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

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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*

1. 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 structures are especially vulnerable to horizontal forces due to Earthquakes.

Figure 1 Bending Shear Failure in Beam

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. 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, shown in Figure 1. 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 [1-3].

1.1. 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

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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 considers the time-dependent effects on structures [4-7].

2. Comparison of Time History and Response Spectrum

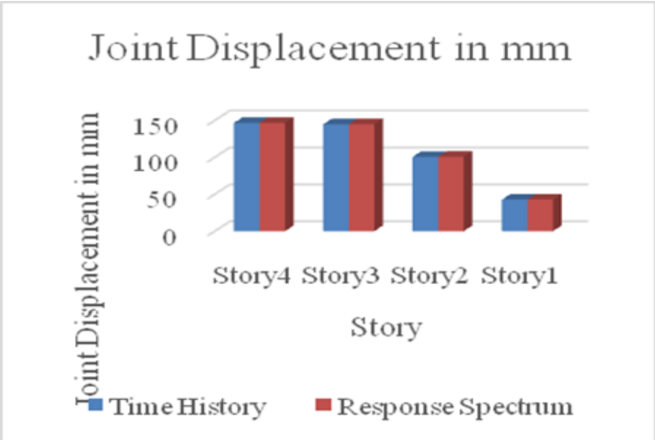

Figure 2 **Joint Displacement with Full Condition**

Joint displacement is observed for water tank model. It shows a comparison of time history and Response Spectrum of a structure under full condition. X axis shows different story and Y axis shows joint displacements in mm. the highest displacement is 146.638 mm for Story 4 (Response Spectrum), and the lowest displacement is 42.771 mm for Story 1.

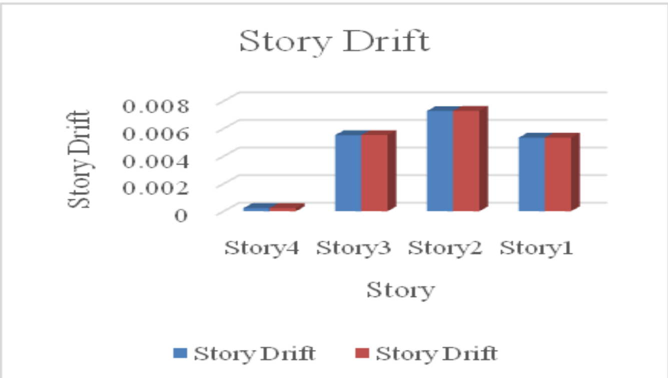

Figure 3 **Joint Displacement with Half Condition**

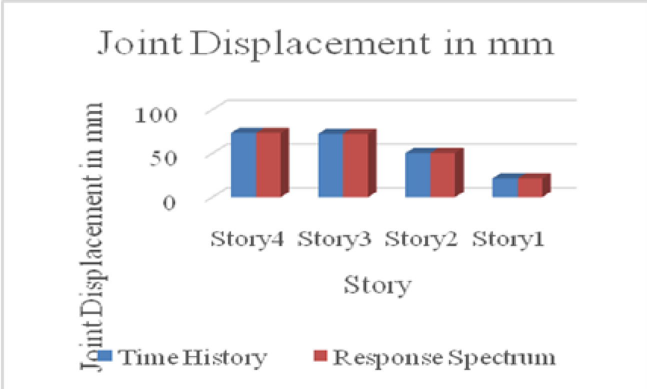

Figure 4 **Story Drift with Full Condition**

Joint displacement is observed for water tank model. It shows a comparison of time history and Response Spectrum of a structure under half condition. X axis shows different story and Y axis shows joint displacements in mm. the highest displacement is 73.319 mm for Story 4, and the lowest displacement is 21.385 mm for Story 1, Shown in Figure 2, Figure 3, Figure 4.

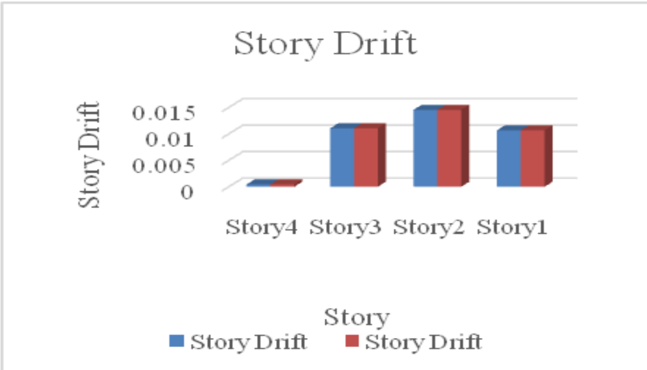

Figure 5 **Story Drift with Half Condition**

Story drift is observed for water tank model. It shows a comparison of time history and Response Spectrum of a structure under full condition. X axis shows different story and Y axis shows story drift in mm. The minimum drift at Story 4 with 0.000459 (time history) and 0.00046 (response spectrum), while the maximum drift is at Story 2 with 0.014543 (time history) and 0.014548 (response spectrum). Story drift is observed for water tank model. shows a comparison of time history and Response Spectrum of a structure under half condition. X axis shows different story and Y axis shows story drift in mm. The minimum drift is observed at Story 4 with

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0.00023, while the maximum drift at Story 2 with 0.007274, Shown in Figure 5, Figure 6, Figure 7, Figure 8.

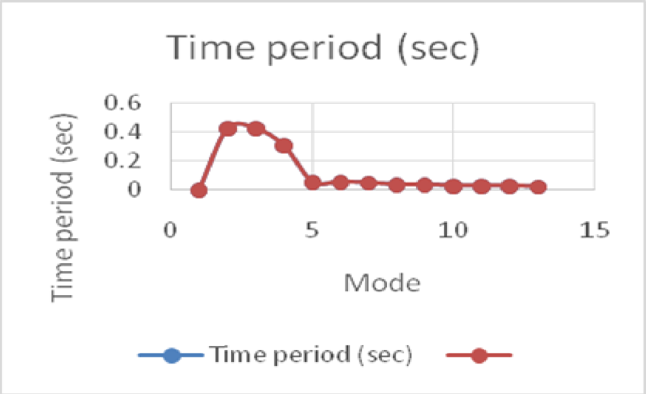

Figure 6 **Time Period with Full Condition**

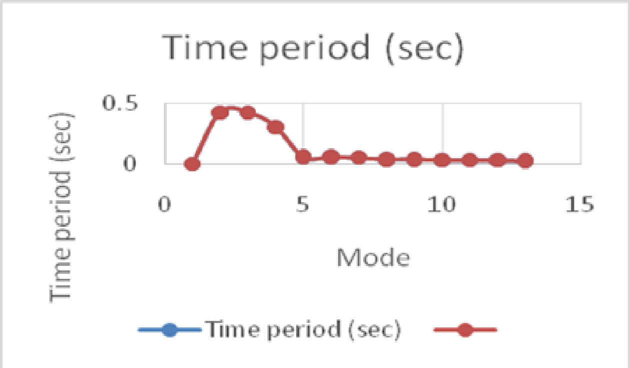

Figure 7 **Time Period with Half Condition**

Time period is observed for water tank model. It shows a comparison of time history and Response Spectrum of a structure under full condition. X axis shows different mode and Y axis shows Time period in sec. The minimum time periods 0.026 seconds to a maximum of 0.424 Sec.

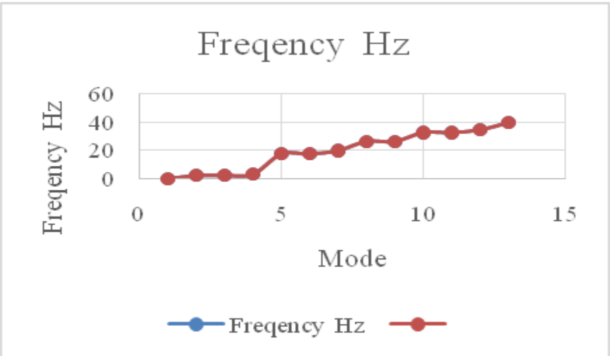

Figure 8 **Frequency with Full Condition**

Frequency is observed for water tank model. It shows a comparison of time history and Response Spectrum of a structure under full condition. X axis shows different mode and Y axis shows Frequency in Hz. Frequencies range from a minimum of 2.358 Hz to a maximum of 39.164 Hz [8-9].

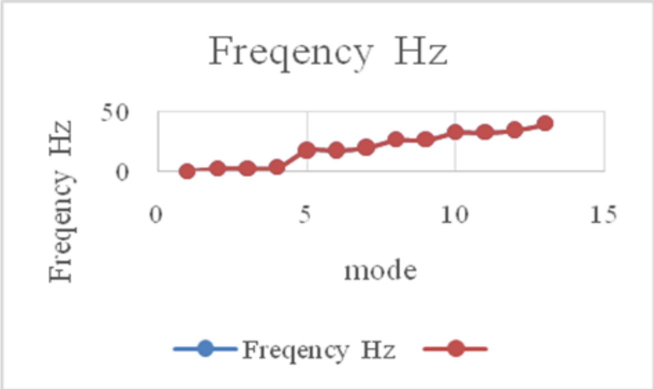

Figure 9 **Frequency with Half Condition**

Frequency is observed for water tank model. It shows a comparison of time history and Response Spectrum of structure under half condition. X axis shows different mode and Y axis shows Frequency in Hz. Frequencies range from a minimum of 2.358 Hz to a maximum of 39.164 Hz, Shown in Figure 9.

2.1. Different Bracing

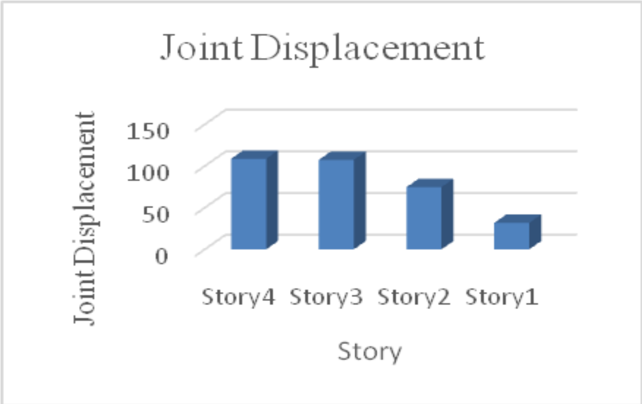

Figure 10 **Joint Displacement with Full Condition Cross Bracing**

Joint Displacement is observed for Cross Bracing with full condition. Figure 10 x axis showsdifferent stories and y axis shows displacement in millimeters. The minimum displacement is 31.719 for story 1 the maximum displacement is 108.745 for Story4.

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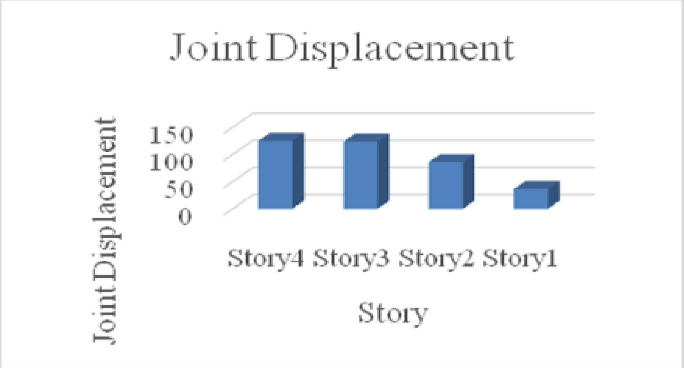

Figure 11 Joint Displacement with Full Condition Alternate Bracing

Joint Displacement is observed for Alternet Bracing with full condition. Figure 11, x axis shows different stories and y axis shows displacement in millimeters. The minimum displacement is 36.419 for story 1 the maximum displacement is 124.862 for Story4.

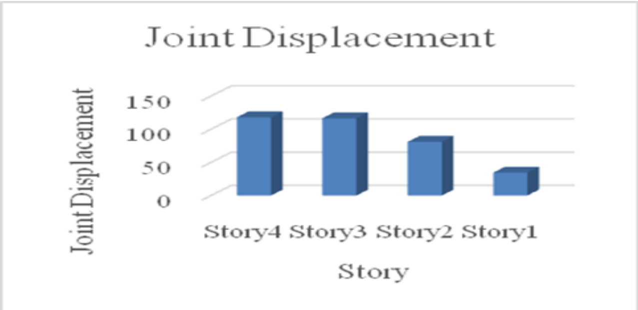

Figure 12 Joint Displacement with Full Condition Diagonal Bracing

Joint Displacement is observed for Diagonal Bracing with full condition. Figure 12, x axis shows different stories and y axis shows displacement in millimeters. The minimum displacement is 34.381 for story 1 the maximum displacement is 117.875 for Story4.

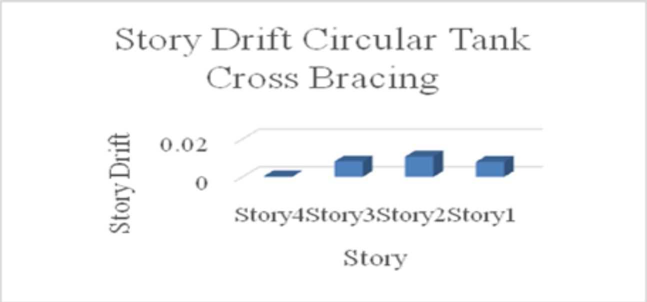

Figure 13 Story Drift with Full Condition Cross Bracing

Story Drift is observed for Cross Bracing with full condition. Figure 13, x axis shows different stories and y axis shows Story Drift in millimeters. The minimum Story Drift is 0.000341 for story 1 the maximum Story Drift is 0.010788 for Story4.

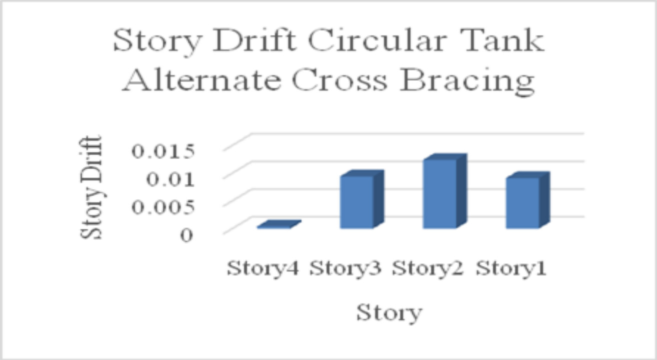

Figure 14 Story Drift with Full Condition Alternet Cross Bracing

Story Drift is observed for Alternet Cross Bracing with full condition. Figure 14, x axis shows different stories and y axis shows Story Drift in millimeters. The minimum Story Drift is 0.000391 for story 4 the maximum Story Drift is 0.012387 for Story2.

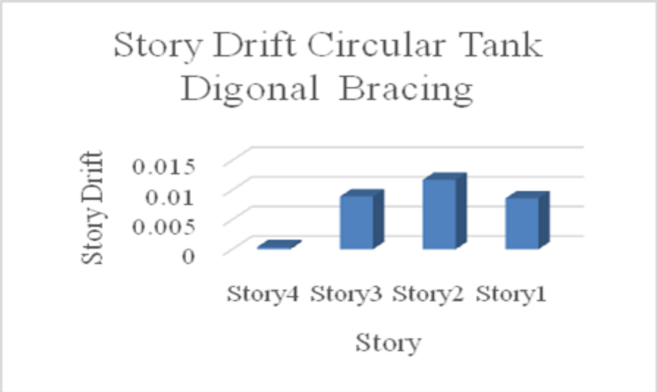

Figure 15 Story Drift with Full Condition Digonal Bracing

Story Drift is observed for Digonal Bracing with full condition. Figure 15, x axis shows different stories and y axis shows Story Drift in millimeters. The minimum Story Drift is 0.000369 for story 4 the maximum Story Drift is 0.011694 for Story2. Time period is observed for Digonal Bracing with full condition. Figure 16 x axis shows different modes and y axis shows Time Period in seconds. The

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minimum time period is 0.022 seconds for Mode 12. the maximum time period is 0.365 seconds for Modes 1 and 2.

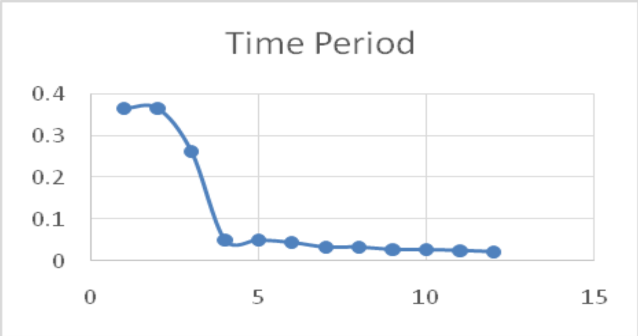

Figure 16 **Time Period with Full Condition Cross Bracing**

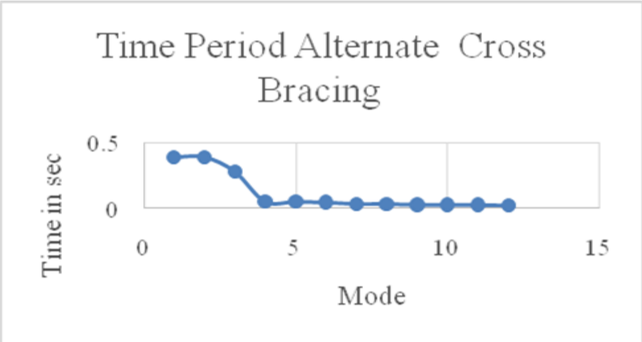

Figure 17 **Time Period with Full Condition Alternate Cross Bracing**

Time period is observed for Alternate Cross Bracing with full condition. Figure 17, x axis shows different modes and y axis shows Time Period in seconds. The minimum time period is 0.024 seconds for Mode 12. the maximum time period is 0.391 seconds for Modes 1 and 2.

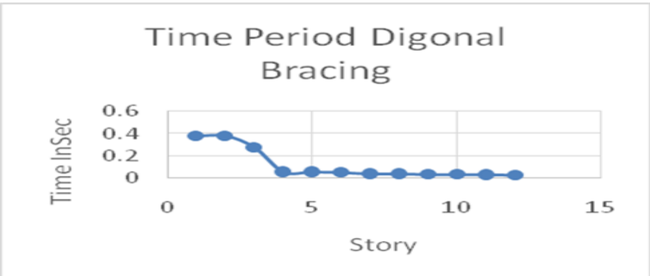

Figure 18 **Time Period with Full Condition Diagonal Bracing**

Time period is observed for Diagonal Bracing with full condition. Figure 18, x axis shows different modes and y axis shows Time Period in seconds. The minimum time period is 0.023 seconds for Mode 12. the maximum time period is 0.38 seconds for Modes 1 and 2.

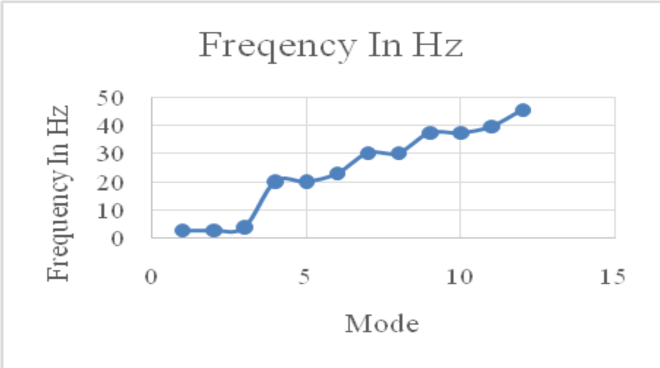

Figure 19 **Frequency with Full Condition Cross Bracing**

Frequency is observed for Cross Bracing with full condition. Figure 19, x axis shows different modes and y axis shows frequency in seconds. The minimum frequency is 2.739 seconds for Modes 1 and 2. the maximum frequency is 45.47 seconds for Mode 12.

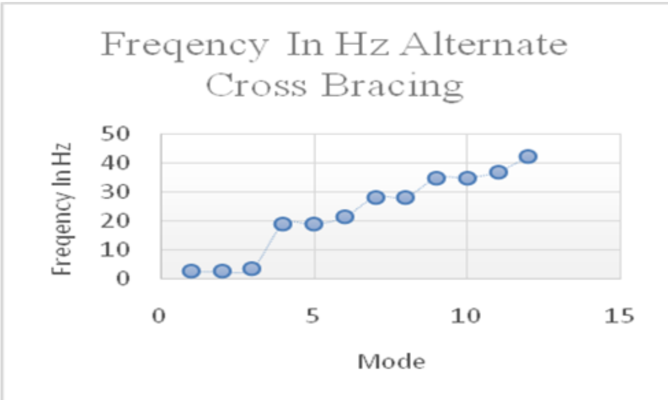

Figure 20 **Frequency with Full Condition Alternate Cross Bracing**

Frequency is observed for Alternate Cross Bracing with full condition. Figure 20, x axis shows different modes and y axis shows frequency in seconds. The minimum frequency is 2.556 seconds for Modes 1 and 2. the maximum frequency is 42.434 seconds for Mode 12.

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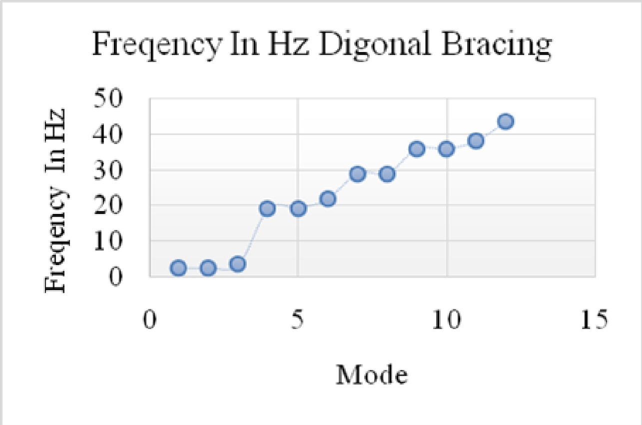

Figure 21 **Frequency with Full Condition Diagonal Bracing**

Frequency is observed for Digonal Bracing with full condition. Figure 21, x axis shows different modes and y axis shows frequency in seconds. The minimum frequency is 2.63 Hz for Modes 1. the maximum frequency is 43.674 Hz for Mode 12.

2.2. Comparison of Different Bracing

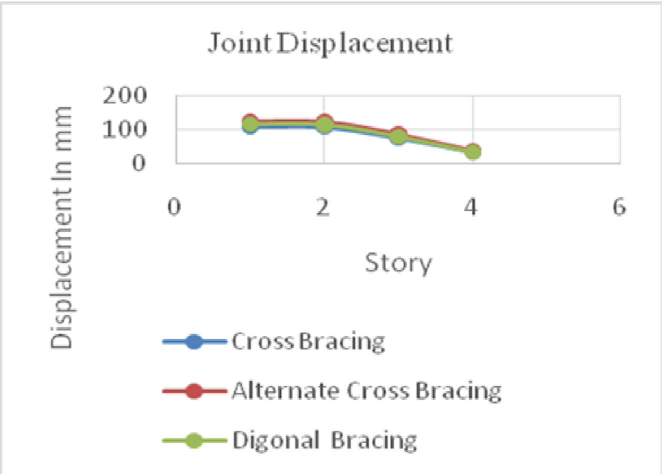

Figure 22 **Joint Displacement with Comparison of Different Bracing**

Joint displacement is observed for full condition. It shows a comparison of three bracing Cross, Alternate Cross, Digonal Bracing. Figure 22, X axis shows the different story and Y axis shows displacement in mm. As we can see that Max Joint Displacement is 124.862 mm at Story4 with Alternate Cross Bracing. And Min joint displacement is 31.719 mm at Story1 with Cross Bracing.

Figure 23 **Story Drift with Comparison of Different Bracing**

Story Drift is observed for full condition with a comparison of three bracing types: Cross, Alternate Cross, and Diagonal Bracing. The x-axis represents different stories, while the y-axis shows Story Drift in millimeters (mm). The maximum Story Drift is0.391seconds in Modes 1 and 2 with Alternate Cross Bracing while the minimum Story Drift is 0.022 seconds, observed in Mode 12 with Cross Bracing, Figure 23.

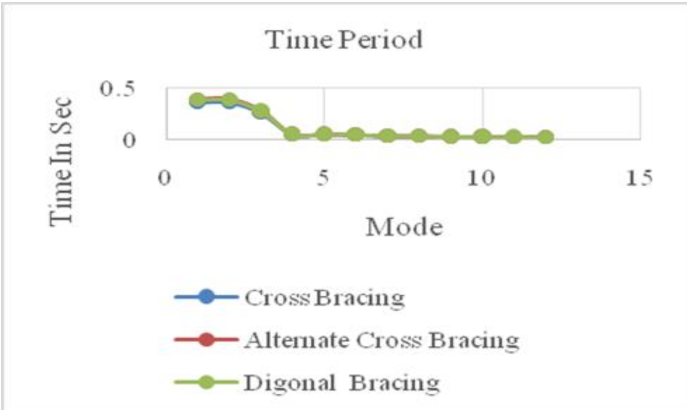

Figure 24 **Time Period with Comparison of Different Bracing**

Time Period is observed for full condition with a comparison of three bracing types: Cross, Alternate Cross, and Diagonal Bracing. The x-axis represents mode number, while the y-axis shows Time period in seconds. The maximum time period is 0.391seconds at Modes 1 and 2 with cross bracing while the minimum time period is 0.022 seconds, observed in Mode 12 with Cross Bracing, Figure 24.

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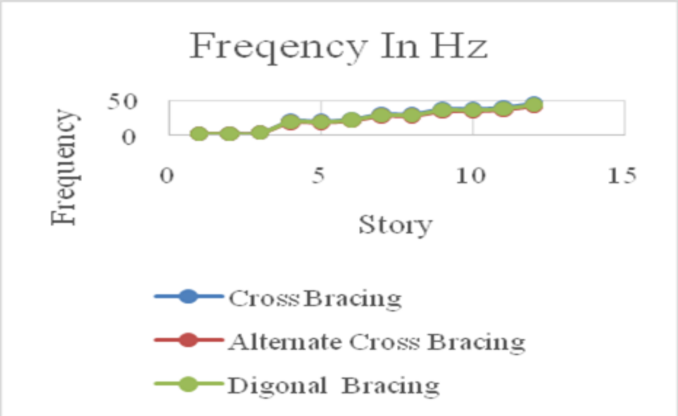

Figure 25 Frequency with Comparison of Different Bracing

Frequencys observed for full condition with a comparison of three bracing types: Cross, Alternate Cross, and Diagonal Bracing. Figure 25, The x-axis represents mode number, while the y-axis shows frequency in (Hz). The minimum frequency is 2.556 Hz in Modes 1 and 2 with Alternate Cross Bracing. The maximum frequency is 45.47 Hz, in Mode 12 with Cross Bracing.

Conclusion

The dynamic analysis of elevated water tanks is crucial for ensuring their structural integrity and resilience against various loading conditions. In this study, we employed both the time history method and the response spectrum method to investigate the behavior of such structures under different scenarios. Key parameters such as joint displacement, story drift, frequency, and time period were meticulously examined to gain insights into the structural response. Additionally, we explored the impact of different bracing configurations, including Cross Bracing, Alternate Cross Bracing, and Diagonal Bracing, on the overall performance of the water tank structure. Through a comprehensive comparison of these analyses and bracing types, we aimed to evaluate their effectiveness and suitability in enhancing the structural robustness and stability of elevated water tanks. By shedding light on the dynamic behavior of these structures and the influence of various design choices, this study contributes to advancing our understanding of how to optimize the design and construction of elevated water tanks for improved performance and safety.

Key Points of The Conclusion

1. **Analysis of Elevated Water Tank**
   - Both Time History Analysis Method and Response Spectrum Method were employed to analyze the dynamic behavior of the elevated water tank.
   - Parameters such as joint displacement, story drift, time period, and frequency were investigated for a comprehensive understanding of the structural response.
2. **Comparison of Analysis Methods**
   - The comparison between Time History Analysis and Response Spectrum Analysis revealed insights into the structural behavior under seismic loading.
   - Joint displacements, story drifts, time periods, and frequencies were compared, showcasing the differences and similarities between the two methods.
   - Joint Displacement: The maximum and minimum joint displacements are recorded for different stories and conditions, comparing both time history and response spectrum analyses. The type of bracing also influences these displacements, with different configurations resulting in varying displacement values.
   - Story Drift: Similar to joint displacement, story drift is compared under different conditions and bracing types, showcasing the structural response in terms of drift for each story of the tank.
   - Time Period: Time period analysis reveals the natural vibration periods of the structure, showing how they vary across different modes and conditions. Again, the choice of bracing affects these periods
3. **Impact of Bracing Configurations**
   - Different bracing configurations including Cross Bracing, Alternate Cross Bracing, and Diagonal Bracing were studied to evaluate their influence on the dynamic response of the water tank.
   - Joint displacements, story drifts, time periods, and frequencies were compared for each bracing configuration, highlighting their

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respective strengths and weaknesses. The analysis indicated that bracing configurations significantly affect the structural response, with each configuration offering unique advantages in mitigating seismic forces.

- Validation of Findings: Consistency between the study's results and established literature reaffirmed the validity of the analysis methods and the impact of bracing configurations on the dynamic behavior of elevated water tanks.

4. Recommendations for Design Practice

- Based on the analysis results and comparisons, recommendations can be made for designing elevated water tanks to withstand seismic loads effectively.
- Designers may consider employing a combination of analysis methods, such as using time history analysis for detailed assessment and response spectrum analysis for preliminary design evaluations. The selection of bracing configurations should be based on specific project requirements, considering factors such as structural performance, construction feasibility, and cost-effectivenes. In conclusion, the dynamic analysis of elevated water tanks using different methods and bracing configurations provides valuable insights for seismic design and engineering practice, contributing to safer and more resilient infrastructure development.

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