Non-Linear Time History Analysis of Elevated Water Tank

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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. Due to post earthquake functional needs, seismic safety of water tanks is of most important. These structures have large mass concentrated at the top with a supporting structure of beams and columns (staging).The present study focuses on the response of the elevated circular water tanks to dynamic forces. Tanks of various capacities viz. 1000 m3, 1500 m3 and 2000 m3 having different staging heights such as 16 m, 20 m, 25 m, and 30 m are considered. The present study is an effort to identify the behaviour of RCC Elevated water tank, by varying the volume of water in the tank viz. tank empty, tank 25% filled, tank 50% filled tank 75% filled and tank full condition to determine the effect on staging height under five different earthquake ground motion viz. EI-Centro (1979), Bhuj (1993), Uttarkashi (1993), Koyna (1993) and Chamoli (1992). Non linear time history analysis has been carried out. The simulation of water tank is done in SAP2000 v18. For modelling of water in SAP2000 v18, water mass is divided into two main components namely impulsive and convective. These impulsive and convective masses are obtained from IS1893 (Part 1):2002. Various response quantities such as base shear, time period, displacements, acceleration are obtained. A circular acrylic elevated water tank of 0.0044 m3 capacity having internal diameter 0.266 m and height of 0.058 m is considered for the study. For validation the results obtained from experiment and analysis, of scaled down model same steel model is used. A comparison of experimental and numerical results is also carried out for validation purpose.

Key words: Water Tank, Staging Height, Tank Fill Condition, Earthquake Ground Motion

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. 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 structures has large mass concentrated at the top of slender which have Supporting structure and hence these structure are especially vulnerable to horizontal forces due to Earthquakes.

II. RESEARCH SIGNIFICANCE

From past experience it is seen that, though adequately designed, elevated water tanks were heavily damaged or collapse during earthquakes. Most of the damages observed during the seismic events due to lack of knowledge regarding the behaviour of the supporting structure.To protect the elevated water tank from significant damage and response reduction of structures under severe earthquakes has become an important topic in structural engineering. Hence, the present study deals with Non-linear Time History analysis of elevated water tank. The main objective of this study is to know the response of RCC elevated water tank with different earthquake ground motion.

III. SYSTEM DEVELOPMENT

A. Nonlinear Time History Analysis

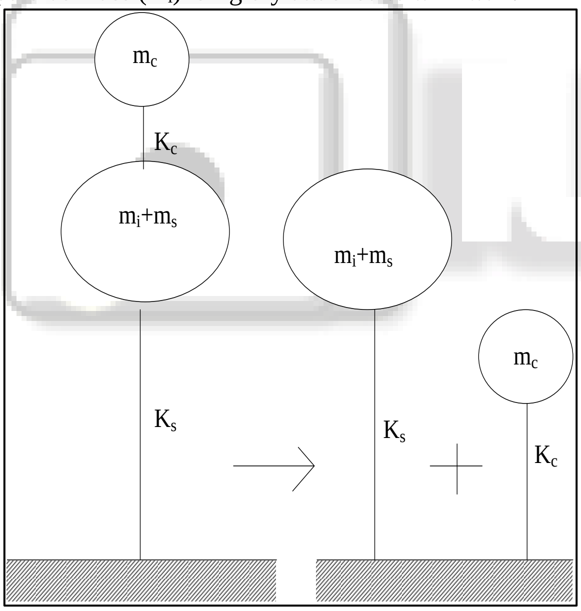
The present study focuses on the response of the elevated circular water tanks to dynamic forces. Tanks of various capacities viz. 1000 m^3, 1500 m^3 and 2000 m^3 having different staging heights such as 16 m, 20 m, 24 m, and 28 m are considered. The present study is an effort to identify the behaviour of RCC elevated water tank, by varying the volume of water in the tank viz. tank empty, tank 25% filled, tank 50% filled tank 75% filled and tank full condition to determine the effect of staging height under five different earthquake ground motion. Grade of concrete and steel considered are M20 and Fe 415 respectively, density of concrete is 25 kN/m^3. The time history analysis is carried out from the recorded ground motion of past five earthquakes viz. EI-Centro (1979), Bhuj (1993), Uttarkashi (1993), Koyna (1993) and Chamoli (1992).

Time-History analysis is a step-by-step procedure where the loading and the response history are evaluated at successive time increments. Non linear time history analysis is the dynamic analysis in which the loading causes significant changes in stiffness. 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.

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 structures. The various case studied and Properties of ground motions under consideration are tabulated given below in Table

B. Two Mass Model

A satisfactory spring mass analogue to characterize basic dynamics for two mass model of elevated tank was proposed by Housner (1963) after the Chilean earthquake of 1960, which is more appropriate and is being commonly used in most of the international codes including GSDMA guideline. The pressure generated within the fluid due to the dynamic motion of the tank can be separated into impulsive and convective parts. When a tank containing liquid with a free surface is subjected to horizontal earthquake ground motion, tank wall and liquid are subjected to horizontal acceleration. The liquid in the lower region of tank behaves like a mass that is rigidly connected to tank wall, termed as impulsive liquid mass. Liquid mass in the upper region of tank undergoes sloshing motion, termed as convective liquid mass. For representing these two masses and in order to include the effect of their hydrodynamic pressure in analysis, two-mass model is adopted for elevated tanks. In spring mass model convective mass (m_c) is attached to the tank wall by the spring having stiffness (K_c), whereas impulsive mass (m_i) is rigidly attached to tank wall.

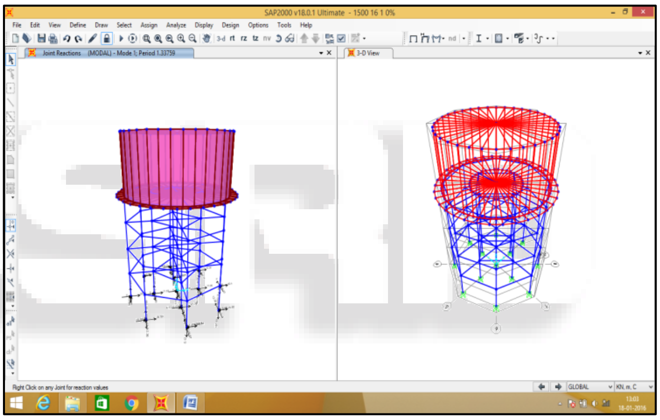


C. SAP2000

SAP2000 which stands for Structural Analysis Program is a full-featured program that can be used for the simplest problems or the most complex projects. Its advanced analytical techniques allow for step-by-step large deformation analysis, Eigen and Ritz analyses based on stiffness of nonlinear cases, velocity-dependent dampers, and base isolators. Nonlinear analyses can be static and/or time history, with options for nonlinear time history dynamic analysis and direct integration. From a simple small 2D static frame analysis to a large complex 3D nonlinear dynamic analysis, SAP2000v18 is the easiest, most productive solution for structural analysis and design needs.

SAP2000v18 is very much suited for analysis of shell structures like domes, circular tank, intz tank etc. because of its flexibility in accounting for arbitrary geometry, loading, water pressure and variation in material properties. A number of models have been developed and analysis that perform satisfactorily in many situations in practice and are also computationally economical.

IV. VIEW OF ELEVATED WATER TANK



A. Ground Motion

Earthquake	Year	Magnitude	PGA
EI-Centro	(1940)	7.2	0.35 g
Bhuj	(2001)	7.7	0.38 g
Uttarakashi	(2001)	6.6	0.31 g
Koyna	(1967)	6.5	0.36 g
Chamoli	(1999)	6.8	0.37 g

B. Cases Studied

Sr. No.	Capacity of Tank	Staging height (m)	Tank Conditions	No. of Earthquake Intensities	No. of Cases	Total Cases
1	1000 m^3	16, 20, 24, 28	0%, 25%, 50%, 75% and 100%	5	5 x 5 x 4 = 100	300
2	1500 m^3	16, 20, 24, 28	0%, 25%, 50%, 75% and 100%	5	5 x 5 x 4= 100	
3	2000 m^3	16, 20, 24, 28	0%, 25%, 50%, 75% and 100%	5	5 x 5 x 4 = 100	

Components	Size of various components (m)		
Capacity of tank	1000 m^3	1500 m^3	2000 m^3
Roof slab	0.15 m	0.20 m	0.25 m
Wall	0.25 m	0.27m	0.30 m

Floor slab	0.30 m	0.35 m	0.40 m
Floor Beams	0.30 x 0.50 m	0.35X0.55 m	0.35X0.60 m
Braces	0.25X0.30 m	0.30X0.45 m	0.30X0.60 m
Columns Diameter	0.45 m	0.50 m	0.65m
Diameter of tank	16 m	16 m	16 m
Height	5.3 m	7.8 m	10.3 m

V. RESULT AND DISCUSSION

In this chapter results of Non-linear Time History analysis for R.C.C elevated water tank with various conditions such as tank empty, 25% filled, 50% filled, 75% filled and tank full condition are presented. The response quantities are obtained at the bottom of the column and at the top of the column, under recorded ground motion data of different earthquakes as given in

VI. BASE SHEAR

Earthquake	16 m			20 m			24 m			28 m		
	1000 m^3	1500 m^3	2000 m^3	1000 m^3	1500 m^3	2000 m^3	1000 m^3	1500 m^3	2000 m^3	1000 m^3	1500 m^3	2000 m^3
El-Centro	129.71	123.50	219.87	137.38	134.17	223.78	135.92	144.32	223.18	143.26	154.45	242.78
Bhuj	197.67	207.05	233.08	171.27	206.20	327.35	182.28	217.21	329.68	186.19	221.95	326.91
Uttarakashi	138.19	156.18	223.37	150.67	166.12	276.54	152.70	173.58	267.19	159.17	178.90	269.18
Koyna	163.70	341067	455.68	152.89	351.45	506.84	159.52	360.45	521.87	169.50	362.67	526.78
Chamoli	153.54	423.19	534.06	154.78	433.37	548058	161.51	444.86	543.09	164.84	451.17	553.13

Maximum displacement of Convective mass (m_c)

Staging height (m)	1000 m^3		1500 m^3		2000 m^3	
16	0.061 (75%)	Koyna	0.055 (75%)	Uttarakashi, Bhuj	0.058 (75%)	Uttarakashi
20	0.059 (75%)	Koyna	0.065 (75%)	Uttarakahi	0.062 (75%)	Uttarakashi
24	0.066 (75%)	Koyna	0.069 (75%)	Uttarakashi	0.069 (75%)	Koyna
28	0.068 (75%)	Koyna	0.066 (75%)	Koyna	0.065 (75%)	Koyna

Displacement at roof (m)

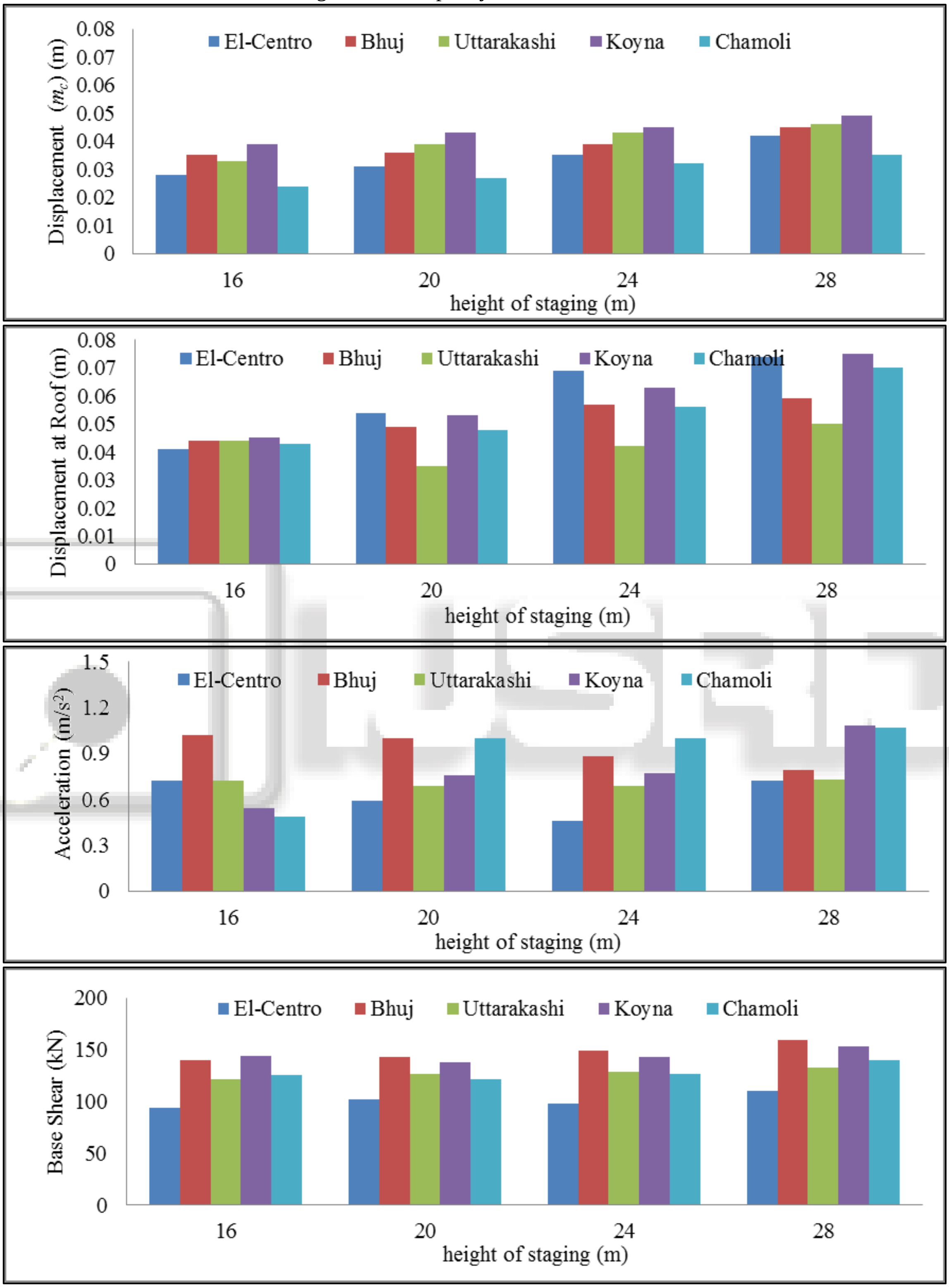
Staging height (m)	1000 m^3		1500 m^3		2000 m^3	
16	0.051 (100%)	Uttarakashi, Bhuj	0.052 (0%)	Koyna	0.093 (100%)	Chamoli
20	0.056 (0%)	El-Centro	0.055 (0%)	Koyna	0.080 (100%)	Chamoli
24	0.073 (100%)	El-Centro	0.064 (0%)	Koyna	0.078 (75%)	Uttarakashi
28	0.079 (0%)	Koyna	0.075 (0%)	Koyna	0.071 (50%)	Uttarakashi

Acceleration at roof level (m/s^2)

Earthquake	1000 m^3				1500 m^3				2000 m^3			
	16	20	24	28	16	20	24	28	16	20	24	28
El-Centro	0.76 (50%, 75%)	0.72 (50%, 75%)	0.47 (0%)	0.72 (25%)	0.73 (75%)	0.47 (0%)	0.70 (25%)	0.75 (50%)	0.72 (50%, 75%)	0.70 (50%)	0.76 (50%)	0.81 (50%)
Bhuj	1.03 (100%)	1.02 (0%, 50%)	1.01 (75%)	0.96 (50%)	1.35 (100%)	1.42 (100%)	1.51 (100%)	1.62 (100%)	1.02 (0%, 50%)	1.09 (0%)	1.19 (0%)	1.21 (0%)
Uttarakashi	0.76 (0%)	0.73 (0%)	0.73 (0%)	0.85 (50%)	0.80 (0%)	0.87 (0%)	0.96 (0%)	1.06 (0%)	0.73 (0%)	0.77 (0%)	0.83 (0%)	0.89 (0%)
Koyna	0.54 (25%, 50%)	0.78 (0%)	0.78 (0%)	1.21 (100%)	0.61 (50%)	0.67 (50%)	0.76 (50%)	0.97 (100%)	1.63 (100%)	1.68 (100%)	1.74 (100%)	1.80 (100%)
Chamoli	0.50	1.02	1.02	1.29	0.55	1.36	1.40	1.52	2.01	2.04	2.10	2.17

	(0%)	(100%)	(75%, 100%)	(100%)	(50%)	(100%)	(100%)	(100%)	(100%)	(100%)	(100%)	(100%)

Fig. 1: Tank Capacity 1000 m3 for 25%



VII. Conclusions

Generally if the water tank is excited due to earthquake ground motion the displacement of water in the tank depends upon the volume of water contained in it. As capacity of tank increases the displacement and acceleration values go on decreasing. With increase in tank capacity, the time period of tank increases which makes the tank more flexible. As the tank capacity increases base shear also increase, base shear of water tank also increases.

– As capacity of water tank increase the acceleration also reduce proportionately. All the responses (i.e.

displacement, acceleration and base shear values) are proportional to the staging height.

– As capacity of water tank increase the displacement also reduce proportionately but after 50% tank condition the displacement is almost constant.

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