Review on Seismic Analysis of Elevated Storage Reservoir

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Abstract— The objective of Earthquake Engineering is to design a structure in such manner so that the damage of structure or structural member during earthquake is minimized. The paper aims the review on the different methods for the seismic analysis of the Elevated Storage Reservoir (ESR) as it may be dynamic or static and it can be linear or nonlinear in terms of geometry or material. Response spectrum and time history are dynamic analysis whereas seismic coefficient and pushover analysis are the static seismic analysis methods. This paper is attempted 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.

Key words: ESR, Circular Water Tank, Elevated Tank

I. INTRODUCTION

Elevated storage reservoir must remain functional even after the earthquake for the purpose of life supporting and firefighting element. Numbers of researches have attempted to evaluate the seismic response of the elevated storage reservoir. Different seismic evaluation methods are characterized as static and dynamic methods. seismic coefficient method is an equivalent static analysis which includes factors such as Zone factor, Importance factor, Soil-foundation factor, Response reduction factor, Code of practice preferred seismic coefficient method to simplify the analysis to determine the effect of earthquake on structure. Response spectrum is dynamic analysis characterized by the modal combination carried out by different method such as CQC, SRSS for the linear structure. Time history analysis is linear and nonlinear method for structure. 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 behavior and predict maximum displacement of structure during particular earthquake. Static pushover procedure 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. Where different retrofitting techniques can be suggested about the location where damage are produced in the form of plastic hinges. It is efficient method to understand the performance of the structure during earthquake. Methods of seismic analysis are tabulated below.

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

Table 1: Analysis Methods

II. LITERATURE REVIEW

1) Dynamic Analysis of Circular Water Tank and Study of Relevant Codal Provision [Arshal Nikhade, Ajay Dandge and Anshul Nikhade]

In this paper provisions of existing codes are compared with the draft code. The draft code considers various parameters like convective and impulsive loadings on liquid retaining structure, it is found to be covering many facets related to seismic loading. There are many parameters common in both the codes while the draft codes needs calculations of horizontal shear force, shear moment, sloshing wave height, time period etc. in impulsive & convective modes in addition to other parameters. To Study the design of elevated water tank the staging system seismic force calculation of IS 1893-1984 and 1893-part II (draft code) for 3 tanks of 1000 Cum, 2000 Cum, 3000 Cum capacity of cylindrical and Intz type where design manually. Concluding remarks of this work are 1) Horizontal seismic coefficient in impulsive and convective mode is to found more in 1000 Cum as compared to 2000 Cum and 3000 Cum tank. 2) Total base Shear in convective and impulsive mode found to be more in 2000 Cum, 3000 Cum. 3) Time period in case of convective mode is found to be varying between 4 sec to 17 sec. For medium soil condition Sa/g is calculated using formula 1.36/T, resulting in very low values of Sa/g.

2) Comparison between Static and Dynamic Analysis of Elevated Water Tank [Harshal Nikhade, Ajay Dandge and Anshul Nikhade]

Object of this paper is to compare the static and dynamic analysis of elevated water tank, to study the hydrodynamic effect on elevated water tank and to compare the effects of impulsive and convective pressure results. With the same configuration of water tank both the method differs considerably. Increase in the capacity of tank shows difference between static and dynamic response is increasing in order and also the small capacity of the tank the impulsive pressure is greater than the convective pressure but it is reverse for the larger capacity. Conclusion shows that in any zone the response for static analysis is on higher side than that of dynamic analysis. This happens because in static analysis water mass sticks to the container and hence the peak of water mass & structure are achieved at same time period. On the other hand dynamic response of water tank gives lesser values due to sloshing of water.

3) Pushover Analysis for an Elevated Water Tanks [N. Vinay, Dr. GopiSiddappa and Dr. G.S. Suresh]

This paper attempts to carry out nonlinear static analysis on elevated water tank for which an elevated circular liquid storage tank with capacity of 90k liters with height of staging 16m up to the bottom of the tank is supported with 8 columns symmetrically placed on a circle of 10.6m mean diameter as shown in figure 1. The staging of the tank is divided into 4 panels each of 4m height. The columns are connected to foundation by means of ring beam, the top of which is

provided at 1m below the ground level so that actual height of first panel is 5m. Over this geometry pushover analysis is carried out and capacity curve is determined which concludes that the frame behaved linearly elastic up to a base shear value of around 310 kN where at 910 kN base shear, it depicted non-linearity in its behavior. Increase in deflection has been observed to be more with load increments of the base-shear of 910 kN showing the elasto-plastic behavior.

Fig. 1: Elevated Circular Liquid Storage Tank with Columns Rigid at Top and Fixed at Footings
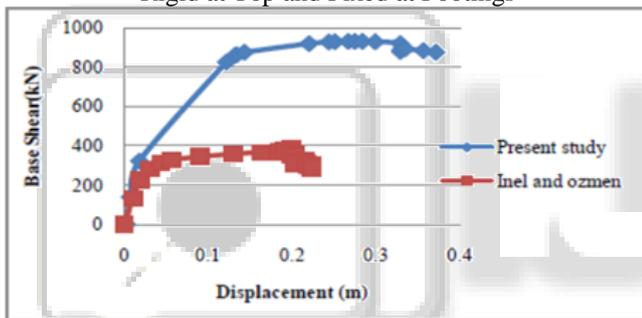

Fig. 2: Combined Capacity Curve

4) *Practical Three Dimensional Nonlinear Static Pushover Analysis [Ashraf Habibullah and Stephen Pyle]*
This article presents the steps used in performing a pushover analysis of a simple three-dimensional building. SAP2000 is used as a tool for performing the pushover. The SAP2000 static pushover analysis capabilities, which are fully integrated into the program, allow quick and easy implementation of the pushover procedures prescribed in the ATC-40 and FEMA-273 documents in which the magnitude of the structural loading is incrementally increased in accordance with a certain predefined pattern. With the increase in the magnitude of the loading, weak links and failure modes of the structure are found. Pushover analysis is a static, nonlinear procedure. This paper discusses pushover stapes in detail and to evaluate the real strength of the structure. It promises to be a useful and effective tool for performance base design.

5) *Parametric Study of Behavior of an Elevated Circular Water Tank by Non–Linear Static Analysis [Prakash Mahadeo, Mohite Saurabh and Arun Jangam]*
In this paper the parametric study behavior of an elevated circular water tank by 'Non–Linear Static Analysis' is carried out considering various parameters like water storage capacity 400 m³, staging height 16 m and 20 m, diameter of columns 500 mm and 650 mm, number of columns 8, 10 and

12 with single layered and double layered column arrangements. By combination of these parameters 20 tank models checked for base reaction with respect to others, top roof displacement and plastic hinge formation sequence and its pattern and target displacement within the staging with the help of their individual capacity curve or pushover curve using SAP2000. These concludes that displacement goes on decreasing as the number of column increases while it increases for increasing staging heights where the base reaction goes on increasing as the number of column increases but no much variation is observed for increasing staging heights.

6) *Effects of Plastic Hinge Properties in Nonlinear Analysis of Reinforced Concrete Buildings [Mehmet Inel and Hayri Baytan Ozmen]*
The paper discusses the effects of plastic hinge properties on nonlinear response of four storey and seven storey reinforced concrete buildings. The results of pushover analysis with default and user defined hinge properties. Study is carried out with the help of SAP2000. The study gives emphasis on the comparison of pushover curves with different plastic hinge lengths and other parameters such as spacing of transverse reinforcement are also included in the study. The study concludes the base shear capacity does not depend on whether the default or user-defined hinge properties are used. Plastic hinge length(Lp) has considerable effects on the displacement capacity of the frames. Comparisons show that there is a variation of about 30% in displacement capacities due to Lp.

7) *Seismic Performance Evaluation of Corroded Reinforced Concrete Structures by Using Default and User-Defined Plastic Hinge Properties. [HakanYalçiner and KhaledMarar]*
This study was to investigate the effects of default hinge properties based on FEMA-356 and user defined hinge properties on the time dependent seismic performance levels of corroded RC buildings. An assumed corrosion rate was used to predict the capacity curve of the buildings by using default and user defined plastic hinge properties as a function of time (*t*:25 years, and *t*:50 years). Two, four and seven stories RC buildings were considered to represent the effects of default and user defined hinge properties on story levels. For the modeling of user-defined hinge properties, the time dependent moment-curvature relationships of structural members were predicted as a function of corrosion rate for two different time periods in order to perform push-over analyses, while default hinge properties were used for the other case based on the ready documents by FEMA-356. The conclusion shows that the user defined plastic hinge properties give better and correct results than default hinge properties.

B. *Structural Assessment of Circular Overhead Water Tank Based on Shaft Staging Subjected to Seismic Loading [D. K. Landge, Dr. P. B. Murnal]*

This study is to understand the seismic behavior of the elevated water tank with consideration and modeling of impulsive and convective water masses inside the container as supported on shaft as one mass model and two mass model as per IS: 1893-2002 under different time history records using software SAP 2000. The present work aims at checking the adequacy of water tank supported on shafts for the seismic excitations.
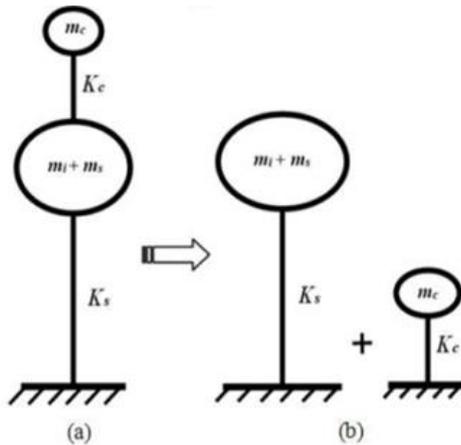
Fig. 3: Two Mass Model for Elevated Tank

It is observed that the displacements for two mass models are less than one mass and existing model. Base shear also shows a minimum value for two mass models for all the three capacities. Time period for two mass models is also higher than one mass and existing model.

1) Pushover Analysis of Medium Rise Multi-Story RCC Frame With and Without Vertical Irregularity [Mohommed Anwaruddin, Akberuddin Mohd. and Zameeruddin Mohd.]
This study is evaluating and comparing the response of five reinforced concrete building systems by the using different methodologies suggested by the ATC-40 and the FEMA-273 by nonlinear static procedures with different number of story criteria. The study aimed for doing Nonlinear Static Pushover Analysis of G+3 RCC residential building frame which is to be designed by conventional design methodology. A Nonlinear Static Analysis had been used to obtain the inelastic deformation capability of frame. It was found that irregularity in elevation of the building reduces the performance level of structure and decrease in deformation or displacement of the building is also observed. The lateral displacement of the building is reduced as the percentage of irregularity increased. As the percentage of vertical irregularity increases, the story drift reduces and go on within permissible limit as clause no. 7.11.1 of IS 1893-2002 (Part I). There is 2% to 5% difference in lateral displacement. It is also concluded that as the no of bays reduces vertically the lateral load carrying capacity increases with reduction in lateral displacement.

2) Observations on the Reliability of Alternative Multiple Mode Pushover Analysis Methods [T.Tjhin; M.Aschheim; E.Hernández-Montes]
This study compares estimates of response quantities obtained with the pushover analysis method and a new pushover analysis method that uses the energy-based displacement for five building models subjected to 11 ground motions. Conclusion carried out by the study is that the energy-based MPA methods have utility for estimating mean floor displacements and inter story drifts for some buildings, but neither is able to provide consistently reliable estimates of story shears and overturning moments over the height of the buildings considered.

3) Application of Pushover Analysis for Evaluating Seismic Performance of RC Building. [RizaAinul Hakim, Mohammed SohaibAlama, Samir A. Ashour]

Level	Description
Operational	Very light damage, no permanent drift, structure retains original strength and stiffness, all systems are normal
Immediate Occupancy	Light damage, no permanent drift, structure retains original strength and stiffness, elevator can be restarted, Fire protection operable
Life Safety	Moderate damage, some permanent drift, some residual strength and stiffness left in all stories, damage to partition, building may be beyond economical repair
Collapse Prevention	Severe damage, large displacement, little residual stiffness and strength but loading bearing column and wall function, building is near collapse

Table 2: Performance Level of Building

The paper is to investigated gravity supporting building its resistance to expected seismic loading in different regions. A test RC building that was designed for gravity loading only is investigated. This will be accomplished by performing the nonlinear static analysis according to ATC 40. Pushover analysis produces the pushover curves, capacity spectrum, plastic hinges and performance level of the building. This analysis gives better understanding seismic performance of buildings and also traces the progression of damage or failure. The building performance level is determined by intersection of demand and capacity curves and the hinge developed in the beams and the columns. The study concludes that Pushover analysis is a simple way to investigate nonlinear behavior of the building. The result gives understanding into nonlinear behavior, which is real behavior of structure. Pushover analysis can identify weak elements by predicting failure mechanism and account for redistribution of forces during progressive yielding. The damage associated with difference performance level is described in the Table 2.

4) Proposal of lateral load pattern for pushover analysis of RC buildings [F. Khoshnoudian∗, S. Mestri, F. Abedinik]
The proposal lateral load pattern for pushover analysis is given in two forms for symmetric concrete buildings. These two forms give more realistic results as compared to conventional load patterns such as triangular and uniform load patterns. The assumed buildings of 4, 8, 12, 16, 20 and 30 stories concrete buildings are SMRF which have been designed according to 2800 standard. Then using conventional load patterns and proposal load patterns, the pushover analysis has been done and results have been compared with the outcomes of nonlinear time history analysis. The work results that in high-rise buildings, before formation of the plastic hinges on the upper stories the hinges in lower stories turn to life safety (LS) and even collapse prevention (CP). That is the reason for differences between pushover capacity curve and dynamic capacity curve for high-rise buildings. It means that in pushover analysis of high-rise buildings the capacity of the upper stories is not considered.

5) Evaluation response reduction factor of RC framed staging elevated water tank using static pushover analysis [Tejash Patel, Jignesh Amin and Bhavin Patel]

The study evaluate the response reduction factors of RC framed staging elevated water tanks having staging height of 12 m but having varying capacities. The effects of seismic zone and fundamental time period of water tank on the Response reduction factor are also discussed. It is observed that value of R for elevated water tank is significantly affected by the seismic zone, time period and capacity of tanks. The study concludes that The response reduction factor is considerably affected by the seismic zone and fundamental time period of water tanks. It reduces as the seismic zone increases and increases as the fundamental time period increases. To ensure the consistent level of damaged, values of response reduction factor should be based on both fundamental period of the staging and type of soil. Estimation of response reduction factor with exact analysis will help in an economical design. It is observed that response reduction varies from 2.63 to 4 for tank in full condition in seismic zone V.
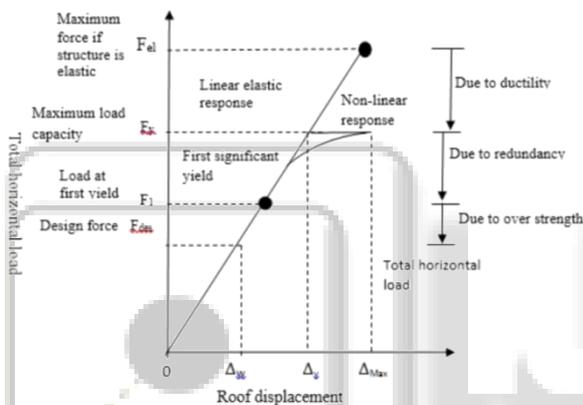

Fig. 4: Conception of Response Reduction Factor

6) Evaluation of seismic ground motion scaling procedures for linear Time-history analysis of liquid storage tanks [Miguel Ormeño, Tam Larkin and Nawawi Chouw]

The research reported here concerns the seismic response of storage tanks, in terms of base shear, overturning moment and wall stresses, when subjected to scaled ground motions using the procedures of three design specifications. It was found that the Eurocode 8 approach produces the highest seismic response on storage tanks. ASCE/SEI 7-10 gives intermediate results in terms of applied load and seismic response compared to the other two specifications. The study also shows that the restriction imposed by NZS 1170.5 for tanks, produces an underestimate of the seismic load on storage tanks. A series of time-history earthquake response analyses have been carried out using 3 different procedures to match an earthquake record to a target spectrum. Six different liquid storage tanks were considered. The main aim was to evaluate the different Scaling procedures given by three internationally used design specifications and to develop an understanding of the different consequences of the scaling procedures for the tank response. The study concludes that Most liquid storage tanks are not in the period range of interest defined by NZS 1170.5 for scaling earthquake records, and therefore, the frequency range considered over which to scale the records does not match the predominant dynamic properties of liquid storage tanks. Eurocode 8 also

gives the highest values of base shear and overturning moment in most cases, predicting the highest number of exceedance of the elastic limit The authors of this work recommend analyzing liquid storage tanks disregarding the lower period restriction imposed by NSZ 1170.5. This recommendation is made because the reasons for establishing the lower limit for the fundamental period do not generally apply to liquid storage tanks.

7) A Study of Overhead Water Tanks Subjected to Dynamic Loads [Dona Rose K J, Sreekumar M. and Anumod A S]

The present study focuses on the response of the elevated circular type water tanks to dynamic forces. Overhead water tanks consist of huge water mass at the top of a slender staging which are most critical consideration for the failure of the tank during earthquakes. Tanks of various capacities with different staging height are modeled using ANSYS software.
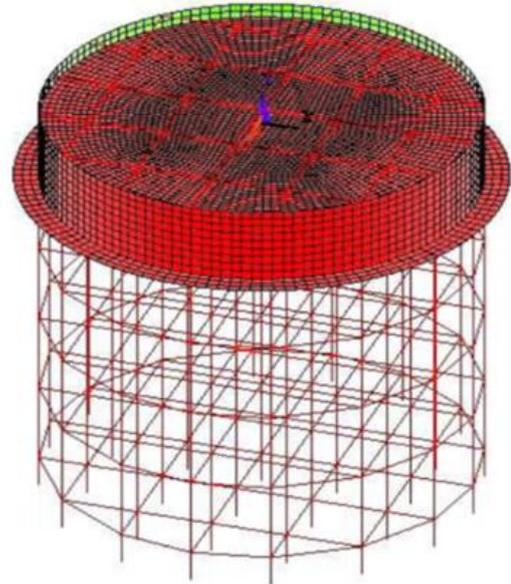

Fig. 5: ANSYS Model of Elevated Water Tank in Full Water Level Condition (1200m3- 18m Staging Height)

The analysis is carried out for two 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 study concludes that the peak displacement from the time history analysis increases with staging heights, But the displacement first decreases and then increases with capacities. The displacement for half-filled tanks is lesser than the displacement for tanks with full capacity. The base shear values from time history analysis were increases as staging height increases. Also, the base shears decreases and then increases with capacity. Base shear for half capacity tanks are lesser than that for full capacity tanks under same staging condition. The peak displacements from the time history analysis under El Centro earthquake records are below the maximum permissible displacement for different water levels.

8) Behavior of Elevated Concrete Water Tank Subjected to Artificial Ground Motion. [Gareane A. I., Algreane Siti Aminah Osman, Othman A. Karim and Anuar Kasa]
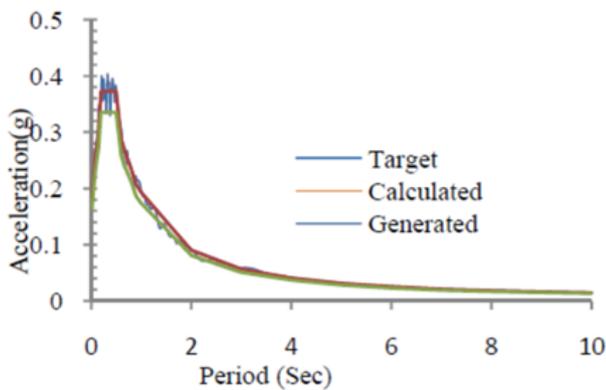

Fig. 8: Target and Calculated Response Spectrum at the Bed Rock.

This paper is concerned with the soil and water behavior of elevated concrete water tank under seismic load. An artificial seismic excitation has been generated according to Gasparini and Vanmarcke approach, at the bedrock, and then consideration of the seismic excitation based on one dimension nonlinear local site has been carried out. Seven cases are chosen to make comparisons with direct nonlinear dynamic analysis, mechanical models with and without soil structure interaction (SSI) for single degree of freedom (SDOF), two degree of freedom (2DOF), and finite elements method (FEM) models. The analysis is based on superposition modal dynamic analysis. SSI and fluid structure interaction (FSI) have been accounted using direct approach and added mass approach respectively.

The study concludes that the simplified procedure that can be utilized for evaluating the dynamic characteristics and the dynamic response of elevated tank is more adequate by using 2DOF, and economically may applicable. Furthermore, analysis with DOF procedure needs less computational efforts than FEM. The result of FEM based on first mode (Impulsive Mode) are reveals a very good estimation.
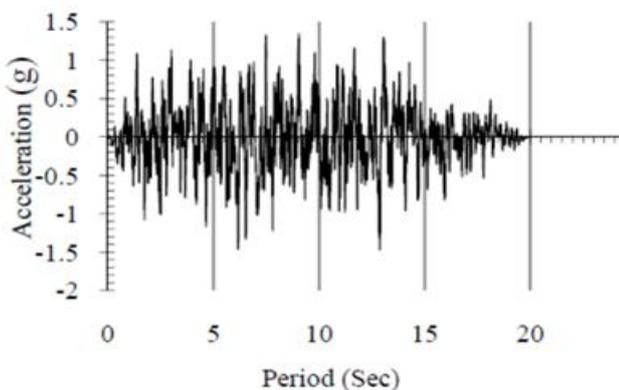

Fig. 9: Artificial Seismic Excitation Compatible with Target Response Spectrum

9) Performance Based Analysis of RCC Building [Nilang J. Pansuriya1 Prof. Tarak P. Vora]

In this study the analysis is performed on new as well as existing R.C.C. buildings and the performance of buildings in future earthquake is obtained. Non Linear static analysis is performed in existing as well as new buildings in finite

element program. It helps in the investigation of the behavior of the structure under different loading conditions, its load deflection behavior and the cracks pattern. the concludes that the As per my scope shear wall is to be provided for the retrofitting purpose. Following are the four cases for the shear wall.

1) Case 1- Modelling of G+5 Existing Building with Shear wall at Corner having length L 1 = 3ft 10.5 Inch L 2 = 4ft 5.5 Inch L 3 = 2ft 7.5 Inch L 4 = 4ft 6 Inch Location: 2 X –Direction 2 Y- Direction For these case 3 hinges are formed in Collapse prevention level in X Direction and no hinges are formed in Y Direction. 2) Case 2- Modelling of G+5 Existing Building with Shear wall at Corner having length L1 = 3ft 10.5 Inch L 2 = 4ft 5.5 Inch L 3 = 2ft 7.5 Inch L 4 = 4ft 6 Inch Location: 2 X – Direction 2 Y- Direction In this case the length of the shear wall is increased and so only one hinge is formed in Collapse prevention level in X Direction. 3) Case 3- Modeling of G+5 Existing Building with Shear wall at Corner having length L 1 = 5ft 10 Inch L2 = 5ft 8 Inch L 3 = 3ft 8.5 Inch L 4 = 3ft Location:4 Y- Direction In these both the location of the shear wall are changed and so one hinge was formed in Collapse Prevention Level in X direction.

III. CONCLUSIONS

Elevated water tanks, which typically consist of a large mass supported on the top of a slender staging, are particularly susceptible to earthquake damage. Thus, analysis & design of such structures against the earthquake effect is of considerable importance. After details study of all the papers, following points are to be considering at the time of seismic analysis of elevated water tank.

1) In India, there is only one IS code i.e. IS 1893: 1984, in which provisions for aseismic design of elevated water tanks are given. IS 1893 (Part-1): 2002 is the fifth revision of IS 1893, still it is under revision. So detail criteria for aseismic analysis of elevated water tank are not mentioned in above IS code. Thus, the recommendations & suggestions given by all the above author has to be considered at the time of analysis. IITK-GSDMA has given some guidelines for seismic design of elevated water tank that should consider at the time of analysis.

2) Nonlinear static analysis concludes that the for 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 and the propagation of the damage due to the lateral loading during earthquake event. And the analysis also gives the target displacement buy generation of roof displacement vs. applied force which may not be possible any other analysis, it conclude the actual behavior of the structure by giving the plastic hinges at the region of beam column junction.

3) Most elevated water tank are never completely filled with water. Hence, a two – mass idealization of the tank is more appropriate as compared to one-mass idealization.

4) Basically, there are three cases that are generally considered while analyze the elevated water tank – (1)

Empty condition. (2) Partially filled condition. (3) Fully filled condition. For (1) & (3) case, the tank will behave as a one-mass structure and for (3) case the tank will behave as a two-mass structure.

5) If we compared the case (1) & (3) with case (2) for maximum earthquake force, the maximum force to which the partially filled tank is subjected may be less than half the force to which the fully filled tank is subjected. Actual forces may be as little as 1/3 of the forces anticipated on the basis of a fully filled tank.

6) During the earthquake, water in the tank get vibrates. Due to this vibration water exerts impulsive & convective hydrodynamic pressure on the tank wall and the tank base in addition to the hydrostatic pressure. The effect of impulsive & convective hydrodynamic pressure should consider in the analysis of tanks. For small capacitytanks, the impulsive pressure is always greater than the convective pressure, but it is vice-versa for tanks with large capacity. Magnitudes of both the pressure are different.

7) The effect of water sloshing must be considered in the analysis. Free board to be provided in the tank may be based on maximum value of sloshing wave height. If sufficient free board is not provided, roof structure should be designed to resist the uplift pressure due to sloshing of water.

8) Earthquake forces increases with increase in Zone factor & decreases with increase in staging height. Earthquake force are also depends on the soil condition.

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