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Codal Comparison of Seismic Analysis for Elevated Water Tank Using Different Codes: A Comprehensive Review

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Abstract: Elevated water tanks play a critical role in water distribution systems, ensuring a reliable water supply to communities. However, their structural integrity during seismic events is crucial for public safety. To address this concern, various design codes and guidelines have been developed worldwide, aiming to provide seismic design considerations for elevated water tanks. This paper presents a comprehensive review that compares and evaluates the seismic analysis methods employed in the design of these tanks, as prescribed by different codes such as IS, ACI, EN, and NZS. The primary objective of this review is to analyze and compare the seismic analysis approaches outlined in various design codes. By examining these approaches, the strengths and limitations of each methodology can be identified. This evaluation is essential for understanding the effectiveness and applicability of different design codes in ensuring the seismic resilience of elevated water tanks. The review also highlights potential areas for improvement in seismic analysis methodologies. By identifying limitations and areas that require further research, the study contributes to the continuous refinement and development of seismic design guidelines for elevated water tanks. Engineers and researchers can utilize these findings to enhance the design optimization and seismic behavior understanding of these critical structures.

Keywords: - Elevated water tank, Seismic Analysis, Shaft staging, column staging, STADD Pro., SAP2000, Different codes

I.INTRODUCTION

Water storage structures are of paramount importance for ensuring the availability of clean drinking water in residential, commercial, and industrial settings. Among the various types of water storage systems, water tanks are widely used due to their versatility and convenience. In the aftermath of an earthquake, maintaining a reliable water supply becomes crucial to prevent uncontrolled fires and further devastation. Considering the significance of water tanks in disaster-prone areas, it is vital to incorporate seismic performance considerations in their design. Different types of water tanks are utilized, including ground-supported tanks, underground tanks, and elevated tanks. Elevated tanks are particularly popular as they are built at a sufficient height to provide water supply coverage over a larger area.

Elevated water tanks are prevalent infrastructure components within communities, delivering a dependable water supply for residential and commercial purposes. However, the design and construction of these tanks must adhere to rigorous safety and performance standards to ensure their durability and effective operation. To facilitate this, several codes have been established, offering comprehensive guidelines for the design, construction, and maintenance of elevated water tanks.

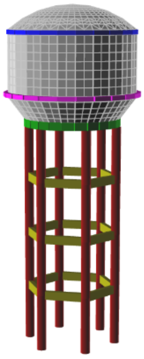

Figure 1 Elevated water tank

The Intze tank is a specific type of water storage system characterized by its cylindrical shape at the top and support provided by a steel or concrete framework. This design is particularly suitable for regions that experience high levels of seismic activity or face challenges related to soil stability. Moreover, the Intze tank is often preferred in areas with intermittent water supply systems. One of its notable advantages is the efficient utilization of construction materials, which makes it a cost-effective option compared to other types of elevated water tanks. The structural integrity of the Intze tank is enhanced through its ability to withstand both high winds and seismic events, rendering it suitable for regions with extreme weather conditions. Over the years, the Intze tank has gained significant popularity worldwide due to its reliability, cost-effectiveness, and adaptability to different geographic and climatic contexts. It serves as a dependable solution for water storage requirements, meeting the needs of diverse communities across various regions

These codes include IS 1893 Part-II: 2014, ACI 350.3-06, EN 1998-4: 2004, and NZSEE: 2009. Each of these codes provides specific criteria and recommendations that address various aspects of elevated water tank design, such as structural integrity, seismic considerations, load requirements, and material specifications. They serve as invaluable references for engineers, architects, and construction professionals involved in the planning and implementation of elevated water tank projects. By adhering to these codes, stakeholders can ensure that elevated water tanks are constructed to the highest standards, promoting safety, longevity, and operational efficiency. Compliance with these guidelines is essential in minimizing the risks associated with structural failures, ensuring the tanks can withstand external forces, including seismic events, and meet the demands of the communities they serve.

II.LITERATURE REVIEW

Kumar et al. (2016)[4] conducted a comparative analysis of dynamic analysis methodologies for rectangular liquid-filled containers, focusing on the application of codal provisions. The study specifically compared the seismic analysis approaches outlined in IS 1893 Part 2, ACI 350.3, and Eurocode 8 for rectangular-shaped tanks. One of the key findings of the study was the different rules recommended by the codes for estimating the total response of the system. While the square root-of-the-sum-of-the-squares (SRSS) rule was suggested by IS 1893 Part 2 and ACI 350.3, Eurocode 8 proposed the use of the absolute summation rule. Additionally, the study revealed that ACI 350.3 and Eurocode 8 suggested the incorporation of a reduction factor to appropriately account for the mass of the tank wall. Consequently, the Impulsive time period obtained from Eurocode 8 was found to be higher than that obtained from ACI 350.3 and IS 1893 Part 2. On the other hand, the Convective time period was observed to remain relatively consistent across all three codes.

El-far et al. (2021)[1] conducted a comparative study evaluating the response reduction factor for reinforced concrete elevated water tanks and various seismic design codes. The research focused on elevated tanks with two-column configurations (vertical and inclined), considering three different heights, capacities, and seismic zones. The study compared the response reduction factor values specified in IBC 2000, FEMA 368, ACI 350-3, AWWA-D100, Eurocode-8, IS 1893-2, and ECP 201 for elevated water tanks. Nonlinear static pushover analysis was employed as the chosen methodology. The findings revealed that elevated water tanks with vertical columns generally exhibited higher response reduction factor values compared to those with inclined columns. Additionally, in all seismic zones, an increase in the tank height resulted in a decrease in the response reduction factor value. Conversely, increasing the capacity of the water tank led to an increase in the response reduction factor value.

Liu (2018)[5] discussed the seismic design and analysis of concrete liquid-containing tanks. In this study, the author discussed three types of consideration. Firstly, they considered the functions as a liquid-containing structure based on ACI 373, and AWWA D115-06 codes. Secondly, they considered hydrodynamic seismic loads. Thirdly, they considered seismic-related events which ACI codes don’t cover, such as tsunami events, liquefaction of soil foundation, and floating uplifting of underground tanks. The design of Liquid containing tanks as per ACI 318.11 and ASCE 7, and seismic analysis was done as per ACI 350.3. Based on ACI 350.3, hydrodynamic pressure distribution involves two components, the convective and the impulsive, and were connected with concrete walls by springs. So, it concluded that this study was very important for concrete tanks to have water-tight, durability from cracking, and corrosion control.

Eliwi (2016)[2] conducted a comprehensive study comparing different seismic design criteria for tanks. The research focused on reviewing the provisions outlined in IBC 2000, Eurocode 8, and NZSEE guidelines for seismic force design, both for tanks and buildings. The author specifically compared the base shear coefficients derived from these codes for ductile buildings and ground-supported unanchored concrete water tanks. Additionally, a comparison was made for the parameter concerning low-ductility and high-ductility tanks. The findings indicated that the base shear coefficients for ductile buildings obtained from Eurocode 8 and NZS 4203 exhibited good agreement, while the results from IBC 2000 were approximately 15% lower. For water tanks, the base shear coefficients derived from Eurocode 8 were approximately 10% higher, and those from NZSEE were about 35% higher compared to the values obtained from IBC 2000.

Santosh (2020)[10] did research on the seismic analysis of overhead water tanks using Indian, American, and British codal provisions. In this study seismic behaviour of RCC overhead tanks in the seismic zone (iii), was carried out by performing dynamic response spectrum analysis using FEM base software (ETABS) as per IS 1893: 2002. The analysis was conducted for elevated RCC tanks under different codal provisions for both empty and full tank conditions. The study focused on the base shear and base moments, and the results were compared among three standards: ACI, IS, and BS. As a result, it found that the ACI standard is the most economical. The codal provisions were ranked in order of economic value as ACI, IS, and BS. All three codes follow the working stress method and lead to higher stability.

Yazdanian et al. (2017)[13] studied on fundamental frequencies of cylindrical storage tanks obtained from codes and the finite element method. In this study, they researched the seismic behavior of tanks and compared convective & impulsive frequencies and other parameters using API 650 and Eurocode 8 for storage tanks. The present investigation obtained frequencies using Finite Element (FE) software and modal analysis, followed by comparing these modes with analytical methods from standards. To ensure comparability, tanks with different (H/R) ratios were modeled with the same volume and weight. The study found a good agreement between convective frequencies obtained from the Finite Element method and those from standards. The results also showed that increasing the liquid level resulted in a rise and dip in convective and impulsive frequencies, respectively. Moreover, increasing viscosity by 1.47 times led to a 17 percent decrease in impulsive frequency values.

Tiwari (2018)[12] researched on the design of the Intze tank and seismic analysis with the help of SAP2000. In this study, the author conducted a seismic analysis of an Intze tank, comparing the behavior of frame and shaft types of staging using SAP 2000. The tank was conventionally designed according to IS: 3370(Part II) - 1965, and seismic design was carried out as per IS: 1893-2002, considering the prevailing conditions in a city like Jabalpur. The analysis involved evaluating pushover behavior, displacement behavior in full water conditions, stress variation along the height, and base shear to accomplish seismic analysis. In addition, a time period study was conducted, and various load combinations were considered. The results showed that the time period for frame staging was higher than that of shaft staging.

Ramazan et al. (2006)[6] discussed the evaluation of seismic models for fluid-elevated tank systems suggested in codes. This study presents the requirements of widely used seismic design codes such as Eurocode-8 and ACI-371R-98 for engineers to evaluate the seismic behavior of elevated tanks. The objective of this study is to compare the results obtained from the analytical model defined in ACI 371R-98 with the model defined in EC-8 Part 4 and provide a discussion of the results obtained from these models. The models presented in this study show that the model suggested by Eurocode-8 is more appropriate than the model suggested in ACI-371R-98.

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Saudagar (2019)[11] studied a comparison analysis of circular and Intze water tanks on sloping ground. This study investigated the performance of two types of elevated water tanks with varying slopes using Response Spectrum Analysis on different slopes. The analysis takes into account various parameters such as constant water storage capacity and staging height, various types of staging arrangements, and variations in the ground slope. As a result, the base shear and base moment for the Circular tank is more than that of the Intze type of tank for full tank condition cases of 00 -200 in seismic zone III. The maximum displacement for the Intze type of tank is more than that of the circular tank for slope cases of 00-200 in seismic zone III.

The summary of the literature review showed that Seismic analysis of water tanks is an important area of research as water tanks are crucial structures that provide clean water to the community. In the literature review, it was found that most studies focused on rectangular and circular tanks supported by columns, which are commonly used in practice. The studies utilized various codes including IS (Indian Standards), ACI (American Concrete Institute), EN (European Norms), IBC2000 (International Building Code), and AWWA-D100 (American Water Works Association Standard). These codes provide guidelines for designing water tanks to withstand seismic forces. To conduct the analysis, researchers utilized different software programs such as STADD Pro, ETABS, and SAP2000. The analysis included the comparison of the resulting base shear, base moment, time period, and frequencies for both tank conditions. Comparing the results of the analysis for both tank conditions, the researchers found that circular tanks were generally more efficient in terms of resisting seismic loads than rectangular tanks. In short, the literature review revealed that seismic analysis of water tanks is a well-studied area, with various codes and software programs available to aid in the design process. The studies conducted focused mainly on rectangular and circular tanks supported by columns, with circular tanks generally found to be more efficient in terms of resisting seismic loads.

III.CONCLUSION

The comparative studies on seismic analysis and design of liquid-filled containers and water tanks have revealed several important findings:

1. Variation in response estimation rules: The studies identified differences in the rules recommended by different codes for estimating the total response of the system. While IS 1893 Part 2 and ACI 350.3 suggested the square root-of-the-sum-of-the-squares (SRSS) rule, Eurocode 8 proposed the use of the absolute summation rule.

2. Impulsive time period differences: The analysis showed variations in the obtained Impulsive time period among the codes. Eurocode 8 resulted in a higher impulsive time period compared to ACI 350.3 and IS 1893 Part 2.

3. Impact of vertical columns: The studies found that water tanks with vertical columns exhibited higher response reduction factor values compared to tanks with inclined columns.

4. Effect of tank height: Increasing the tank height was observed to lead to a decrease in the response reduction factor value. This indicates that taller tanks may require additional measures for seismic design.

5. Base shear coefficients variation: For water tanks, Eurocode 8 and NZSEE provided higher base shear coefficients compared to IBC 2000. This indicates that different codes may result in different levels of seismic forces acting on the tanks.

6. Economic value of codal provisions: The comparative analysis ranked the codal provisions in terms of economic value, with ACI being the most economical. This suggests that the ACI code may provide a cost-effective approach to the design and analysis of overhead water tanks.

7. Suitability of seismic models: The studies concluded that the model suggested by Eurocode 8 was more appropriate for evaluating the seismic behavior of elevated tanks compared to the model proposed in ACI-371R-98.

These findings emphasize the importance of considering specific design criteria, seismic zones, tank configurations, and other factors when selecting appropriate design codes and methodologies for the seismic analysis and design of liquid-containing structures.

In conclusion, the comparative studies on seismic analysis and design of liquid-filled containers and water tanks have provided valuable insights into the different methodologies and code provisions employed in various international standards. These studies have identified variations in factors such as response estimation rules, reduction factors, base shear coefficients, and seismic behavior characteristics. The findings emphasize the importance of considering specific design criteria, seismic zones, tank configurations, heights, and capacities when evaluating the response reduction factor, base shear, moment, and frequency characteristics. Overall, these studies contribute to a better understanding of the seismic performance of liquid-containing structures and offer guidance for engineers and designers in selecting appropriate design codes and methodologies for different types of tanks in various seismic regions.

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