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Influence of Tapered Staging on Seismic Performance of Elevated Water Tank

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Abstract—*Elevated water tanks are one of the most important lifeline structures in earthquake prone regions. In major cities and also in rural areas elevated water tanks form an integral part of water supply scheme. These structures have large mass concentrated at the top of slender supporting structure hence these structures are especially vulnerable to horizontal forces due to earthquake. Elevated water tanks that are inadequately analysed and designed have suffered extensive damage during past earthquakes. The elevated water tanks must remain functional even after the earthquakes as water tanks are required to provide water for drinking and fire fighting purpose. Hence it is important to check the severity of these forces for particular region. Most of damages observed during the earthquakes arise from the causes like unsuitable design of supporting system, mistakes on selecting supporting system. Staging is formed by a group of columns and horizontal braces provided at intermediate levels to reduce the effective length of the column. Apart from vertical column, tapered (inclined) columns are also used to support the tank container. The aim of this paper is to study the Influence of Tapered Staging on Seismic Performance of Elevated Water Tank using software Structural Analysis Programme 2000 (SAP2000) [19] and to study Dynamic Behaviour of Elevated water tank for different levels of water inside the tank for different angles of staging with vertical.*

Keywords*: Earthquake effects, elevated water tank, staging systems, Pushover analysis, seismic analysis, SAP2000.*

1. INTRODUCTION

Water is the prime necessity for survival. Liquid storage tanks are used extensively by municipalities and industries for storing water, inflammable liquids and other chemicals. Thus Water tanks are very important for public utility and for industrial structure having basic purpose of to secure constant water supply at the longer distance with sufficient static head to the desired destination under the effect of gravitational force. It is also essential to ensure that, requirements such as water supply is not hampered during an earthquake and should remain functional in the post-earthquake period. In such situations the elevated tanks may prove most handy tool for the purpose of water distribution and fire protection.

Elevated Storage Reservoirs (ESRs) are one of the most important lifeline structures in earthquake prone regions These structures has large mass concentrated at the top of slender supporting structure, hence these structures are especially vulnerable to horizontal forces due to earthquake. Elevated water tanks that are inadequately analyzed and designed have suffered extensive damage during past earthquakes.

1.1 Main concerns for failure of ESRs:

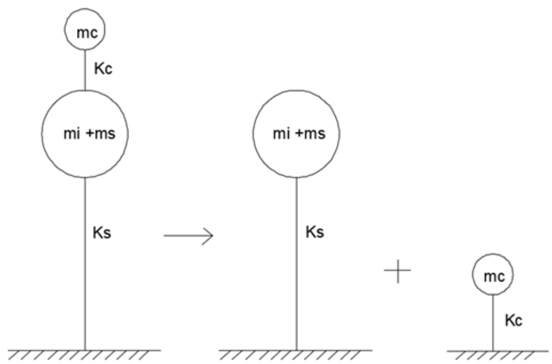
1. Consideration is not given to dynamic effects of liquid and flexibility of container wall while evaluating the seismic forces on tanks.

2. Unsuitable design or wrong selection of supporting system

One of the study on water tanks indicated the dynamic behaviour of water tank is indicated to obtain the response. Some simple expressions were offered in the study to obtain the dynamic properties of tanks with free water surface [1]. Another one study presented the effect of height of water tank, earthquake zones and soil conditions on performance of elevated water tanks [2]. The Static and Dynamic analysis of elevated water tank was compared previously to study the hydrodynamic effect on elevated water tank [3]. Also seismic behavioural effect of elevated circular water tank is studied in other study for constant capacity and constant number of columns; for various types of staging arrangement in plan, and variation in number of stages in elevation by using finite element method based software SAP2000 [4].

One of the researcher carried out non linear static analysis by considering various parameters like water storage capacity and staging height which are constant, different types of h/d ratio, various types of staging arrangement and variation in number of columns [5]. Considered a RC framed staging elevated tank to evaluate the response reduction factor with and without considering the effects of flexibility of soil, the study has been conducted. The existing elevated RC water tank is analyzed using displacement controlled non-linear static pushover analysis to evaluate the base shear capacity and ductility of tank [6]. An attempt was made in another research to understand the basic fundamental of the static pushover analysis with respect to other methods and the review of differential studies of seismic analysis available in the literature on seismic analysis of ESR [7].

The pressure generated within the fluid due to the dynamic motion of the tank can be separated into impulsive and convective parts.



(a) (b)

Fig. 1.1 (a)Two mass idealization (b) Equivalent uncoupled system

1.2 Impulsive liquid mass-

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. This mass is termed as impulsive liquid mass which accelerates along with the wall and induces impulsive hydrodynamic pressure on tank wall and similarly on base.

1.3 Convective liquid mass-

Liquid mass in the upper region of tank undergoes sloshing motion. This mass is termed as convective liquid mass and it exerts convective hydrodynamic pressure on tank wall and base. Thus, total liquid mass of elevated water tank gets divided into two parts i.e., impulsive mass and convective mass. In spring mass model of tank-liquid system, these two liquid masses are to be suitably represented.

Structural mass m_s, includes mass of container and one-third mass of staging. Mass of container comprises of mass of roof slab, container wall, gallery, floor slab, and floor beams. Staging acts like a lateral spring and one-third mass of staging is considered based on classical result on effect of spring mass on natural frequency of single degree of freedom system

Methods of seismic analysis are tabulated below:

Table 1.1 Methods of seismic analysis

Type of Analysis	Linear	Non-linear
Static	Strength-based	Static-Pushover
Dynamic	Response spectrum	Time-History

Out of all these methods nonlinear static pushover analysis is carried out for present study due to following reasons

1) Nonlinear static analysis concludes that the some amount of base shear elevates storage reservoir behave linearly but after a limit of base shear the ESR under go to behave as nonlinear, the nonlinear analysis gives the idea about the performance point of the structure.
2) The propagation of the damage due to the lateral loading during earthquake event
3) The analysis also gives the target displacement buy generation of roof displacement vs. applied force which may not be possible any other analysis.
4) It concludes the actual behaviour of the structure by giving the plastic hinges at the region of beam column junction.It is the modern approach to determine the capacity and performance level of the structure at the same time it can be applicable to new and existing structure.

Pushover analysis is the well-known practical method i.e. Pushover Analysis is that analysis which is carried out under permanent vertical loads and gradually increasing lateral loads to calculate the deformation as well as damage pattern of a structure.. Typically a gravity load pushover is force controlled and lateral pushovers are displacement controlled. Load is applied incrementally to frameworks until a collapse mechanism is reached. Static Pushover analysis is to determine the effect of earthquake on the structure in which the capacity curve that is applied shear v/s Roof displacement and the demand curve of the structure, the intersection point of both this curve gives the performance point which provides the information about nonlinear behaviour and predict maximum displacement of structure during particular earthquake. It is efficient method to understand the performance of the structure during earthquake.

ATC-40 [17] has described the modelling procedure, acceptance criteria and analysis procedures for nonlinear static pushover analysis. The force-deformation criterion for hinges used in pushover analysis is shown in figure.

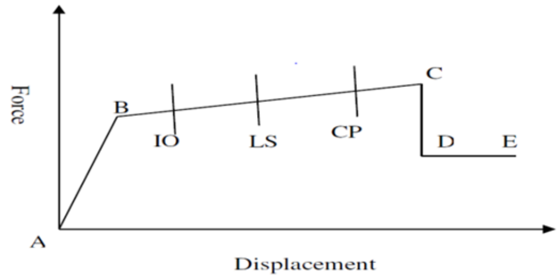


Fig. 1.2 Force-deformation criterion for hinges used in pushover analysis (ASCE 41, 2007)

Five points labelled A, B, C, D, and E are used to define the force deflection behaviour of the hinge and three points labelled Immediate Occupancy (IO), Life Safety (LS) and Collapse Prevention (CP) are used to define the acceptance criteria for the hinge. The values assigned to each of these points vary depending on the type of member as well as many other parameters defined in the ATC-40 [17].

2. SCOPE AND METHODOLOGY

In this paper, An attempt is made to study and compare the results of different angles of staging on seismic performance of elevated water tanks (Base fixed) for different levels of water inside the container of using SAP2000 and the load deformation curves and results are obtained. The methodology includes analysis of 3D modelling of elevated water tanks of different tapering angles. The non-linear analysis is carried out for the different models to compare the effect of earthquake on it. In this study default hinges are used in beams and columns and thus pushover graph is obtained from excel spread sheet.

3. MODELLING OF STRUCTURE AND PROBLEM DISCUSSION

In order to evaluate the seismic response of elevated water tanks dynamic analysis is adopted. The components of Intze type ESR are as shown in Fig. 3.1

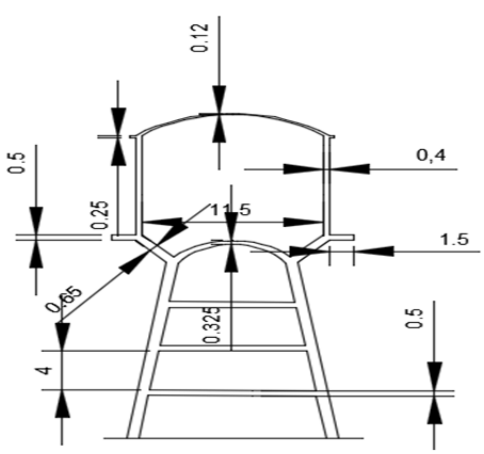


Fig. 3.1 Schematic diagram of Water tank with frame type staging

The finite element analysis software SAP2000 is utilized to create 3D model and run all analyses. The final conclusion will be drawn with help of graphs of Base Reaction Versus Displacement (Roof Displacement) from which we can compare one tank structure with other tank structures and then can predict the behavior of the same.

Problem Description:

The numbers of columns considered in the study are eight symmetrically disposed on a circle. Bracings are considered as straight and provided at three levels with each of 4 m spacing, thus dividing the staging in four column panels.

The bottom panel is numbered 1 and the top panel is numbered 4. Top ends of the columns are connected by a ring beam and the bottom ends of the columns are connected to the foundation ring beam they are assumed to be fixed for the analysis. The inclination of columns to the vertical is 0°, 3°, 6° and 9^0 is considered.

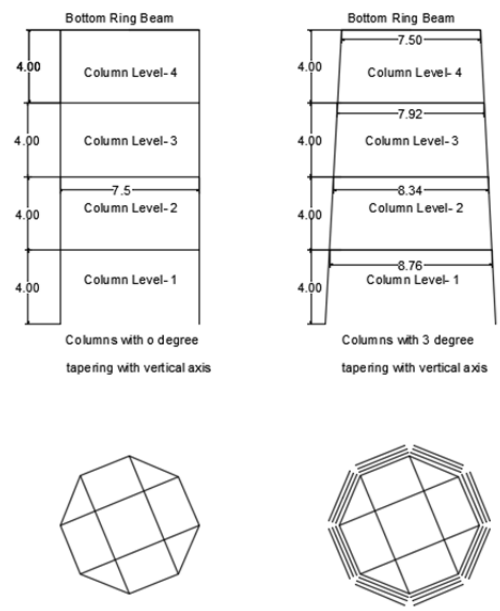


Fig. 3.2 Snapshot of plan and elevation of tapered frame type staging having 0 and 3 degree inclination with vertical axis

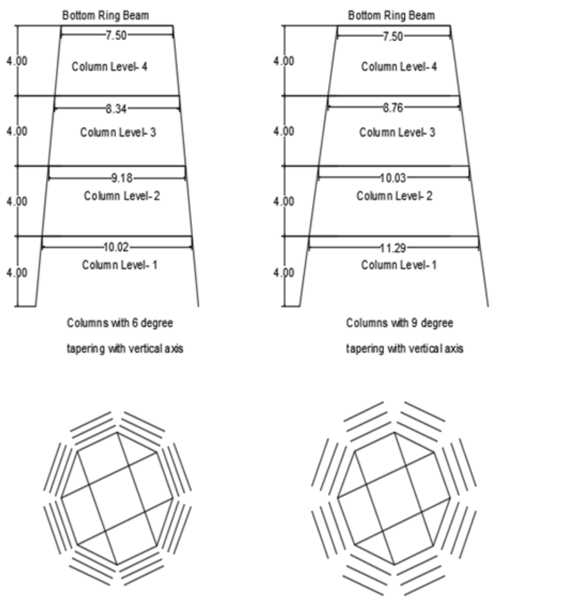


Fig. 3.3 Snapshot of plan and elevation of tapered frame type staging having 6 and 9 degree inclination with vertical axis

In this study, a reinforced elevated water tank with fixed base staging system has been considered for the present study. The elevated tank has a capacity of 900 m3 with staging height of 16 m considering 4 m height of each panel is considered for study .The tank is of intze type. Container of the tank has an internal diameter 11.5 m and height of 13 m.. Grade of concrete and steel used are M20 and Fe415, respectively. zone of the tank has selected in seismic zone IV [18]. Density of concrete is 25 kN/m3.

3.1 Preliminary Data From Conventional Design

Details of sizes of various components and geometry are shown in Table

Table 3.1 Geometrical Data from Conventional Design

Component	Size (mm)
Top Dome	120 thick
Rise of Top Dome	2000
Height of Cylindrical Wall	9000
Cylindrical Wall	400 thick
Size of Bottom Ring Beam	1500 x 500
Conical Dome	650 thick
Rise of Bottom Dome	1500
Bottom Dome	325 thick
Size of Bracing	500 x 500
Column	8 nos. -750 mm dia.

The model is made in SAP2000, Model is studied for comparing lateral displacement, storey drift and base shear. Pushover analysis is carried out on the same models to obtain bilinear curves.

Model I: Elevated Water tank with 0^0angle of column with vertical.
Model II: Elevated Water tank with 3^0 angle of column with vertical.
Model III: Elevated Water tank with 6^0 angle of column with vertical.
Model IV: Elevated Water tank with 9^0 angle of column with vertical.

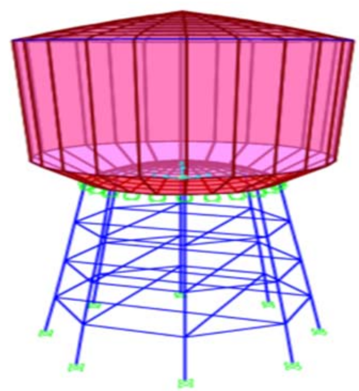


Fig. 3.4 Snapshot of 3 dimensional model of Elevated Water Tank having 9 degree inclination with vertical axis

Procedure to do Pushover Analysis

- Create three dimensional model of tank.
- Implementation and application of gravity loads, live loads, and water load, etc.
- Define properties and acceptance criteria for the pushover hinges .The program includes several built-in default hinge properties that are based on average values from ATC-40 for concrete members and average values from FEMA-356 for steel members.
- Locate the pushover hinges on the model by selecting one or more frame members and assigning them one or more hinge properties.
- Define the pushover load cases.
- Push the structure using the load patterns of static lateral loads, to displacements larger than those associated with target displacement using static pushover analysis.
- The numbers of hinges in each member showing the hinges in columns the immediate occupancy, life safety, collapse prevention to define the force deflection behaviour of the hinge.
- The lateral load is applied on the frame, which when deflected forms hinges. The plastic hinge formation at the yielding and significant difference in the hinging patterns at the ultimate state.
- Developing a pushover curve and estimating the force and deformations in each element at the level of displacement corresponding to target displacement.
- The node associated at CG of container is the target point/node selected for comparison with target

displacement. The maximum limit for roof displacement is given as 0.004H[18], where H is the height of the structure. Base shear and roof displacements are recorded at every step, to obtain the pushover curve.

4. RESULTS AND DISCUSSION

The fundamental time period and base shear values using IS 1893-Part II and from SAP2000 are tabulated below. The base shear is decreasing and time period is increasing in case of software results.

Table 4.1 Analytical and software results comparison for Model with 9 degree tapering

Parameters	Indian Code	Present Study
Time Period (Sec)	0.48	0.59
Base Shear (kN)	1100	1049.35

From Table 4.1 it can be seen that the results obtained and that obtained from IS 1893-Part II [18] are nearly matching.

The results of fundamental time period and base shear for the considered tank with different inclinations of columns with vertical axis are tabulated below.

Table 4.2 Comparison of seismic parameters for different angles of staging with vertical

Paremeters	0^0	3^0	6^0	9^0
Fundamental time period (sec)	0.938	0.879	0.732	0.569
Base shear (kN)	939.12	950.14	961.61	1079.3
Displacement (mm)	23.55	13.39	10.36	11.54

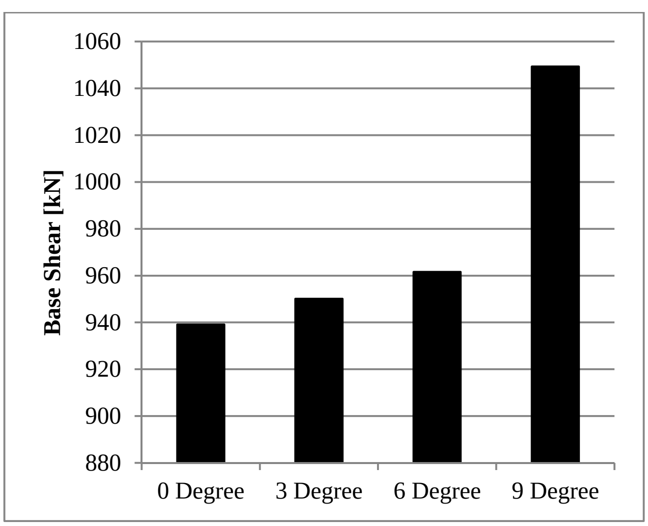


Fig. 4.1 Variation of Base Shear with tapering of staging

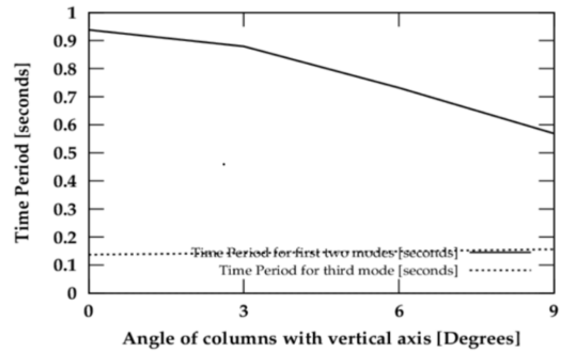


Fig. 4.2: Variation of Time Period with Tapering of staging

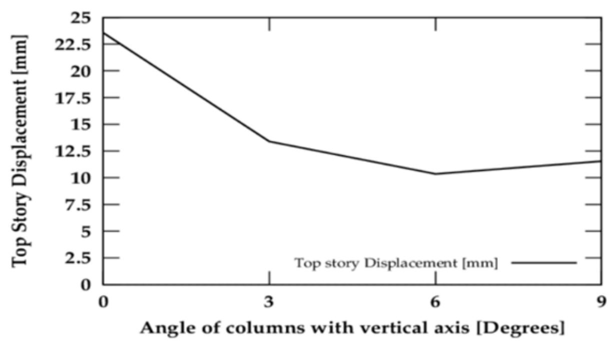


Fig. 4.3 Variation of top story displacement with tapering of staging

The pushover analysis is carried out on model I, model II, model III and model IV and bilinear curves are obtained. The comparison of pushover curves and their corresponding bilinear curves of all models is shown in Fig. 4.4 and Fig. 4.5 below,

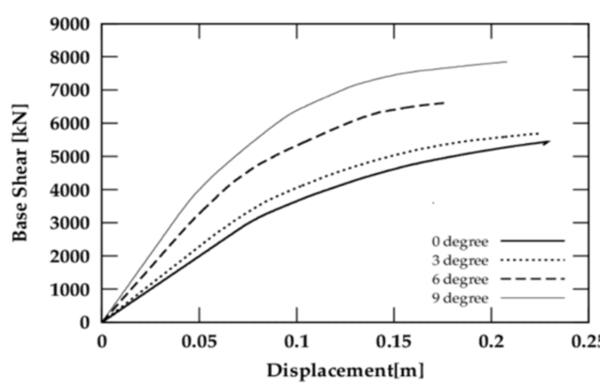


Fig. 4.4 Comparison of Nonlinear Static Pushover curves for different models

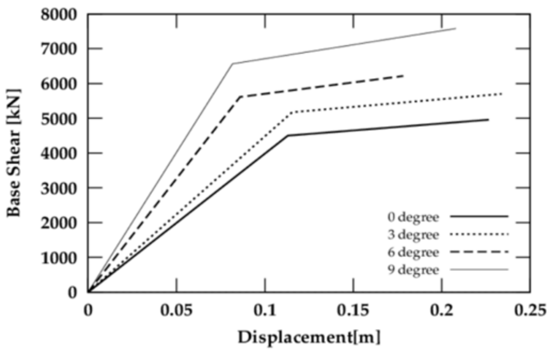


Fig. 4.5 Comparison of Bilinear Nonlinear Static Pushover curves for different models

From the comparison of these graphs , it can be concluded that the elevated water tank having the inclination of 9 degree of columns with vertical gives the better performance than other three models.

5. CONCLUSION

In this study an analysis of elevated water tank having 900 m^3 capacity with the inclination of columns as 0^0, 3^0, 6^0 and 9^0 with vertical is carried out. From above mentioned detailed study and analysis some of the conclusions can be made as follows.

- The time period for elevated water tank having 9^0 inclnation of columns with vertical is minimum and respective base shear is maximum than other three considered models.
- In pushover analysis, at yield point during an elevated water tank with 9^0 inclination of columns with vertical shows better results than other three models with 0^0, 3^0, 6^0 Inclinations.
- Elevated water tank having the inclination 9 degree of columns with vertical gives the better results than other three models considered in the present study

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