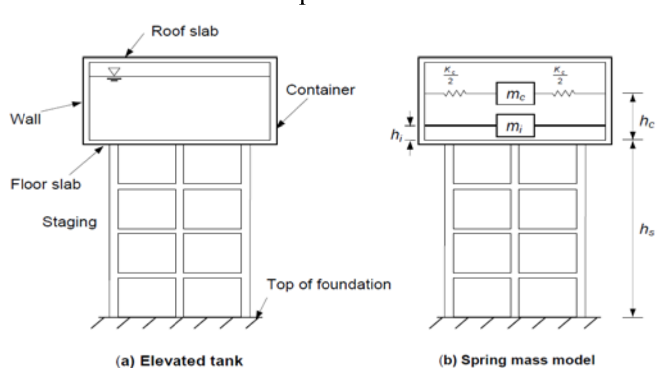
Patel et al. 2012[2]; *Seismic behavior of RC elevated water tank under different staging pattern and earthquake characteristics;* It involves study of the behavior of the supporting system which is more effective under different earthquake time history records in SAP2000. Two different supporting systems such as radial bracing and cross bracing are compared with basic supporting system for various fluid level conditions. Modeling is done as per IITK-GSDMA guidelines and Westergaard's added mass approach.

Shakib et al. 2011[3]; *Seismic response evaluation of RC elevated water tank with Fluid-Structure Interaction and earthquake ensemble;* This paper consist a RCC elevated water tank of 900 cubic meters and height 32 meters subjected to an ensemble of earthquake records. Finite element model of the tank has been employed in ABAQUS. Fluid-structure interaction for modeling is considered by Eulerian method. Seismic responses of the tank such as base shear, overturning moment, displacement and hydrodynamic pressure have been assessed for ensemble earthquake records. Responses of the tank are dependent with earthquake characteristics and frequency of the tank. The maximum response of base shear force, overturning moment, displacement and hydrodynamic pressure occurred in different fluid level conditions.

3. METHODOLOGY

George Housner in 1963 proposed mechanical spring mass model to idealize an elevated water tank so as to characterize the dynamic behavior of the tank due to moving fluid masses inside it. Housner proposed certain provisions and guidelines for seismic behavior of elevated water tank, which are followed by most of the international codes including Indian code of standard IITK-GSDMA (2007). Modeling is done as two mass model as per IITK-GSDMA(2007): Guidelines for seismic design of liquid storage tanks and Draft Code IS 1893 (Part-2), where hydrodynamic pressure is considered and divided into two parts convective and impulsive hydrodynamic pressures and hence the fluid is divided into two masses as convective mass and impulsive mass respectively. The free surface liquid mass which undergoes sloshing motion known as convective mass and the bottom portion liquid of tank accelerates and moves along with the tank walls is impulsive mass. Previous IS 1893(part 2): 1984 suggested single mass model for elevated water tanks but later on IITK-GSDMA (2007) and IS 1893(Part -2):2006 revised the provisions and recommended two mass model for elevated water tanks which was found to be more realistic as in many cases the tank is not completely full and it will result in sloshing of free surface water during an earthquake. FEM software SAP2000 is used for modeling the water tank. The parameters of the spring mass model are calculated as per the guidelines of the draft code IITK-GSDMA (2007): Guidelines for seismic design of liquid storage tanks.

In SAP2000, shell elements are used in modeling the tank walls, top dome, bottom spherical dome and conical dome. Frame element used to model the columns and beams of the staging, top ring beam, bottom ring beam and bottom circular girder. Linear elastic spring elements are used to connect the convective mass with the tank walls and rigid link elements to connect the rigid mass with the tank walls. Thin shell elements (with four nodes and six degrees of freedom per node) are used in modeling the tank walls, top dome, bottom spherical dome and conical dome. Frame elements (with six degrees of freedom per node) are used to model the top ring beam, bottom ring beam, bottom girder and beams and columns of the staging. Also the bracings are modeled with frame elements. Fluid viscous damper is modeled with link elements.



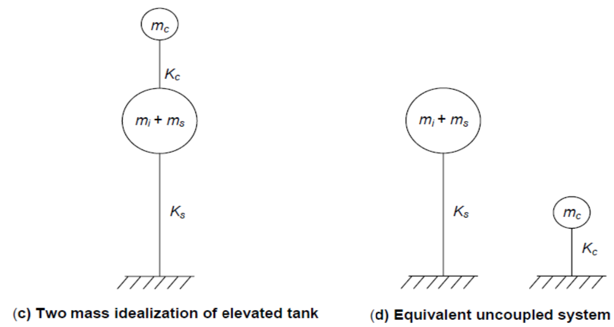
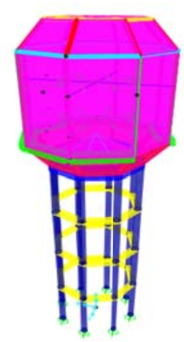
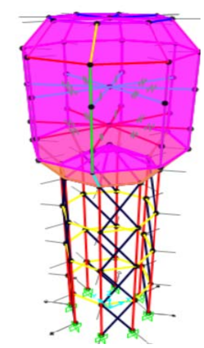


Fig. 1: Spring mass model of elevated water tank; IITK-GSDMA (2007)

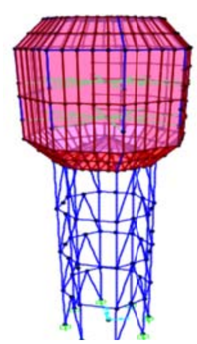
The properties of the fluid viscous damper are taken from a catalogue of a leading manufacturer of seismic protection structures namely ITT Infrastructures. [10]



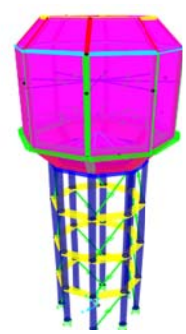
Conventional Braced



Diagonal Braced



Chevron Braced



Fluid viscous damper Braced

Fig. 2: FEM models for different bracing systems of the tank in SAP2000

Table 1: Structural members of the tank

Top Dome, thickness	100 mm
Top Ring Beam; width and depth	200 mm X 400 mm
Cylindrical wall; thickness	300 mm
Bottom ring beam; width and depth	600 mm X 1200 mm
Conical Dome; thickness	600 mm
Bottom Dome; thickness	300 mm
Bottom Circular Girder; width and depth	600 mm X 1200 mm
Columns; diameter	650 mm
Beams; width and depth	500 mm X 500 mm
Bracings, width and depth	500 mm X 500 mm
Fluid viscous damper	Damping force: 2000 KNm/sec; Stiffness : 3333.3 N/mm

4. TIME HISTORY ANALYSIS

Time history analysis is done where the tank is subjected to three different time history functions of previous earthquake records namely Imperial Valley earthquake (1979), Loma Preita earthquake (1989) and Northridge earthquake (1994). The acceleration data available in time history functions of each of the above earthquakes is given as an input data of ground motion in SAP2000. The peak ground acceleration (PGA) values of the above mentioned earthquakes are presented in Table.2.

Table 2: Peak Ground Acceleration of the earthquake records

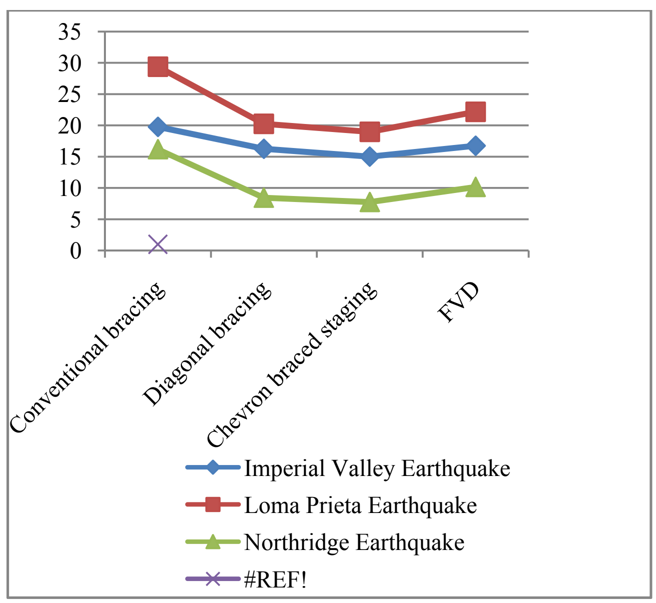
EARTHQUAKE	PGA
IMPERIAL VALLEY (1979)	0.312 g
LOMA PREITA (1989)	0.368 g
NORTHRIDGE (1994)	0.26 g

5. RESULTS AND DISCUSSION

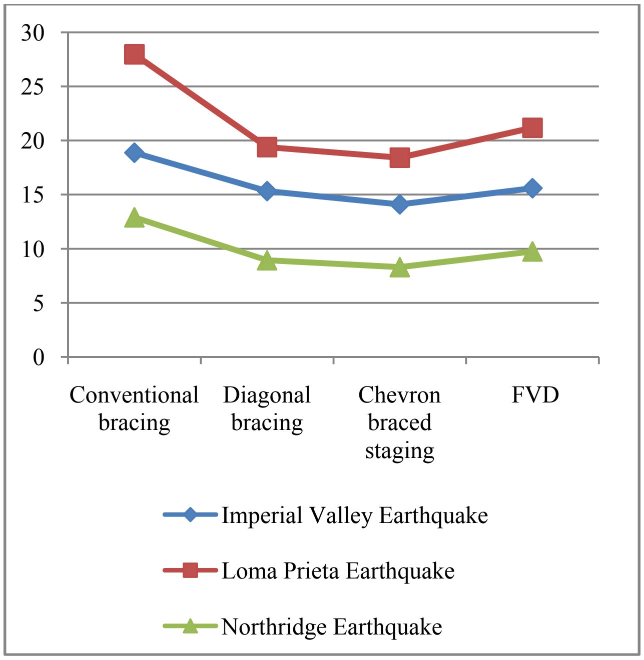
The seismic response of the tank is expressed in terms of roof displacement of the tank and base shear force. From table 3, it can be seen that the diagonal bracing and chevron bracing systems are very effective in reducing the roof displacement of the tank compared to the conventional bracing system and fluid viscous damper braced system, chevron braced system having the least response of all the bracing systems. On the contrary, in terms of base shear, both the diagonal bracing system and chevron bracing system has large responses, quite the opposite compared to roof displacement and chevron bracing displaying the peak response. However fluid viscous damper braced system performed well in reducing the base shear for all the time history records. Fluid viscous damper bracing system also performed well in reducing the roof displacement compared to the conventional bracing but not to that extent as chevron brace and diagonal bracing system had done. However the overall performance of Fluid viscous damper in reducing the seismic parameters is satisfactory.

Table 3: Seismic responses of the tank to different earthquake records for different bracing systems

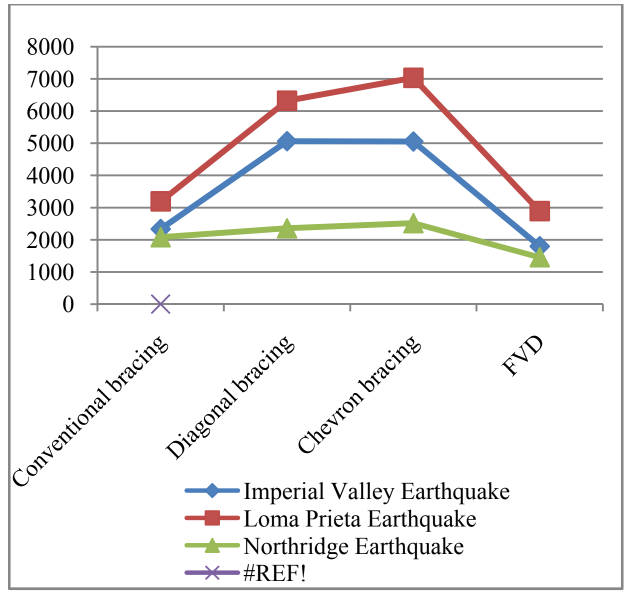
		Roof Displacement (cm)				Base Shear (KN)			
Tank Fill	Staging type Earthquake records	Conventional bracing	Diagonal bracing	Chevron bracing	Fluid Viscous Damper	Conventional bracing	Diagonal bracing	Chevron bracing	Fluid Viscous Damper
Empty	Imperial Valley	20.07	15.60	14.71	17.85	2385	4802	4966	1988
	Loma Prieta	28.77	19.58	18.66	24.43	3179	6498	6974	3003
	North ridge	16.64	8.73	8.8	11.93	2143	2402	2491	1665
Half	Imperial Valley	18.88	15.33	14.10	15.6	2142	4903	4997	1754
	Loma Prieta	27.97	19.40	18.42	21.18	3263	6782	6712	3351
	North ridge	12.90	8.93	8.3	9.75	1767	2541	2397	1420
Full	Imperial Valley	19.78	16.28	15.02	16.76	2336	5064	5055	1798
	Loma Prieta	29.38	20.26	18.97	22.16	3192	6320	7033	2888
	North ridge	16.20	8.44	8.76	10.17	2080	2357	2516	1465



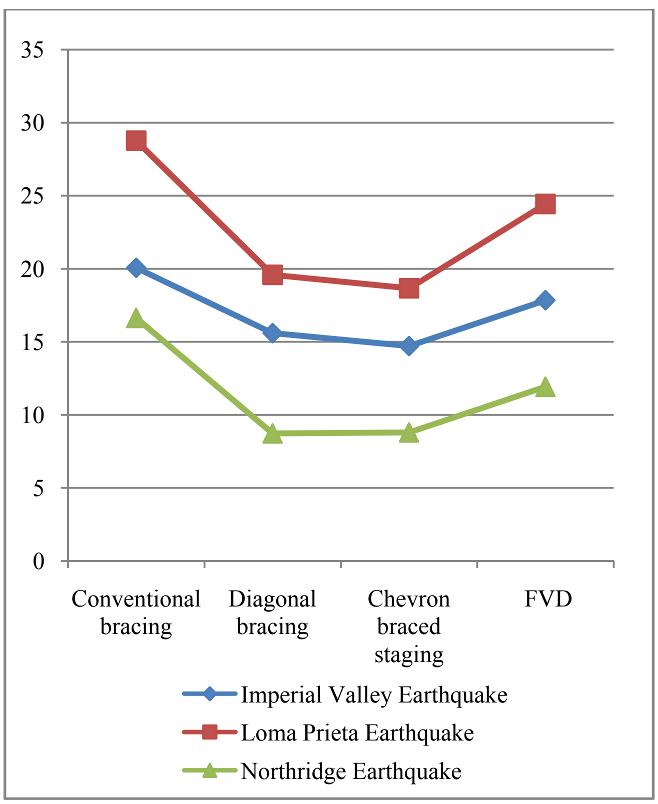
Tank full Roof Displacement (cm)



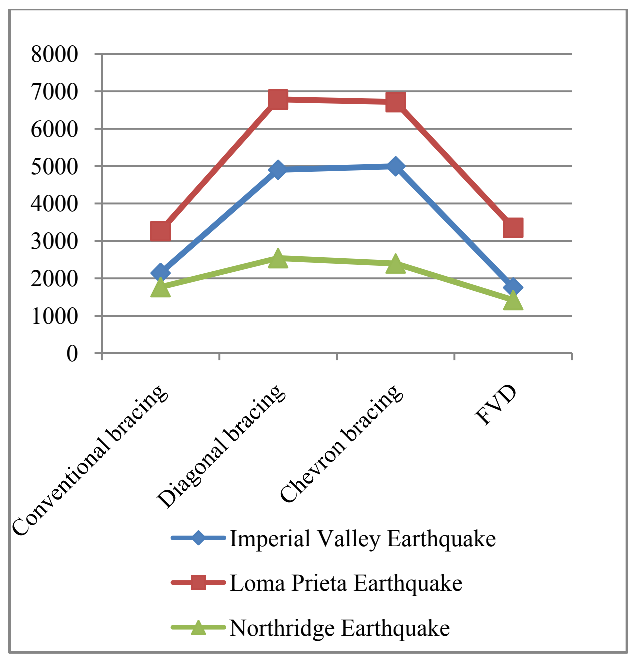
Half Tank Roof Displacement (cm)



Full Tank Base Shear (KN)

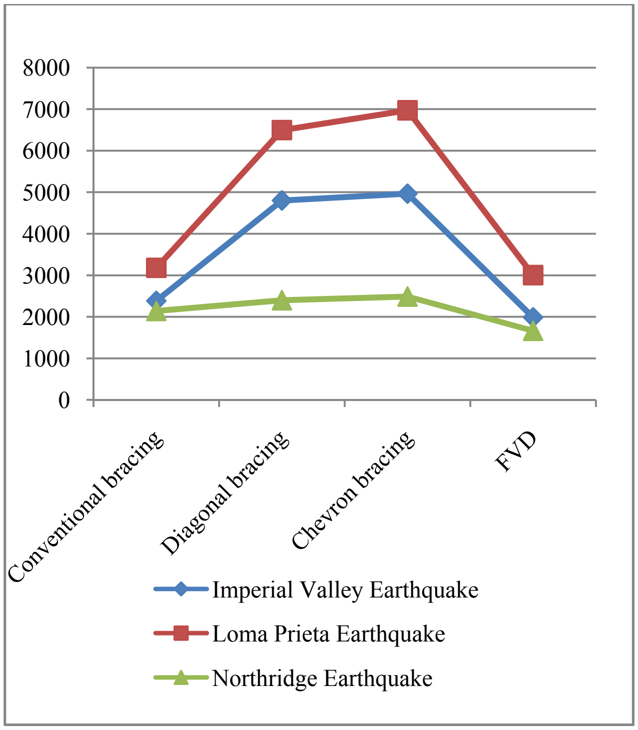


Empty Tank Roof Displacement (cm)



Half Tank Base Shear (KN)

Fig. 3: Roof displacement due to different earthquakes records for different bracing systems in full tank, half tank and empty conditions



Empty Tank Base Shear (KN)

Fig. 4: Base Shear due to different earthquakes records for different bracing systems in full tank, half tank and empty conditions

6. CONCLUSION

From this research work, it can be concluded that fluid viscous dampers may be a feasible solution for elevated tanks with frame staging in highly seismic zones for most of the cases compared to the bracing systems.

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