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Seismic Analysis of RCC Water Tanks under Near-Fault Condition

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Abstract

Reinforced concrete water tank plays a important role in providing sustainable water supply to the our community. We use water supply for our daily basic needs, industrial needs, agriculture, firefighting purposes etc. Due to its importance factor, water tank's structural integrity was important during an critical event of time. Seismic design of reinforced concrete water tanks is a critical aspect of ensuring the safety and functionality of these structures during seismic activities. The importance of seismic design for reinforced concrete water tanks extends beyond just safeguarding the tanks themselves. These tanks often provide a critical water supply during post-earthquake recovery and emergency response operations. Therefore, ensuring their structural integrity helps to maintain an essential resource for drinking, sanitation, and firefighting purposes when it is most needed. Earthquake creates large number of lateral forces. The amount of damage which exerts on the building depends on both the seismic activity and the building's property. Water tanks has a huge amount of mass accumulated on the single point at a certain height which makes them vulnerable to some kinds on critical events. Capacity based design provided to be useful for designing a building for withstanding earthquake. But we need to know how to be building reacts to a certain event before we design the water tank according to it. Performance-based design philosophy plays a vital role in predicting the performance level associated with several levels of hazardous earthquake events. For this purpose, the building needs to be designed beyond the elastic limit of the member. The analysis procedure was broadly classified into linear and nonlinear methods of analysis, in which linear is only used in case the building won't reach the collapse load. But during an earthquake, the structural loading will reach the collapse load, and the material stresses will be above yield stresses. So the material and geometrical properties of the building need to be considered heterogeneous and non-linear. It is focused on behavior of RC water tank under near fault excitation condition. Two water tank model was used for this thesis where one can hold up to 500m3 of water and other is up to 1370m3 of water. The finite element modelling and numerical analysis is done using ABAQUS software.

Keywords: Seismic Analysis; Collapse Load

Abbreviations: IO: Immediate Occupancy; LS: Life Safety; CP: Collapse Prevention; NDA: Nonlinear Dynamic Analysis; LNG: Liquid Natural Gas; FPSO: Floating Production, Storage and Offloading Units.

Objective

- To analyze the elevated water tank using the Time history analysis method under NFE conditions using

Abaqus software
- To study the fluid-structure interaction.
- And to compare the parameters like stress distribution, displacement, failure mechanism etc.

Methodology

- A literature review regarding the thesis will be done.
- Two RC water tanks will be designed using ABAQUS software.
- The NFE condition was taken from PEER Ground motion records.
- The Time history analysis was done in the software and the results has been computed based on the result.

Literature Review

Pushover Curve

To obtain this pushover curve a series of inelastic seismic analyses is performed on a building using monotonically increasing lateral load. The pushover curve is plotted between the base shear to the roof displacement. The common procedure to find out the performance point is by an intersecting capacity curve with a demand curve which is plotted between Sa and Sd values. It is also commonly referred to as a capacity curve since it gives the overall summary of the building's capacity during seismic events. Using the target displacement, the seismic demand or performance point of the building could be figured out.

Pushover curve representation this can be done by using approximate methods provided in American standard code books. The performance point can be used to find some of the performance criteria like Operational (O), Immediate Occupancy (IO), Life Safety (LS), and Collapse Prevention (CP).

Acceptance criteria 2.2 Types of loading Patterns 2.2.1 FEMA-356 (2000) patterns There are several load patterns derived in this codebook [1]. The building which is subjected to load pattern NSP-1 which is distributed across the height of the building is based on the following formula: $Fx = Wxhxk \sum WihikV$ The second load pattern NSP-2 act like a uniform lateral load containing force that is proportional to story mass at each story level. In NSP-3 story shear distribution is determined by using modal responses of the building for the ground motion.

Fivestory RC building was designed and analysed with FEMA 356 and compared with the latest Euro code-8 procedures. He observed that the plastic hinge rotation which is given according to Euro code-8 was seeming to stay constant in the column while the load increased. This makes the value lesser than the FEMA 356. Similarly, the equation to find the rotations given for beams was also not correctly given in the case of Euro-code 8 which makes the FEMA 356 values a bit more accurate [2].

In another paper, they studied the Modal pushover analysis properties using FEMA 356 force distribution and validated them using non-linear response history analysis. Comparing FEMA-356 NSP 2.1 5 and nonlinear RHA showed that FEMA-356 lateral force distributions lead to gross underestimation of story drifts and completely fail to identify plastic rotations in upper stories compared to the values from the nonlinear RHA. The Uniform load distribution completely fails to estimate the story drift and hinge rotation compared to RHA which makes it the most inaccurate method of finding the seismic demand of the structure. 2.2.2 IS 1893 Equivalent Static Method [3].

Indian standard provision gives us the approximate method to calculate and distribute the lateral load to each floor of the building considering the seismic zone and soil condition of the place. This method is more similar to the FEMA 356 inverted triangle procedure where the only difference is in the calculation of the design base shear of the building. $Qi = Wihi2 \sum Wjhj2VB$ Here the lateral load distribution was compared between FEMA-257 and IS 1893 for four different types of loading conditions. He concluded that for all the loading condition the performance point was close to one another. The evaluation results from FEMA 346 uniform load pattern and IS 1893 load pattern are similar [4].

For this case, a RC water tank of different cross-section shapes was designed and analysed using IS 1893 code outlines and cross-checked using Response spectrum analysis. It is noted that the base shear value in the complete reservoir is greater compared to empty and partially full conditions. The Intze-type water tank accounts for greater impact and a large time period for different seismic zones. 2.2 6 2.2.3 other literature methods F Khoshnoudian, et al. [5].

Two different modification patterns based on the height of the building were proposed. For low rise building 1-(X/H)0.5 and for high rise building $2-\sin\left(\pi X/H\right)0.5$. Many iterations of Time history analysis were done in 4,8,12,16,20 and 30-story buildings and compared with conventional and proposed lateral load patterns for pushover analysis. He concluded that it is inappropriate to use uniform load patterns for these types of structures as they give an approximate value with a higher degree of differences. It is not reliable for the estimation of capacity curve purposes. The abovementioned proposal is the combination of uniform and triangle load patterns that removed the above shortcoming, giving us a more accurate value compared to other methods H Gholi Pour, et al. [6].

The new proposed load pattern has load distribution according to weight and stiffness variation in height and mode shape of the structure. They analyzed special steel moment frames with X-type bracings. It is concluded that the proposed load pattern results are closer to nonlinear dynamic analysis (NDA) compared to other pushover load patterns, especially in tall and medium-rise buildings having different stiffness and mass during the height. $Si = mi\psi inhiki\sum mi\psi inhinkin$ Where: Si is the lateral load at Story i, mi is weight at story i, yi is the Modal displacement of story i at mode n, hi is the height of story i, ki is Story Stiffness i and N is the number of building stories Aman Mola Worku, et al. [7].

Here they modified the first mode-based pushover analysis using some modification factors to get more accurate results compared to other methods. They analyzed five, ten, fifteen, and twenty-story buildings with this method and compared it with other NSP procedures [8]. In the conclusion, they found that the SRSS method and this modified method gives similar results and the more accurate result compared to other modal pushover analysis method. The peak error percent only varies up to 10-15% by comparing with other results. $Sj = \beta jmj(T1, \varepsilon 1)$ *where* $\beta j = |(1-2hjhr)r12|$ Kalkan E, et al.

Here they performed the analysis on a 12-story building using three load pattern which is given in FEMA 356 along with their formulation of two new load pattern based on a combination of the mode shape of the building [9]. They referred to their formulas as Modified Combination Procedure-1 which is a combination of any twomode shape of the building and Modified Combination Procedure-2 which is based on any single-mode shape of the building Habibi A, et al.

A new lateral load pattern is developed and discussed in this paper. The Load pattern based on mode shape is estimated by the directed algebraic combination of the weighted vibration mode-shape vectors because high-rise building's effects due to higher vibration mode should be considered for better outcomes. The weight for each mode is calculated using optimization algorithm techniques. It is concluded that, in the inelastic range of structural behavior, it is likely that higher modes have a significant effect on the optimal lateral load distribution. 2.4 8 2.2.4 Optimization Algorithms: a) Meta-heuristic optimization algorithm [10].

Optimization Algorithms

Meta-Heuristic Optimization Algorithm: In this paper, they disused the possibilities of using an optimization algorithm known as a meta-heuristic algorithm to optimize the lateral load pattern which is based on the mode shape of the building to get accurate results [11]. They implemented this method on a 20-story building and analyzed the results compared with other FEMA and MPA methods. The name of this meta-heuristic algorithm is the Cuckoo Search Algorithm (CS) which is based on the parasitic behavior of cuckoo species in combination with the flight behavior of some birds and fruit flies. They concluded that with some innovative approaches, there's a possibility to bring the most accurate seismic results using this static pushover approach.

Genetic Algorithm: To overcome the drawbacks of ordinary conventional methods these authors propose a method for combining a Genetic algorithm with Modal pushover analysis to get better results by optimization modal combinations [12]. The investigation proceeded on a 12-story building given by (Kalkan, 4004). In conclusion, it is found that an optimum combination, using Sn =mØn as a load pattern, estimates the seismic responses satisfactorily with a minimum error index. 2.3 Fluid structure interaction.

A finite element model of 900m3 water tanks was used to assess the fluid structure interaction under various earthquake conditions. Seismic responses like base shear, overturning moment, displacement and hydrodynamic presses were found out during this analysis procedure. It has been concluded that the response of the water tank was based on the natural frequency of the structure, earthquake characteristics and different water filling conditions [13].

Simplified SDOF system of water tank using mass concentration method was created for analytical solution. A finite element model was designed in ABAQUS software and modal analysis was done. The analytical solution of the fundamental frequency of water tower structure in the range of 25m 60m can be obtained by simplifying the structure of water tower to a single degree of freedom vibration model. According to the finite element simulation and analysis, when the lower abutment tube structure of the water tower is dumpy or too slender, the fundamental frequency error will gradually increase.

In this review paper different types of water tank with different boundary condition, seismic condition along with different types of failure was discussed. They discussed about elastic buckling of tank due to axial load, external pressure etc., failure on roof, bottom plate and foundation and finally fracture of piping. They reviewed anchored, pinned and sliding bottom water tanks. They concluded despite over 20-year research there are many gaps left regarding earthquake resistant design of tank.

Coupled Eulerian with shell along with Navier Stokes equations was developed using Finite element Methods to study the fluid structure interactions. The coupling was done by using different meshes mapped around fluid boundary nodes local positions over shell elements. Potential energy theorem was used in nonlinear dynamics of shells which is based on nodal positions and generalized unconstrained vectors to avoid use of large rotation approximations. Arbitrary Larangian Eulerian description was used as fluid solver to accept moving boundaries and coupled Lagrangian shell elements. Based on the studies he concluded that these proposed methods are adequate for fluid-structure interaction and should be studied thoroughly.

Sloshing effect of partially filled water tank was studied under near fault excitation condition and the results were compared with the sub-scale tank subjected to earthquake motion in shake-table test. The liquid pressure due to vertical motion is increased under near fault excitation condition but the sloshing effect can be neglected. The displacement 12 of the liquid depends on spectral acceleration of the earthquake motion. When coming to seismic design, the pressure induced on the water due to earthquake motion and the sloshing wave height both plays a vital role.

In this paper pressure distribution due to liquid sloshing effect has been calculated. There are various number of numerical techniques are available for studying the liquid sloshing. Here both baffled and unbaffled water tanks was used for study. The obtained results shows that baffle walls used to reduce the sloshing load drastically. Model studies need to be considered for study sloshing with different phase to get a accurate values.

Three water tanks was used in this study with and without internal member. For fluid member two- and three-dimensional parameter flow was considered, and Navier Stokes equation was used to solve SOLA scheme. Single value function is assumed for free surface profile. The buffer zone is used for generating impulsive pressure value due to fluid motion on the tank ceiling, which is depends on the size of it. For validating the computer-generated values experimental data need to be calculated manually.

In this paper, new method was developed to calculate sloshing load for designing LNG (Liquid Natural Gas) and FPSO (Floating Production, Storage and Offloading units). The analyses was done using ANSYS software with 6 DOF which are surge, heave, roll, pitch, sway and yaw. The procedure was explained in the flow chart manner. It is concluded that using time-domain motion and simulation, it provides suitable data for analysis purpose. The sloshing data used in this study has only limited amount of data, therefore field measurement date need to be used in this method for accuracy purpose.

In this study near-fault and far-field ground motions effect was investigated and compared on embankment dams. The difference is near-fault ground motion has large energy pulse waves and different pulse shape. It has time period with is 4 times larger than the natural period of the structure. Nearly 180 Nonlinear time history analyses was done with three different intensity level. The studies shows that the ratio between Tp and 13 To has a greater impact on seismic response of the structure along with the spectral shape. The Ration less than 1.5 creates large response comparing to far-field motion. Aggressive type ground motion factor was important due to its increase in motion intensity and nonlinear behaviour.

Vertical seismic effect on Liquid storage tank was analyzed and studied under near conditions.

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