A Comparative Review Of Dynamic Analysis Techniques For Elevated Water Tanks: Time History Method Versus Response Spectrum Method

Ms. Ashwini Baban Sankpal[1], Prof. S. S. Mane [2]
Department of Civil Engineering
[1]PG Student, Padmabhooshan Vasantraodada Patil Institute of Technology, Budhgaon
[2] Assistant Professor, Padmabhooshan Vasantraodada Patil Institute of Technology, Budhgaon

Abstract- *This paper presents a comprehensive review of dynamic analysis techniques for elevated water tanks, with a specific focus on comparing the Time History Method (THM) and Response Spectrum Method (RSM). Drawing upon a wide range of literature sources, the review synthesizes existing research efforts dedicated to understanding structural behavior, seismic performance, bracing configurations, material considerations, and soil-structure interaction in the context of elevated water tanks. Despite the extensive body of literature in this field, a notable research gap exists in the systematic comparison of dynamic analysis techniques, particularly between THM and RSM. This paper highlights the need for a comparative review to evaluate the advantages, limitations, and applicability of THM and RSM for dynamic analysis of elevated water tanks, providing valuable guidance for engineers and researchers in selecting the most suitable method based on project requirements and constraints.*

Keywords: *Water tank, time history analysis, response spectrum analysis, dynamic analysis, RCC, etc.*

I. INTRODUCTION

Elevated Water Tank is the public water distribution system; elevated water tanks are frequently utilized. Water tanks are critical components of the lifeline system, and their seismic safety is critical owing to post-earthquake functioning requirements. Elevated water tanks, also known as elevated service reservoirs (ESRs), are made comprised of a container and a tower (also called as staging). The use of staging in the form of a reinforced concrete shaft and a reinforced concrete column-brace structure is widespread. The column- brace frame staging system is basically a 3D reinforced concrete structure that supports the container and resists lateral stresses caused by earthquakes or wind.

The purpose of this research is to identify and quantify the variations in seismic behavior of column beam (Building) and column-brace (Staging) frames in the post-elastic zone. Nonlinear dynamic analysis is also used to highlight variations in the nonlinear dynamic behavior of different kinds of frames. The structure is exposed to monotonically increasing lateral pressures with an invariant height-wise distribution until a goal displacement is achieved in time history analysis. First, a two- dimensional or three-dimensional model is constructed, including bilinear or trilinear load- deformation diagrams of all lateral force resisting components, and gravity loads are applied. Elevated water tanks are often utilized as part of a lifeline system in public water distribution systems. Seismic safety of water tanks is critical due to post-earthquake functioning requirements.

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. 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 have 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.

So far, there has been no experimental test program (such as shaking table) that has studied the nonlinear response of RC pedestals to the strong ground motions. The number of numerical studies is also very few and mainly limited to only one or two elevated water tanks with certain tank weight and pedestal dimensions. This is despite the fact that elevated water tanks have a wide range of tank sizes and pedestal heights which may result in considerably different seismic response behaviors.

Furthermore, some of the design equations and requirements existing in the current codes are adopted from ACI 318-08 for designing components such as shear walls which are similar to RC pedestals. In addition, in some specific design features such as openings, the current code has adapted materials from ACI 307 (chimneys) and ACI 313 (silos). This shows the need to further evaluate some of the code requirements and equations. Poor performance in previous earthquakes, lack of experimental results, and importance of these structures as lifelines, very limited numerical studies, and evaluation of certain parts of the current code are the main drivers that necessitate a comprehensive study on the nonlinear performance of RC pedestals.

This study aims to fill this gap and investigate various aspects of nonlinear response behavior of RC pedestals by employing a finite element approach. All practical tank sizes and pedestal height and diameters are included in this research in order to define a comprehensive database for the seismic response factors of elevated water tanks. In addition, special topics such as effect of wall openings and shear strength of RC pedestals will be addressed and discussed. Various analysis methods such as pushover and incremental dynamic analysis (IDA) will be employed to serve this purpose. Other than deterministic approaches, a probabilistic method is implemented as well to study the collapse probability of the RC pedestals under different conditions. The outcomes of this research will help better understand the actual nonlinear seismic response of elevated water tanks.

Elevated water tanks are employed in water distribution facilities in order to provide storage and necessary pressure in water network systems. These structures have demonstrated poor seismic performance in the past earthquakes. In this study, a finite element method is employed for investigating the nonlinear seismic response of reinforced concrete (RC) pedestal in elevated water tanks. A combination of the most commonly constructed tank sizes and pedestal heights in industry are developed and investigated. Pushover analysis is performed in order to construct the pushover curves, establish the over strength and ductility factor, and evaluate the effect of various parameters such as fundamental period and tank size on the seismic response factors of elevated water tanks. Furthermore, a probabilistic method is implemented to verify the seismic performance and response modification factor of elevated water tanks. The effect of wall openings in the seismic response characteristics of elevated water tanks is investigated as well. Finally, the effect of axial compression on shear strength of RC pedestals is evaluated and compared to the nominal shear strength from current guideline and standards.

A. 1.2 Overview of Dynamic Analysis

Dynamic analysis is an important tool in structural engineering for evaluating the behaviour of structures under changing dynamic loads. While classic static analysis techniques give information about a structure's reaction to static loads, dynamic analysis expands this knowledge to include dynamic loading circumstances such as seismic occurrences, wind forces, and mechanical vibrations. Dynamic analysis is important because it can properly forecast structural reaction, evaluate structural stability, and assure the safety and serviceability of civil infrastructure. Engineers may improve structural performance and resilience by modelling real-world dynamic events, identifying possible vulnerabilities, optimising structural design, and implementing mitigation strategies. Dynamic analysis plays a crucial role in understanding the behavior of structures subjected to dynamic loads such as earthquakes, wind, and vibrations. This analysis provides valuable insights into the structural response, ensuring the safety, efficiency, and reliability of various engineering systems. In this article, we will explore the concept of dynamic analysis, its significance, different types, steps involved, applications, challenges, and more. Structures are constantly exposed to various dynamic forces, and it is vital to evaluate their response to such loads. Dynamic analysis is a branch of structural engineering that focuses on studying the behavior of structures under dynamic conditions. Unlike static analysis that considers the equilibrium of forces, dynamic analysis takes into account the time-dependent effects on structures.

1) 1.2.1 Types of Dynamic Analysis

Modal Analysis

Modal analysis is a fundamental technique used to identify the natural frequencies and mode shapes of a structure. It involves solving the eigenvalue problem of the structural system to determine its dynamic characteristics. Modal analysis provides crucial information about the dominant modes of vibration and their corresponding frequencies, aiding in the subsequent steps of analysis.

Response Spectrum Analysis

Response Spectrum Analysis (RSA) stands as a cornerstone method, offering critical insights into how structures respond to seismic forces across a spectrum of frequencies. Its significance lies in its ability to predict the maximum response of a structure under earthquake-induced motions, providing engineers with invaluable information for designing resilient and safe structures.

RSA is founded on the understanding that structures exhibit varying responses to seismic excitation at different frequencies. This fundamental principle stems from the fact that structures possess inherent vibrational modes, each characterized by a natural frequency at which the structure resonates most strongly. By quantifying these responses across a range of frequencies, engineers can discern the dynamic behavior of the structure and identify potential vulnerabilities to seismic events.

The process of conducting RSA typically begins with the development of a response spectrum, which serves as a graphical representation of the maximum response of the structure at different frequencies. This spectrum is derived from seismic design codes or historical earthquake records and provides engineers with a valuable tool for assessing structural performance under seismic loading conditions.

One of the key advantages of RSA is its frequency-based evaluation capability, which allows engineers to pinpoint critical vibration modes that contribute significantly to the overall response of the structure. Through modal analysis, engineers extract modal parameters such as natural frequencies, mode shapes, and modal damping ratios, providing essential insights into the dynamic characteristics of the structure. By identifying these critical modes, engineers can focus their efforts on optimizing the structural design to enhance its seismic performance.

RSA plays a crucial role in informing design considerations aimed at bolstering the resilience of structures against seismic events. By analyzing the maximum responses at different frequencies, adjust stiffness and mass distributions, and incorporate supplemental damping systems to mitigate the effects of seismic forces. Additionally, RSA facilitates the assessment of dynamic responses such as displacements, accelerations, and internal forces, implement retrofitting measures to enhance structural integrity and safety.

While RSA offers a simplified approach compared to more computationally intensive methods such as time history analysis, it remains a valuable tool for preliminary design and rapid assessment purposes. Time history analysis involves simulating the actual time-varying ground motions experienced by the structure, providing a more detailed understanding of its dynamic behavior over time. However, RSA's ability to quickly evaluate structural responses across a range of frequencies makes it well-suited for initial design iterations and seismic risk assessments.

Time History Analysis

Time History Analysis is a crucial technique in understanding how structures respond to real-life scenarios over time. Unlike simpler methods that assume loads are constant and instant, time history analysis considers how forces change over time, offering a more realistic view of structural behavior. This method is essential for capturing the complexities of how structures react to dynamic events, such as earthquakes or strong winds.

One of the main benefits of time history analysis is its ability to provide a detailed picture of how structures move and react under different conditions. By simulating real-time loads or ground movements, it helps us understand how structures behave when faced with actual challenges. This includes fluctuations in loads over time, which can greatly affect a structure's stability.

Through time history analysis, examine various aspects of structural response, like how much a building moves, how fast it accelerates, or where stress and pressure points occur. This comprehensive evaluation lets us identify any weak spots or areas that need strengthening. By understanding these aspects, we can make better decisions about how to design and reinforce structures to make them safer and more resilient.

Time history analysis is vital for understanding how materials behave under different conditions. Some materials may change their properties when subjected to dynamic loads, and this analysis helps us account for those changes. By considering these factors, create designs that better withstand the challenges posed by real-life situations.

In essence, time history analysis provides us with a realistic view of how structures respond to dynamic events. By understanding these responses, design structures that are better equipped to handle the challenges they may face during their lifetime.

B. 1.3 Water Tank

Water storage tanks are used to store water for fire protection and potable drinking water within a designated area or community. Elevated tanks allow the natural force of gravity to produce consistent water pressure throughout the system. Based on the intended application and needs of the distribution area, elevated water tanks can be engineered using a broad range of shapes, sizes, and materials. Storage tanks are among the most important structures that serve multiple purposes for society and industry, generally tanks are used to store chemicals, oil, liquefied gas, also to store water for supplying to households as drinking purpose, for industries as a coolant and irrigational water for agricultural farming in some areas, also they use for firefighting and for emergencies.

One of the basic needs of all human being is water, so for that need there are various types of water tank depending upon their size, shapes and position.

I. Depending upon shape there are Intze, Circular, Conical, and rectangular water tank.

II. Depending on position there are Elevated, Underground and Ground supported water tank.

III. Depending on material there are Reinforced concrete, steel and Prestressed concrete tanks.

1) 1.3.1 Elevated water tank

Water is human basic needs for daily life. Sufficient water distribution depends on design of a water tank in certain area. An elevated water tank is a large water storage container constructed for the purpose of holding water supply at certain height to pressurization the water distribution system. Many new ideas and innovation has been made for the storage of water and other liquid materials in different forms and fashions. There are many different ways for the storage of liquid such as underground, ground supported, elevated etc. 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. Elevated 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. Elevated water tanks are critical and strategic structures and damage of these structures during earthquakes may endanger drinking water supply, cause to fail in preventing large fires and substantial economical loss.

From all types of water tank elevated water tank which is also called as Elevated Service Reservoir (ESR) typically comprises of a container and a supporting tower (also called as staging) cover large area of distribution of water and ESR are specially constructed to maintain high pressure during supply of water at required locations. These tanks are most prone to get affected by earthquake forces, since large concentrated fluid mass is at the top which is supported by some staging system.

Fig 1: Elevated water storage tanks (ESR)

In general, there are three kind of water tanks-tanks resting on ground, underground tanks and elevated tanks among them elevated intze tank are considered in this study. Elevated Intze type tanks having a container at its top and it was supported over various type of staging as shown in Figure-1, a) Shell type staging, b) R.C.C Moment resisting Frame type staging, c) Steel Staging, d) Masonary Pedestal, R.C.C Frame type staging with bracing, Composite staging etc.

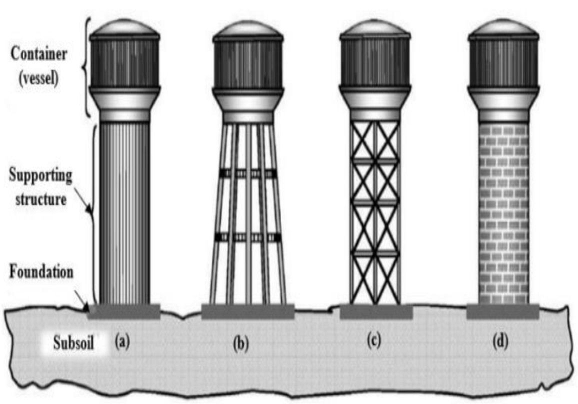

Fig 2: Different Staging Systems

Elevated water tanks are clearly displayed in public spaces, visible from both close and far distances. In India, the Intze style of overhead water tank is widely utilised. A significant number of overhead water tanks are now employed to supply water for public consumption. They are frequently used as markers in the landscape. As a result, the container's shape and form, as well as the supporting structure, must be given careful consideration from an aesthetic standpoint. Water storage tanks should stay operational in the postearthquake period to guarantee that earthquake-affected areas have access to drinkable water and to meet firefighting demands. Industrial liquid storage tanks may contain highly hazardous and combustible substances, and the contents of these tanks should not be lost in the event of an earthquake. Several big high water tanks were badly damaged during the earthquakes, but others were unharmed. The motion of the water relative to the tank, as well as the motion of the tank relative to the ground, must be considered while analysing the dynamic behaviour of such tanks. Because it is intended for wind and seismic pressures, the existing design of supporting structures for elevated water tanks is particularly sensitive to lateral forces caused by an earthquake. Water tanks can be damaged in many components for a variety of causes, including incorrect structural configuration design, inferior materials and workmanship, reinforcement corrosion, wind forces, earthquake forces, and so on. The lateral force design parameters in the zone of strong seismic activity are more or less governed by earthquake forces because of the enormous mass, especially when the tank is full. Total tank collapse must be prevented in the worst-case scenario. Some damage (repairable) may, nevertheless, be acceptable.

1.4 The objectives of this study are as follows

1. To analysis of elevated water tank by time history analysis method and response spectrum method.
2. To compare responses of time history and response spectrum methods.
3. To study the parameter such as Story displacement, base shear, Nodal Displacement obtained from seismic analysis in ETABS software.

II. II. LITERATURE REVIEW

Sneha Govindrao Mane, Dr. S. S. Angalekar "Seismic analysis of Water tank at different storey height of the Building and to check fluid sloshing effect." (2022)

The current study is the extension of the "environmental floor" concept, where installing the DOSIWAM system at intermittent levels of a multistoried building is carried out. The water coming out of this tank has very low BOD, so the water becomes suitable for reuse in gardening, irrigation, and firefighting operations. A novel approach was used, combining the CFD software and structural analysis software to check the sloshing effect. This is part of a research effort dedicated to developing a CAE (Computer-Aided Engineering) methodology. The project's objective was to check the effect of the storage tank on the environmental floor. Thus, a storage tank and a water tank with an aspect ratio close to 1 can be safely provided. The difference in time period of the water tank and the structure was found to reduce the effect of sloshing. Hence, the Storage tank of the DOSIWAM system can be safely installed on the structure.

W. A. Adil, M. A. Baluch et.al "Effect of Different Column Arrangements on Structural Behavior of Square Overhead Water Tank by Response Spectrum Analysis" (2022)

Overhead water tanks are involved in the important structures of any industrial areas and societies etc. Water tanks should remain in the functional condition during and after an earthquake or in any other emergency. The intension of researchers is very limited to structural analysis and design of overhead water tanks whereas tanks are very important structures. In this study, the author investigated the effect of different column arrangements on the structural behavior of square overhead water tank in terms of Base Shear, Time Period, Axial Force, and Main Column Moment according to the seismic zone 2A of Building Code of Pakistan by Response Spectrum Analysis using SAP2000.

Boggula Rajesh, G. Sreekanth "Design and analysis of diffrent water tanks by considering slab wall and capacity in seismic zones" (2022)

Elevated water tanks subjected to dynamic loads supported on RC framed structure and concrete shaft structure with varying capacity and located in different seismic zones. The history of the earthquake demonstrates that it has inflicted numerous losses to the life of people in its active time.These structures have a large concentration on slender support structures and are at risk of horizontal forces due to the earthquake in specific. They are essential elements in municipal water deliver hearth combating structures and in many commercial centres for garage of water. Hence increased water tanks ought to continue to be functional even after the earthquake. In this study guide seismic analysis of improved square water tank is achieved according with IS: 1893-1984 (i.e. Lumped mass version) and IS: 1893-2002 (Part-2) draft code (i.e. Two mass version).The structures are analysed with different simulated soft ware's Staad-pro and E-tabs. The results are compared for optimal value analysis in particular forces.

Krushnarth Chondikar "Design of Overhead Tank with Carbon Fibre/Fiber Rebar as Reinforcement and Time History Analysis using STAAD-Pro software." (2022)

The Construction and Design industry is always trying to find new and better technologies, ways, materials and equipment. One such technology/material is the using Carbon Fibre/fiber as Reinforcement for design the structure which is a new material in this industry that brings alternative for steel in the designing of the structure and offers design opportunities to enhance the performance of the structure with encouraging innovation. The use of this material in designing of the structure reflects economical. In present work, design of the overhead tank using carbon fibre/fiber as reinforcement, has been checked against the several loads, time history analysis and the maximum considered level criteria by performing the linear and nonlinear procedures with the help of STAAD-Pro software. In further work, the performance of overhead tank using carbon fibre/fiber as reinforcement will be checked at the several loads, time history analysis and the maximum considered level criteria.

Nasser Dine Hadj Djelloul,, Mohamed Djermane "Non-linear numerical study of the dynamic response of elevated steel conical tank under seismic excitation" (2022)

Elevated cylindrical and conical steel tanks are widely used to conserve water or chemical liquids. These important structures are required to stay protected and operative at any time. The wall angle inclination of conical tank part, as well as the presence of the vertical earthquake component, can cause damage to this structure and even lead to its failure. The purpose of this study is to examine the effect of the wall angle inclination of the tank and the vertical earthquake acceleration component on the nonlinear dynamic stability of the elevated steel conical tanks under seismic excitation. The elevated steel conical tank is simulated utilizing the finite element analysis method using ANSYS software. The fluid-structure interaction is considered using a suitable interface that allows the fluid to apply hydrodynamic pressures on the structure. Three different models, namely Model – A-30°, Model –B-45°and Model –C-60°were investigated; it has been concluded that the impact of inclination of the tank wall significantly affects the nonlinear stability of the elevated steel conical tank. While considering the vertical ground acceleration, inclination plays a significant role in the design of this type of structures. Therefore, it should be appropriately included in the seismic analysis of elevated steel conical tanks to satisfy the safety of the elevated steel conical tank response under seismic loading.

Latha M. S. "Comparison of analysis between Rectangular and Circular overhead water tank" (2021)

The study predicts the analysis and design of the rectangular and circular overhead water tank using ETABS software. The water tank is modeled and analyzed by using dynamic analysis to resist lateral loads and design is made using working stress method manually. Dead load, live load, wind load and seismic loads are applied based on IS codes. The behavior of structure for the parameters like Story drift, displacement, stiffness, deflection, storey shear, base shear, area of steel and hoop tension for circular and rectangular water tank are studied and then comparison of the results is made between circular and rectangular overhead water tank. By this study we say that the circular water tank is suitable for larger capacity and rectangular is suitable for smaller capacity and it is economical for larger capacity.

TayyabaAnjum, Mohd. Zameeruddin "Evaluation of Efficacy of the Elevated Water Tank Under the Seismic Loads" (2021)

Elevated water storage tanks are the lifeline structures in urban areas that should remain serviceable during and after a seismic event. Experience learned from the past earthquakes worldwide showed that elevated water tanks were heavily damaged or collapsed during a seismic event. This failure attributes to the deficiency and misjudgment in the analysis and design aspects. Design procedures available in the present seismic codes indirectly address the inelastic behavior, and they showed the overestimates of the actual strength. Proper selection of a staging system and engineering demand parameters are the key elements of the elevated water reservoir design. In the present work, we performed a non-linear time history analysis on the models prepared about the data of existing elevated water tanks available within the Nanded region (Maharashtra-India). The obtained engineering demand parameters were used to predict the efficacy of elevated water tanks.

Amit K. Mali, "Performance of Various Staging Systems for Elevated Water Tank" (2021)

In this study, a comprehensive comparative analysis of a 29.2 m tall elevated water tank with framed-type staging was conducted, yielding several significant conclusions. Firstly, it was found that empty elevated Intze tanks exhibit less vulnerability during earthquakes, with wind forces exerting a more predominant effect, surpassing the impacts of earthquakes, dead loads, and live loads. Moreover, earthquakes primarily affect the vertical direction less compared to the vertical component of dead and live loads combined. Full water conditions in Intze tanks were associated with higher values of base shear, displacement, and shear forces. Additionally, circular tanks demonstrated less susceptibility to wind effects compared to regular-shaped tanks. Shell-type staging systems emerged as the most effective and economical option among various systems, including framed-type staging and variations with bracing. Notably, shell-type staging systems exhibited lower displacement, base shear, and structure weight compared to framed-type staging, as well as framed-type staging with bracing and cross steel bracing. These findings underscore the importance of considering both seismic and wind effects in the design and selection of staging systems for elevated water tanks, with shell-type staging offering superior performance and cost-effectiveness.

Vangaveti Sai Santhosh, Susanta Kumar Sethy et.al "Seismic Analysis of Overhead Water Tank Using Indian, American and British Codal Provisions" (2020)

Reinforced cement concrete overhead water tanks are very important structures. They are considered as main lifeline elements during and after earthquakes. An overhead water tank behaves like an inverted pendulum, which consist of huge water mass at the top of a slender staging. This is most critical consideration for the failure of the tank during earthquakes. Basically, supporting system, so called staging is formed by a group of columns and horizontal braces provided at intermediate levels to reduce the effective length of the column. In this study seismic behaviour of RCC overhead tanks in seismic zone (iii), was carried out by performing dynamic response spectrum analysis using FEM base software (ETABS) as per IS 1893: 2002.Analysis was carried out for elevated RCC tank for empty & full tank condition under different codal provisions. The responses include base shear, base moments and Compared among the three standards, ACI proves to be more economical. In terms of economic value, the codal provisions are queued as ACI, IS and BS. All the three codes follow working stress method and results in higher stability.

Bhakti B. Jani et.al "Effects of Soil Condition on Elevated Water Tank Using Time History Analysis with Different Staging Systems" (2020)

Due to colossal need by the public, water has to be stored and supplied according to their requirements. Waterdemand is not constant throughout the day. It fluctuates hour to hour. In order to supply constant amount of water, we need to store water. This paper presents time history analysis of intze elevated liquid storage tanks supported on RC framed structure with different capacities, different Staging configuration and full and empty condition on three different soil types (Hard rock, Medium soil, Soft soil). Tank responses including base shear, overturning moment and roof displacement have been observed, and then the results have been compared. Results state that the dynamic analysis replies as base shear, over-turning moment and displacement are vastly influenced.

Yaman sami shareef al-kamaki et.al **"A Comparative Study of Real full scale ground Rectangular water tank in duhok city" (2020)**

It is well known that facilities like storage reservoirs and tanks have a great priority as it serves mainly for portable drinking water for a huge population. In general, water tanks are designed based on their shapes and ground positions. In this comparative study an attempt is made to consider a rectangular reinforced concrete (RC) ground water tank of a real full scale as a case study in Duhok city. The study involves calculations of bending moments, shear forces, and reinforcement. The tank walls are subjected to dead load and hydrostatic load due to water. A parametric study has been undertaken also by considering water level and soil bearing capacity as variables in this investigation. A good agreement has been obtained in this comparison. It may be deduced that a design software can be used accordingly with a reasonable degree of accuracy than manual calculations. This can maintain a reasonable cost and avoid human errors in any structure which is a critical local and global issue nowadays.

Anik N Soniwala, "Comparative Study on Effect of Different Configuration of Horizontal Bracings on the Performance of Elevated Water Tank" (2020)

The investigation reveals significant findings regarding the stiffness and dynamic characteristics of water tanks under different bracing configurations and loading conditions. The study highlights that the fully filled tank with an octagonal bracing configuration and a staging height of 4m exhibits the maximum stiffness, surpassing the horizontal bracing configuration (considered as the base configuration) by 16.8%. Conversely, the empty tank with a square bracing configuration and a staging height of 5m demonstrates the minimum stiffness, being 31.1% less than the base configuration. Moreover, the analysis identifies the octagonal bracing configuration as having the maximum impulsive time period, indicating its potential for enhanced stability during dynamic loading events. Additionally, it is observed that partially filled tank conditions are more critical in terms of natural time period in the impulsive mode compared to fully filled tanks.

Bhakti B. Jani, "Effects of Soil Condition on Elevated Water Tank Using Time History Analysis with Different Staging Systems" (2020)

The dynamic analysis of a 250 m3 water tank supported by a moment-resisting frame using Time History Analysis reveals critical responses under various earthquake scenarios, considering both empty and full tank conditions. The significance of earthquake frequency content on structural responses is underscored, with higher frequency content correlating with intensified responses such as base shear force, overturning moment, and displacement. Notably, earthquake records with higher frequency content tend to evoke greater structural responses. Among the bracing configurations studied, radial bracing stands out for attracting more seismic forces in full tank conditions, resulting in higher base shear and reduced tank displacements compared to other patterns. The superiority of radial bracing over other configurations is evident in its performance, particularly in mitigating seismic effects. The critical response is strongly influenced by earthquake characteristics, with frequency content playing a pivotal role. Static and dynamic analyses indicate substantial impacts on base shear and displacement. The heightened critical response observed in full tank conditions is attributed to higher hydrodynamic pressures compared to empty tanks. Furthermore, the study highlights the significant influence of soil type on soil-structure interaction, with soft soil exhibiting greater interaction with the structure compared to rocky or medium soil types. These findings emphasize the importance of considering earthquake characteristics, bracing configurations, and soil types in optimizing the seismic design and performance of water tank structures.

Prashant Bansode, "Seismic Response of Overhead Water Tank with Different Staging System" (2019)

The seismic analysis and behavior of RC overhead water tanks, particularly with frame-type staging systems, have been meticulously examined, revealing crucial insights into their structural performance under seismic loads. These findings are paramount considering the vulnerability of overhead water tanks to failure during strong ground motion events. Utilizing STAAD PRO software and employing the two-mass model method, the seismic performance of RC overhead water tanks with different staging configurations was thoroughly investigated. Notably, previous literature underscores the effectiveness of frame staging systems, adhering to IS: 1893 (Part-2) guidelines, due to several key characteristics. Firstly, the study demonstrates that base shear increases with the level of bracing and lateral bracing, especially transitioning from no bracing to vertical diagonal or lateral cross bracing configurations. Moreover, base shear is observed to be higher for tanks under full conditions compared to empty ones, with Intze tanks exhibiting maximum base shear. Bending moment at the top of the foundation also escalates with increased bracing levels, particularly for tank full conditions. Interestingly, upgrading the staging configuration system by one level results in a 23% increase in both base shear and base moment for both tank full and tank empty conditions. Seismic design considerations are emphasized, with the assertion that tank full conditions necessitate more robust seismic design due to higher base shear and moment. Additionally, the study highlights the heightened vulnerability of empty water tanks during earthquakes, attributing this to the upward shift of the center of gravity, resulting in increased bending moments at the base. Importantly, the inclusion of bracing beam flexibility in IS: 1893-2002 (Part-2) draft code enhances the accuracy of lateral stiffness calculations for tank supporting systems. The study also addresses sloshing wave height considerations, underscoring the importance of ensuring the height of sloshing waves remains within the provided free board to prevent additional pressure on the roof slab. Notably, the study was conducted in zone III, where sloshing wave height was observed to be within acceptable limits.

Furthermore, the analysis reveals that storey displacement decreases with increasing bracing levels, indicating the significant role of bracing systems in reducing structural displacement. Among the various bracing configurations studied, Intze tanks with lateral cross and vertical X-bracing exhibit superior seismic performance, suggesting their effectiveness during earthquake events. These comprehensive findings contribute valuable insights into optimizing the seismic design and performance of RC overhead water tanks, enhancing their resilience against seismic hazards.

Prashant A Bansode, "Seismic Analysis of Elevated Water Tank with Different Staging Configuration" (2018)

The analysis reveals several key insights regarding the behavior of elevated water tanks, particularly of the Intze type, under varying bracing configurations. Firstly, it is observed that as the level of bracing increases, both the base shear and base moment of the structure also increase. This phenomenon is attributed to the additional mass introduced by the bracing system, consequently elevating the base shear values. Similarly, the introduction of bracing systems leads to an increase in the base moment. Secondly, the study highlights a significant reduction in lateral displacement and vibration time period as a result of implementing bracing systems. This reduction is attributed to the heightened stiffness of the structure facilitated by the bracing, which effectively mitigates lateral displacement and subsequently reduces the vibration time period. Moreover, the study identifies potential areas for future research, including investigating the seismic behavior of water tanks by altering their shapes (e.g., rectangular or circular) and exploring their response to different soil types and seismic zones in India. Such endeavors aim to enhance our understanding of water tank behavior under diverse conditions, thereby informing more robust structural designs and bolstering seismic resilience strategies.

Shirley Susan Varughese, "Effect of Bracing system on Seismic Behavior of Rectangular Elevated RC Water Tank" (2017)

The dynamic analysis of rectangular elevated RC water tanks necessitates the consideration of hydrodynamic effects, thus requiring the tank to be analyzed using a two-mass spring model. It is observed that the base shear and overturning moment are higher in full tank conditions compared to empty conditions, indicating the necessity of designing elevated rectangular water tanks for full conditions to accommodate these higher loads. The introduction of braces leads to a considerable decrease in the time period, suggesting an increase in structural stiffness compared to unbraced structures. The significant variation in time period between empty and full conditions is attributed to the sloshing effect of water, with the convective time period remaining constant across different bracing systems, indicating its dependence on tank size rather than staging. Among the different bracing systems studied, X bracing exhibits the shortest time period and highest base shear and overturning moment, followed by diagonal braces. Interestingly, radial bracing shows minimal change compared to other systems, potentially due to the incorporation of steel bracing within RC braces. Additionally, the base shear and overturning moment of rectangular elevated water tanks increase due to the weight of the bracing system. These findings underscore the importance of considering hydrodynamic effects and selecting appropriate bracing systems in optimizing the seismic design and performance of rectangular elevated RC water tanks.

Srikanth S, "Time History Analysis of an Elevated Water Tank Under Different Ground Motions" (2017)

The elevated water tank is one of the most crucial components during an earthquake. To pressurize the water distribution system, an elevated water tank is designed to keep water at a certain height. During earthquakes, high water tanks were severely damaged or collapsed, as is well-known from traumatic experiences. Owing to the raised water tanks' sensitivity to earthquake characteristics such as peak ground acceleration, frequency contents, and length of recorded earthquakes. The objective of this study is to comprehend the dynamic behavior of an elevated water tank paired with a UG sump under varied observed ground vibrations caused by earthquakes. Using StaadPro software, a Time History Analysis was performed on an elevated RCC square water tank with varying staging heights of 14 m, 17 m, and 20 m under five distinct seismic ground movements. Observations were made of the tank reactions, including Roof Displacement, Velocity, Acceleration, Base Shear, Drift, and Natural frequency, and the findings were compared for empty, half-filled, and full tank situations. The strongest seismic reactions were seen in the Bhuj earthquake and the weakest in the Kobe earthquake.

Rajkumar, "Response Spectrum Analysis of Elevated Circular and Intze Water Tank" (2017)

In a public water distribution system, elevated water tanks are utilized to store water. In places with a high seismic intensity, these water tanks are the most vital constructions; their collapse might pose grave dangers to humans owing to a lack of water or trouble extinguishing fires during an earthquake. Many forms of failures, such as soil collapse and damage to supporting staging, are caused by earthquakes. In the current research, a total of twelve raised circulars and Intze water tanks of 2L litres capacity supported on RCC frame staging under earthquake loads as per draft code Part II of IS 1893: 2002 are evaluated, including six Intze models and six circular models. STAAD Pro V8i SS6 is used to analyze the response spectrum for raised circular and Intze water tanks with empty, half-filled, and full conditions in seismic zones II and V.

Manish N. Gandhi, "Earthquake Resistant Analysis of Circular Elevated Water Tank with Different Bracings in Staging" (2016)

In this parametric study investigating different patterns of bracing in the staging of an elevated water tank, several key conclusions have been drawn. Firstly, it is evident that the base shear values decrease for alternate bracing patterns in staging, attributed to an overall reduction in the structure's stiffness. Secondly, the effectiveness of cross bracing in staging is highlighted, particularly in reducing displacement due to lateral loading. The observed reduction in displacement is substantial, reaching 81.09% in the X direction and 92.98% in the Z direction compared to structures without bracings. Furthermore, a comparison between displacement values for different bracing systems and alternate bracing configurations underscores the superior performance of the cross bracing pattern, yielding the minimum displacement values. These findings emphasize the importance of selecting appropriate bracing patterns to enhance structural stability and mitigate displacement effectively, ultimately contributing to the resilience and safety of elevated water tank structures.

Gaurav s. Atalkar, "Comparative analysis of elevated water storage structure using different types of bracing patterns in staging" (2014)

This literature review delves into the behavior of different staging configurations under various loading conditions, with a specific focus on strengthening conventional staging during seismic events. Through the application of the seismic coefficient method and STAAD Pro V8i software, the study investigates five different bracing patterns for elevated circular water tanks in seismic Zone IV. The comparison of base and storey shear, as well as nodal displacements, across different loading scenarios reveals that the alternate diagonal bracing pattern demonstrates optimal performance in terms of both base shear and displacement reduction compared to other patterns studied. The study underscores the efficacy of the seismic coefficient method implemented in STAAD Pro V8i, which provides results consistent with manually calculated values. Furthermore, a parametric study elucidates the impact of different bracing patterns on the overall stiffness of the structure, with the alternate bracing pattern demonstrating a reduction in base shear. While the alternate cross bracing pattern yields the minimum displacement values, the paper suggests the alternate diagonal bracing pattern for its practical construction feasibility and overall economic benefits. This comprehensive analysis provides valuable insights for optimizing the staging of elevated water tanks in seismic-prone regions, contributing to the advancement of structural engineering practices.

Despite the extensive literature on dynamic analysis techniques for elevated water tanks, there remains a notable research gap in the comparative evaluation of the Time History Method (THM) and Response Spectrum Method (RSM) specifically for this application. While existing studies have investigated various aspects such as structural behavior, seismic performance, bracing configurations, and material considerations, a comprehensive comparison between THM and RSM in the context of elevated water tanks is lacking. Moreover, most studies focus on specific aspects of dynamic analysis or structural design, such as the effect of different staging systems, material properties, soil conditions, or seismic zone considerations. Thus, there is a need for a systematic review that synthesizes and compares the advantages, limitations, and applicability of THM and RSM for dynamic analysis of elevated water tanks, providing valuable insights for engineers and researchers in selecting the most suitable method based on project requirements and constraints.

III. III. METHODOLOGY

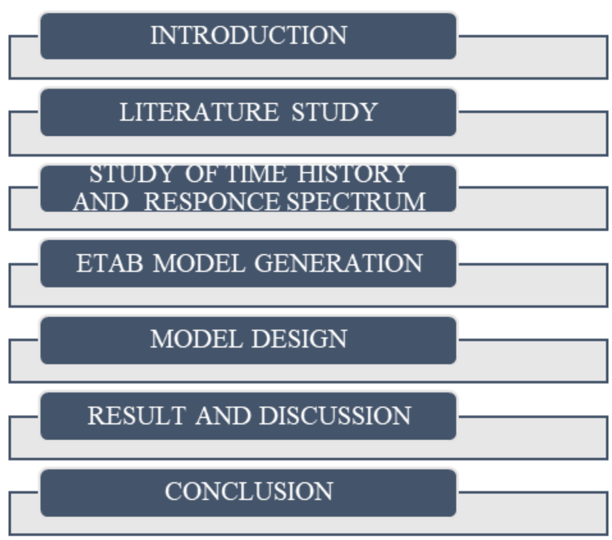

Fig 3: flowchart

A. *3.1 Introduction*

The seismic parameters obtained from the non-linear time history analysis of the elevated water tank provide valuable insights into its dynamic behavior and response to seismic loading conditions. Through meticulous analysis and interpretation of these parameters, engineers can better understand the structural performance and resilience of the tank under seismic events. The ground acceleration, velocity, and displacement recorded during the analysis serve as critical indicators of the seismic forces acting on the structure. By examining these parameters, engineers can assess the severity of the seismic excitation and its impact on the tank's stability and integrity. Additionally, studying the response of the tank under both full and empty conditions provides valuable data for evaluating the effects of water mass and storage levels on its dynamic behavior. seismic parameters such as storey displacement, base shear, and nodal displacement offer detailed insights into the distribution and magnitude of forces within the structure. These parameters help identify potential areas of vulnerability and deformation, allowing engineers to implement targeted design modifications or reinforcement measures to enhance the tank's seismic resistance.

B. *3.2 Time History Analysis*

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 building structures.

In this method of dynamic analysis, instead of going through a process of determining a response spectrum for a given ground motion and then applying the results to given structure, it is possible by using computers to apply the earthquake motion directly to the base of a given structure. Instantaneous stresses throughout the structure are calculated at small interval of time for full duration of the earthquake or significant portion of it. The maximum stress in any member that occur the earthquake can then be found by scanning the output records and the design reviewed. The procedure usually includes the following steps: The earthquake record is selected which represent the expected earthquake. The record is digitized as a series of small time interval of about 1/4 to 1/25 of a second with given levels of acceleration occurring for each interval. The digitized record is applied to the model as acceleration at the base of structure. The acceleration and relative displacement of the lumped masses are translated into member stresses. The maximum values can then be found by scanning of each output record. This process automatically included various modes of vibration and combines their effects as they occur, thus eliminating the uncertainties of combining the modes which are inherent to the spectrum analysis Response spectrum technique is a simplified case of modal analysis. The modes of vibration are determined in period and shape in the usual way and the maximum response magnitude corresponding to each mode is found by reference to a response spectrum. An arbitrary rule is then used for superposition of the maximum response in various modes. The resultant moments and forces in the structure correspond to envelop of maximum values rather than as set of simultaneously existing values. The response spectrum method has the great virtues of speed and cheapness. This technique is strictly limited to a linear analysis because of the use of superposition. Simulations of nonlinear behavior have been made using pairs of response spectra, one for deflection and one for acceleration.

Table 1:Properties of Ground Motion

Earthquake Area	Magnitude	Record/ Component	PGA
EI-Centro (1940)	7.2	El-Centro 1940,	0.35 g
Bhuj (2001)	7.7	Bhuj (2001), India	0.38 g
Uttarkashi (2001)	6.6	Uttarkashi (2001), India	0.31 g
Koyna (1967)	6.5	Koyna(1967)	0.31g
Chamoli (1999)	6.8	Chamoli(1999)	0.31g

C. *3.3 Types of bracing*

1) 3.3.1 Single diagonals

Trussing, or triangulation, is formed by inserting diagonal structural members into rectangular areas of a structural frame, helping to stabilise the frame. If a single brace is used, it must be sufficiently resistant to tension and compression.

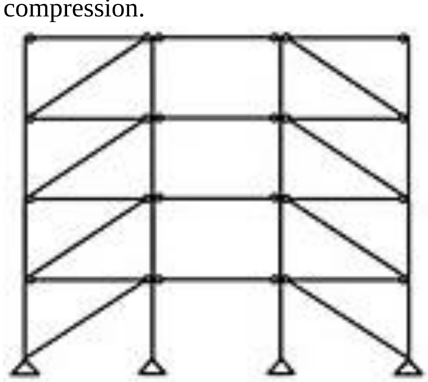

Fig 4:Single bracing

2) 3.3.2 Cross-bracing

Cross-bracing (or X-bracing) uses without diagonal members crossing each other. These only need to be resistant to tension, one brace acting to resist sideways forces at a time depending on the direction of loading. As a result, steel cables can also be used for cross-bracing.

Fig 3. 1:Cross bracing

However, this provides the least available space within the façade for openings and results in the greatest bending in floor beams.

3) 3.3.3 K-bracing

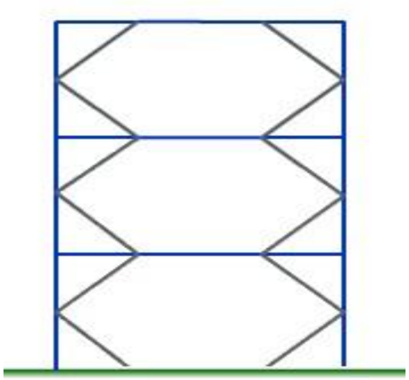

Fig 5:K-bracing

Braces connect to the columns at mid-height. This frame has more flexibility for the provision of openings and results in the least bending in floor beams. K-bracing is generally discouraged in seismic regions because of the potential for column failure if the compression brace buckles.

4) 3.3.4 V-bracing

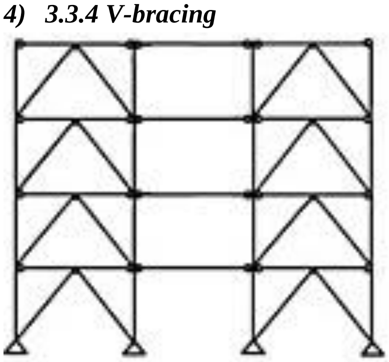

Fig 6:V-bracing

This involves without diagonal members extending from the top without corners of a horizontal member and meeting at a centre point at the lower horizontal member, in the shape of a V. Inverted V-bracing (also known as chevron bracing) involves the without members meeting at a centre point on the upper horizontal member. Both mean that the buckling capacity of the compression brace is likely to be significantly less than the tension yield capacity of the tension brace. This can mean that when the braces reach their resistance capacity, the load must instead be resisted in the bending of the horizontal member.

5) 3.3.5 Eccentric bracing

Fig 7:Eccentric bracing

This is commonly used in seismic regions. It is similar to V-bracing but instead of the bracing members meeting at a centre point there is space between them at the top connection. Bracing members connect to separate points on the horizontal beams. This is so that the 'link' between the bracing members absorbs energy from seismic activity through plastic deformation. Eccentric single diagonals can also be used to brace a frame.

The methodology for the comparison between time history method and response spectrum method for dynamic analysis of an elevated water tank involves several sequential steps aimed at achieving the outlined objectives.

The study commences with an introduction providing context and rationale for the research. Following this, a comprehensive literature review is conducted to gather existing knowledge, theories, and findings related to dynamic analysis techniques, particularly focusing on elevated water tanks. Subsequently, the study delves into the analysis of time history and response spectrum methods. Time history analysis involves simulating the actual seismic events recorded over time, capturing the dynamic behavior of the structure under realistic seismic conditions. On the other hand, response spectrum analysis is a simplified approach that estimates the structure's response based on a predefined spectrum of ground motion.

In order to conduct these analyses, an ETABS model of the elevated water tank is generated. This includes defining the geometry, material properties, and boundary conditions of the structure within the software environment. The model design phase entails setting up the analysis parameters and selecting appropriate input motions for both time history and response spectrum analyses. Once the models are prepared, the dynamic analyses are performed using the prescribed methods. The responses obtained from each analysis, including story displacement, base shear, and nodal displacement, are carefully recorded and compared.

The comparison of responses from both methods forms the crux of the study, where similarities, differences, and the accuracy of each method are thoroughly evaluated and discussed. This discussion is enriched by analyzing how the structural performance and behavior vary under different seismic loading scenarios. Finally, based on the findings from the comparative analysis, conclusions are drawn regarding the effectiveness and suitability of each method for dynamic analysis of elevated water tanks. Insights gained from this study contribute to enhancing the understanding of seismic response behavior in such structures and inform better engineering practices for their design and assessment in seismic-prone regions.

REFERENCES

[1] Govindrao Mane, S., & Angalekar, D. S. S. (2022). Seismic Analysis of Water Tank At Different Storey Height of the Building and To Check Fluid Sloshing Effect. International Journal of Engineering Applied Sciences and Technology, 7(1),141–146. https://doi.org/10.33564/ijeast.2022.v07i01.021

[2] Adil, W. A., Baluch, M. A., Ullah, Z., Adil, M. A., & Rashid, M. U. (2022). Effect of Different Column Arrangements on Structural Behavior of Square Overhead Water Tank by Response Spectrum Analysis. 27(2), 1–9.

[3] Rajesh, B., Sreekanth, G., & Student, M. T. (2022). ISSN NO : 0377-9254 DESIGN AND ANALYSIS OF DIFFRENT WATER TANKS BY CONSIDERING SLAB WALL AND CAPACITY IN SEISMIC ZONES Page No : 405 Vol 13 , Issue 04 , APRIL / 2022 ISSN NO : 0377-9254 Page No : 406. 13(04), 405–417.

[4] Chondikar, K. S., & Undre, A. R. (2022). Design of Overhead Tank with Carbon Fibre/Fiber Rebar as Reinforcement and Time History Analysis using STAAD-Pro software. International Research Journal of Engineering and Technology, 1–20. www.irjet.net

[5] Djelloul, N. D. H., Djermane, M., & Sharari, N. (2022). “Non-linear numerical study of the dynamic response of elevated steel conical tank under seismic excitation.” Revista Romana de Inginerie Civila/Romanian Journal of Civil Engineering,13(3), 82–98. https://doi.org/10.37789/rjce.2022.13.3.5

[6] S, L. M. (2021). Comparison of Analysis Between Rectangular and Circular Overhead Water Tank. Applied Research on Civil Engineering and Environment (ARCEE), 2(02), 77–95. https://doi.org/10.32722/arcee.v2i02.3646

[7] Desai, H. (2021). Performance of Various Staging Systems for Elevated Water Tank. Emerging Research and Innovations in Civil Engineering, August, 0–12.

[8] Anjum, T., & Zameeruddin, M. (2021). Evaluation of Efficacy of the Elevated Water Tank Under the Seismic Loads. International Journal of Civil Engineering, 8(1), 20–26.

[9] Santhosh, V. S., Kumar Sethy, S., & Shankar, A. N. (2020). Seismic Analysis of Overhead Water Tank Using Indian, American and British Codal Provisions. International Research Journal of Engineering and Technology, May, 480–490. www.irjet.net

[10] Jani, B. B., Agrawal, V. V, & Patel, V. B. (2020). Effects of Soil Condition on Elevated Water Tank Using Time History Analysis with Different Staging Systems. International Journal of Civil Engineering, 7(6), 41–47. https://doi.org/10.14445/23488352/ijce-v7i6p105

[11] Al-kamaki, Y., Jafar, R., & Hassan, G. (2020). A Comparative Study of Real Full Scale Ground Rectangular Water Tank in Duhok City. The Journal of the University of Duhok, 23(2), 157–172. https://doi.org/10.26682/csjuod.2020.23.2.13

[12] Jani, B. B., Agrawal, V. V, & Patel, V. B. (2020). Effects of Soil Condition on Elevated Water Tank Using Time History Analysis with Different Staging Systems. International Journal of Civil Engineering, 7(6), 41–47. https://doi.org/10.14445/23488352/ijce-v7i6p105

[13] Student, P. G., Engineering, S., & Engineering, C. (2020). Comparative Study on Effect of Different Configuration of Horizontal Bracings on the Performance of Elevated Water Tank Anik N Soniwala. International Research Journal of Engineering and Technology (IRJET), May, 6691–6697.

[14] Bansode, P., & Rajemahadik, C. (2019). Seismic Response of Overhead Water Tank with Different Staging System. Proceedings of National Conference …, July. https://www.researchgate.net/profile/Prashant-Bansode/publication/337007447_Seismic_Response_of_Overhead_Water_Tank_with_Different_Staging_System/links/62c6acc73e5be72b6a9d4fa5/Seismic-Response-of-Overhead-Water-Tank-with-Different-Staging-System.pdf

[15] Prashant A Bansode and V. P. Datye. (2018). Seismic Analysis of Elevated Water Tank with Different Staging Configuration. Journal of Geotechnical Studies, 3(1), 1–6.

[16] Tirandaz, A., Khannavar, S., & Kolhar, M. H. (2018). Response Spectrum Analysis of Elevated Water Tank. International Research Journal of Engineering and Technology, 886–891.

[17] Susan Varughese, S., & Philip, V. (2017). Effect of Bracing system on Seismic Behavior of Rectangular Elevated RC Water Tank. International Research Journal of Engineering and Technology (IRJET), 04(05), 3200–3203.

[18] Srikanth, S., & Karanth, S. (2017). Time History Analysis of Elevated Rc Reservoir Under Different Ground Motions. International Journal of Advance Engineering and Research Development, 4(01), 307–314. https://doi.org/10.21090/ijaerd.040111

[19] Rajkumar,Shivraj Mangalgi (2017) –Response Spectrum Analysis of Elevated Circular and Intez water Tank. International Research Journal of Engineering and Technology,(IRJET) Volume 4 Issue 10

[20] Gandhi, M. N., & Rajan, A. (2016). Earthquake Resistant Analysis of Circular Elevated Water Tank with Different Bracings in Staging. IJISET-International Journal of Innovative Science, Engineering & Technology, 3(11), 255–259. www.ijiset.com

[21] Analysis, C., Elevated, O. F., Storage, W., & Staging, P. I. N. (2014). RESEARCH PAPERS COMPARATIVE ANALYSIS OF ELEVATED WATER STORAGE STRUCTURE USING DIFFERENT TYPES OF BRACING. I-Manager's Journal on Structural Engineering, 3(1), 1–6.