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Evolving the ESR Design using Precast Staging with Galvalume Tanks for Various Heights, Volumes and Seismic Zones to Fulfil Jal Jeevan Mission Targets- A Review

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Abstract: Elevated Service Reservoirs (ESRs) are one of the most important components of water supply systems, especially under the implementation of the Jal Jeevan Mission in India. Conventional reinforced cement concrete (RCC) ESRs require large construction time, high maintenance, and considerable dead load, which increases seismic vulnerability. In recent years, researchers have focused on improving ESR performance using advanced structural analysis software, optimized staging systems, and revised IS code provisions. However, limited studies are available on the application of precast staging systems combined with Galvalume steel tanks for different heights, capacities, and seismic zones. This review paper critically examines previous research related to RCC and Intze water tanks, seismic behavior, staging configurations, design methodologies, and software-based analysis. The study identifies significant research gaps concerning lightweight Galvalume tanks, modular precast staging, rapid construction techniques, sustainability, and seismic optimization. The review concludes that integrating precast staging with Galvalume tanks can provide economical, durable, lightweight, and rapidly deployable ESR systems suitable for fulfilling Jal Jeevan Mission targets in seismic-prone regions of India.

Keywords: Elevated Service Reservoir, ESR, Precast Staging, Galvalume Tank, STAAD Pro, Seismic Analysis, Jal Jeevan Mission, Intze Tank, RCC Water Tank, Sustainability.

I. INTRODUCTION

Water storage structures play a vital role in ensuring continuous and safe water supply in urban and rural regions. Elevated Service Reservoirs (ESRs) are widely used because they distribute water through gravity without requiring continuous pumping. With the implementation of the Jal Jeevan Mission, there is a massive demand for rapid construction of reliable water storage infrastructure across India. Traditionally, ESRs are constructed using reinforced cement concrete (RCC) with cast-in-situ staging systems. Although RCC tanks provide durability and strength, they involve higher dead load, longer construction duration, increased labor dependency, and considerable maintenance requirements. In seismic regions, heavy RCC tanks induce larger seismic forces due to increased mass, which can affect structural safety. Recent advancements in precast concrete technology and Galvalume steel tanks provide a promising alternative to conventional RCC ESRs. Galvalume tanks are lightweight, corrosion-resistant, easy to install, and suitable for modular construction. Similarly, precast staging systems reduce construction time, improve quality control, and minimize site labor requirements. Several researchers have studied ESR design, seismic behavior, staging configurations, and structural optimization using software such as STAAD.Pro and SAP2000. However, comprehensive research integrating precast staging with Galvalume tanks for varying seismic zones and storage capacities remains limited. This review paper critically analyzes earlier research studies and identifies major research gaps for future development of sustainable ESR systems.

II. LITERATURE REVIEW

[1] Design of Water Tank for the Town of Population 50000 and Analysis by STAAD Pro (2023) By Dr. Vidya Saraf et al. presented a comprehensive study on the design and analysis of water tanks for a growing urban population. The study emphasized that tanks designed for water, liquid petroleum, or similar fluids share common principles, with the primary objective being the prevention of leakage through proper crack control and detailing. The authors reviewed both theoretical design methods and practical applications by integrating STAAD Pro for the analysis of circular water tanks (both with flexible and rigid bases) and rectangular underground water tanks. Their study highlights the importance of using modern analysis tools to validate manual calculations and achieve accurate, safe designs for water tanks, particularly when considering seismic forces. The paper also demonstrates the comparative analysis of results obtained through computer-aided design and traditional manual calculations based on established references such as standard concrete design books, affirming the accuracy and reliability of design software in modern engineering practice. The study aligns with the broader literature on water tank design, including research on seismic behavior, staging effects, and the dynamic response of liquid-containing structures. Previous researchers have also explored the impact of tank shape, staging height, and foundation conditions on the overall performance of tanks, particularly during seismic events. While the theoretical background for tank design has been extensively discussed in codes like IS 3370, IS 456, and IS 1893, the integration of computer-aided design tools like STAAD Pro provides an additional layer of accuracy, efficiency, and design optimization, especially for larger tanks catering to populations of 40,000–50,000 people and above. Dr. Saraf and team contribute significantly to the field by demonstrating practical applications of theoretical design principles and validating them through modern software tools. However, there remains a gap in addressing the long-term performance of tanks in varying environmental conditions, the effects of climate change on material properties, and the need for sustainable practices in tank design, which warrants further research.

[2] Design Methods of Elevated Water Tank (2023) By Nikhil Yadav, Sunil Mane. Elevated water tanks are vital components in water distribution systems, providing storage and maintaining pressure in the network. These structures, due to their slender staging and the large water mass at the top, are critical in ensuring water availability during natural disasters like earthquakes. The study by Nikhil Yadav and Sunil Mane emphasizes the significance of employing advanced design methodologies to enhance the safety and functionality of elevated water tanks. The research explores traditional and modern design approaches, focusing on the Working Stress Method and the Limit State Method as outlined in IS 3370. The Limit State Method, now included in the latest version of the code, is preferred for its superior strength and serviceability compared to the Working Stress Method. A key requirement in the design of water tanks is to ensure a crack-free structure to prevent leakage and corrosion, particularly under low-cycle fatigue caused by fluctuating water levels. This study underscores the importance of designing tanks with resilience to post-disaster conditions, prioritizing safety, durability, and sustainability.

[3] Appendix 2 Design and Analysis of RCC Water Tank by Using STAAD Pro (2023) By Abhinav Kumar Anand, Abhinav Sharma. A significant contribution in this field is by Abhinav Kumar Anand et al. (2023), in their study titled "Design and Analysis of RCC Water Tank by Using STAAD Pro" published in the International Research Journal of Modernization in Engineering, Technology, and Science (IRJMETS). The authors emphasize the critical role of structural analysis in optimizing water tank designs for safety, stability, and long-term performance. The study systematically investigates the design process for elevated water tanks using STAAD Pro, addressing key considerations such as material selection, structural modeling, and the application of realistic boundary conditions and load scenarios—including dead loads, live loads, wind loads, and seismic forces. The research highlights the capabilities of STAAD Pro in performing static, dynamic, and stability analyses to identify critical stress points, potential failure modes, and required reinforcements. It also stresses the importance of considering factors like hydrostatic pressure, temperature variations, and corrosion protection measures for enhancing durability and reducing maintenance requirements. The study's outcomes contribute to the development of optimized design guidelines that improve the efficiency of RCC water tanks while minimizing lifecycle costs. This research demonstrates that the integration of advanced structural analysis tools, like STAAD Pro, with IS code provisions ensures the safety, functionality, and longevity of water storage systems. These studies underscore the necessity of a comprehensive design approach that not only meets the code requirements but also enhances the tank's resilience under seismic and environmental stresses. However, despite the advancements in computational analysis, there remains a need for further exploration into the long-term performance of tanks under environmental degradation, differential settlement effects, and real-world maintenance challenges.

[4] Design of Intze Water Tank by Using Staad Pro for Hathipur Village (2022) By Shivam Chaudhary, Anuj Verma, Nitish Katiyar, Parwez Ansari, Mr. Azeezurrahman Ansari. Intze water tanks are a specific type of elevated water tank designed to supply water effectively in various applications such as domestic use, firefighting, irrigation, and agriculture. The study conducted by Shivam Chaudhary et al. focuses on designing an Intze tank for Hathipur village, Kanpur, using STAAD Pro software. The research outlines the importance of constructing water tanks that can withstand various natural loads such as earthquakes, wind, and extreme temperatures. Previous designs relied on older IS 3370-1965 codes, which resulted in thicker structural sections. With the advent of IS 3370-2009, more efficient and optimized designs are achievable. This study involves detailed analysis of load combinations, hydrostatic pressure, and stress conditions under full and empty tank scenarios. The research highlights the importance of ensuring crack-free construction to prevent leakage and maintain structural integrity. The project serves as a comprehensive guide for designing water tanks in rural areas, incorporating local data and modern design methodologies to ensure efficiency, durability, and cost-effectiveness.

[5] Design and Analysis of Under Ground Water Tank Considering Different Fill Conditions Using STAAD.PRO (2022) By Deepshikha Gadekar, Rakesh Patel Water tanks are essential structures for storing liquids, serving both domestic and commercial needs. The study by Deepshikha Gadekar and Rakesh Patel focuses on the design and analysis of a rectangular underground water tank with a capacity of 2 lakh liters, considering different fill conditions. Unlike overhead tanks, underground tanks must account for additional forces such as lateral earth pressure and water pressure, requiring precise calculations as per IS code standards. This project employs STAAD Pro software for structural analysis, evaluating forces, moments, and deflections to ensure safety and efficiency. The design process covers key structural elements, including sidewalls, base slabs, and roof slabs, using the limit state method. The study highlights the importance of integrating advanced tools like STAAD. Pro for optimizing structural designs and ensuring the tank's stability and durability under varying load conditions.

[6] Design and Analysis of R.C.C Overhead Water Tank for Town (2022) By Aadil Ahmad Bhat, and Er. Ashish Kumar. Designing water tanks is a critical aspect of civil engineering, requiring careful consideration of structural integrity, crack control, serviceability, and safety under various load conditions. The authors emphasize the importance of selecting the appropriate tank geometry and staging system before initiating the structural design. Their research highlights that the prevalent building techniques, the physical properties of materials, and the climatic conditions greatly influence the design, construction, and performance of water tanks. The study specifically investigates the behavior of Intze tanks under hydrostatic pressure, transverse and longitudinal loads, and seismic effects, considering critical factors such as overturning stability, crack formation, and distribution of meridional and hoop stresses. The paper further emphasizes that the worst-case loading conditions, including the full and empty states of the tank, must be analyzed to ensure safe and durable designs. The study adheres to IS code provisions, including IS 3370 and IS 456, and presents an evaluation of different types of tanks, including square tanks, showcasing how pressure gradients and strain distributions impact tank performance. Bhat and Kumar complements existing literature by reinforcing the importance of accurate load estimation, detailed analysis of pressure distributions, and consideration of critical design forces. The focus on Intze tanks also provides valuable insights into how specific tank geometries behave under operational stresses. Their study contributes to a broader understanding of water tank behavior, particularly regarding the structural response to hydrostatic forces, seismic loading, and staging design. While the research emphasizes theoretical analysis and IS code compliance, it also underscores the need for practical validation of design choices through computational tools like STAAD Pro, especially for complex geometries and load combinations.

[7] Design of Elevated Level Storage Reservoir (2019) By Tejaswi Koramutla & Anuskha. Elevated Level Storage Reservoirs (ELSR) are essential for ensuring a continuous water supply, particularly in areas with growing water scarcity. These structures store water at a height to utilize gravity for distribution, eliminating the need for constant pumping. The design of ELSRs requires impervious concrete to prevent leakage and ensure durability, while accounting for loads such as dead load, live load, wind, and seismic forces. Tejaswi Koramutla and Anusha Sapatla's study focuses on designing an overhead tank for a population of 4,419 at the Annamacharya Institute of Technology and Sciences (AITS) using both manual calculations and software tools. The research highlights the importance of integrating technology in optimizing the structural dimensions and ensuring economical and efficient water storage solutions. With advancements in materials and design techniques, future reservoirs can incorporate sustainable practices to enhance environmental performance.

[8] Behaviour of RC Overhead Water Tank Under Different Staging Patterns (2017) By Shrigondekar, Parulekar, and Kasar. Water tanks and especially the elevated water tanks are structures of high importance which are considered as main lifeline elements that should be capable of keeping the expected performance i.e. operation during and after earthquakes. Thus researchers, in recent years, have focused on studying seismic behaviors of these tanks, particularly ground tanks, while only few of these researches have concerned with the elevated tanks and even less with the reinforced concrete elevated tanks. Reinforced Concrete (RC) overhead water tanks are critical infrastructure components designed to ensure water availability and maintain operational performance during and after seismic events. Elevated tanks, in particular, are highly sensitive to seismic forces due to their height and structural configuration. The study by Shrigondekar, Parulekar, and Kasar focuses on the seismic behavior of an RC elevated water tank with a capacity of 400 m^3 under varying staging patterns. Using a linear dynamic analysis method, the researchers evaluated seismic responses such as base shear and tank displacement under empty tank conditions. Their findings highlight the significant impact of staging configurations on the tank's structural stability and performance. By comparing results across different configurations, the study provides insights into optimizing staging patterns to enhance seismic resilience, emphasizing the importance of tailored designs for elevated tanks in earthquake-prone areas.

[9] Analysis and Economical Design of Water Tanks (2016) By Thalapathy M, Vijaisarathi R. P, Sudhakar P, Sridharan V, Satheesh V.S. Water tanks are essential structures used to store water and other liquids such as petroleum and similar substances, requiring designs that ensure crack-free structures to prevent leakage. The study by Thalapathy et al. explores the analysis and design of liquid-retaining structures using the Working Stress Method, focusing on three types of tanks: underground tanks, tanks resting on the ground, and overhead water tanks. The research emphasizes the importance of achieving a balance between safety and cost-effectiveness in tank design. Utilizing Microsoft Excel for analytical design, the study provides a framework for safe and economical water tank construction, including relationship curves between design variables to assist designers in optimizing structural parameters. This approach not only simplifies the design process but also ensures reliability and cost minimization, making it a valuable reference for understanding the fundamentals of water tank design.

[10] Economic Design of Water Tank of Different Shapes with Reference To IS: 3370 2009 (2014) By M. Bhandari, Karan Deep Singh. The study by M. Bhandari and Karan Deep Singh focuses on the cost-effective design of overhead water tanks with different shapes—circular, square, and rectangular—using the Limit State Method as per IS: 3370 (2009). It highlights the shift from the Working Stress Method (IS: 3370-1965), which resulted in thicker sections and higher reinforcement, to the more efficient Limit State Method. Circular tanks were found to be the most economical due to their smaller perimeter, which reduced material and formwork costs. Square tanks showed moderate cost-efficiency, while rectangular tanks were the least economical due to larger surface areas and higher material requirements. The study also emphasized the importance of checking crack width under serviceability conditions to ensure durability and leak resistance. Overall, circular tanks were concluded to be the most efficient and economical choice, especially for capacities of 100 kL, 150 kL, and 200 kL. This research provides valuable insights for selecting tank shapes based on cost and structural performance.

[11] Design of Intze Tank in Perspective of Revision of IS: 3370 (2013) By Pavan S. Ekbote and Dr. Jagadish. G. Kori. The study emphasizes the critical importance of understanding the dynamic behavior and interaction between the liquid and the structural components of elevated water tanks, particularly in the context of seismic activity. High water tanks, such as Intze tanks, are highly vulnerable during earthquakes, often suffering significant damage or even complete collapse due to inadequately designed support systems and an improper selection of geometric configurations for the tank stages. The seismic behavior of these tanks is a complex phenomenon, driven by the intricate interaction between the contained liquid mass and the tank's structural framework, which amplifies the dynamic forces acting on the tank during ground motion. This research, therefore, aimed to investigate the performance of various support system configurations for Intze tanks, with a specific focus on the changes introduced by the revision of the Indian Standard IS: 3370. By leveraging SAP 2000 software for dynamic analysis, the study evaluated the effectiveness of different support system designs, including various bracing patterns and staging arrangements, in resisting seismic loads and reducing the vulnerability of the tank structure. The ultimate goal was to identify a more resilient support system for Intze tanks that can effectively withstand the complex dynamic actions induced by seismic events, thereby ensuring the safety and stability of such critical water storage infrastructure. This research contributes valuable insights toward the revision of design codes and promotes a better understanding of how to design elevated water tanks in seismically active regions.

[12] IITK-GSDMA (2014): IS 1893: 1984 has a very limited stock of earthquake-resistant water tanks. These rules apply exclusively to high-water tanks; low-water tanks are not included. The impact of the sloshing vibration effect is not considered in IS 1893: 1984, even in high water tanks. Furthermore, the standards of IS 1893: 1984 have numerous limitations as compared to current international practise in seismic tank design. As a result, one discovers that India now lacks the appropriate level of design for earthquake-resistant water tanks. The existing recommendations are created to assist the designers of a water tank design project due to the lack of the Standard in the construction of an earthquake tank. These Guidelines are written in a format that is quite similar to the IS code, and the BIS may adopt it as IS 1893 in the future (Part 2). O. R. Jaiswal and colleagues (2006), The requirements of the 10 seismic codes on water tanks are reviewed and compared in this study article. This analysis demonstrates that the design of seismic stresses in various water tanks differs significantly between these codes. The reasons for this discrepancy are investigated thoroughly, and the importance of an integrated seismic design for liquid storage tanks is emphasised.

[13] Design of Circular Water Tanks in Perspective of IS:3370-2009 by R.V.R.K. Prasad and Akshaya B. Kamdi (2012): High water tanks play a vital role in the storage and distribution of water, serving as essential components in infrastructure systems. Recognizing the importance of safe and efficient water tank design, the Bureau of Indian Standards (BIS) revised IS 3370 (Parts 1 & 2) in 2009, several decades after its original publication in 1965. The updated code was developed with a specific focus on the design of liquid-retaining structures, incorporating modern analytical methods and practical considerations for fluid storage tanks. In their study, Prasad and Kamdi explored the design of circular water tanks using both the Working Stress Method (WSM) and the Limit State Method (LSM), providing valuable insights into the comparative performance and cost-effectiveness of these approaches. Their analysis emphasized the use of boundary condition techniques in the design process to ensure the structural integrity of water tanks under various loading conditions. The authors highlighted that while WSM has been traditionally used in tank design, LSM offers significant advantages in terms of material efficiency and economy, requiring less equipment and resources for construction. Furthermore, given the critical role of water tanks in storing and distributing water, the authors stressed the importance of crack width control in the tank walls to prevent leakage and ensure long-term durability. This study underlines the importance of adhering to the updated IS 3370 code provisions and adopting modern design methods such as LSM to achieve safer, more durable, and cost-effective water storage solutions.

III. RESEARCH GAP

From the extensive review of previous studies, the following major research gaps have been identified:

1. Most previous research focuses primarily on conventional RCC water tanks, while very limited studies are available on Galvalume steel ESR systems.
2. Existing studies mainly investigate cast-in-situ staging systems, whereas the application of precast staging technology for ESRs has not been extensively explored.
3. Limited research is available on the combined behavior of precast staging and lightweight Galvalume tanks under seismic loading.
4. Previous researchers mainly concentrated on structural safety and seismic behavior, while rapid construction techniques required for Jal Jeevan Mission implementation have received less attention.
5. Comparative studies considering different seismic zones, tank capacities, and staging heights for modular ESR systems are insufficient.
6. Very few studies investigate lifecycle cost analysis, maintenance reduction, and sustainability benefits of Galvalume tanks compared to RCC tanks.
7. The influence of lightweight superstructures on seismic base shear reduction and overall ESR performance has not been comprehensively studied.
8. Existing literature lacks optimization studies for standardized modular ESR configurations suitable for rural and semi-urban water supply schemes.
9. Research related to corrosion resistance, long-term durability, and environmental performance of Galvalume ESR systems under Indian climatic conditions remains limited.
10. There is a need for integrated analytical studies using advanced structural software to compare RCC ESRs and precast Galvalume ESR systems under various loading conditions.

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CONCLUSION

This review paper critically examined previous research related to ESR design, seismic behavior, staging configurations, and water tank analysis using modern structural software. The literature indicates that conventional RCC ESR systems have been extensively studied with respect to crack control, seismic resistance, and economical design. Researchers have also contributed significantly toward understanding staging effects, dynamic response, and IS code revisions. However, the review reveals that very limited work has been carried out on integrating precast staging systems with lightweight Galvalume tanks. Existing studies rarely address modular construction techniques, rapid deployment, sustainability, lifecycle economy, and seismic optimization simultaneously. Considering the urgent infrastructure requirements under the Jal Jeevan Mission, there is a strong need to develop innovative ESR systems that are lightweight, economical, durable, and easy to construct. The adoption of precast staging with Galvalume tanks has significant potential to reduce construction time, minimize seismic forces, improve corrosion resistance, and enhance sustainability. Therefore, future research should focus on detailed analytical and comparative studies for different tank capacities, staging heights, and seismic zones to develop optimized ESR solutions suitable for modern water supply infrastructure.

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