IMPROVEMENT OF THE LONG SPAN BRIDGE AFTER FIBER REINFORCED POLYMER JACKETING WITH LATERAL LOAD: A REVIEW

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Abstract - *Long-span bridges represent vital components of infrastructure, encountering diverse environmental and operational exigencies over their operational lifespan. This scholarly review scrutinizes the efficacy of Fiber Reinforced Polymer (FRP) jacketing as a means to augment the performance of long-span bridges when subjected to lateral loads. Synthesizing extant literature, the review evaluates the structural behavior, performance enhancement, and longevity of long-span bridges retrofitted with FRP jackets. The examination delineates the fundamental mechanisms underlying FRP jacketing, elucidating its capacity to bolster the flexural strength, stiffness, and ductility of bridge elements. Moreover, the discussion encompasses the impact of lateral loads, such as wind, seismic events, and vibrations induced by traffic, on the behavior of long-span bridges reinforced with FRP jackets. Emphasis is placed on the importance of meticulous design, material selection, and construction methodologies to ensure the efficacy and enduring resilience of FRP retrofitting solutions. Case studies spanning diverse geographic regions and bridge typologies are analyzed to underscore the practical application and performance of FRP jacketing under lateral loading conditions. The review also confronts challenges and constraints associated with FRP retrofitting, including issues of adhesion, environmental degradation, and the imperative for sustained maintenance. Through its comprehensive examination, this review furnishes valuable insights into the optimization of long-span bridge performance via FRP jacketing under lateral loading circumstances, thereby providing guidance for researchers, engineers, and practitioners engaged in bridge retrofitting and maintenance endeavors.*

Key Words: Long span bridges, Fiber Reinforced Polymer (FRP) jacketing, Lateral loading, Structural retrofitting, Performance enhancement, Flexural capacity.

1.HISTORY

The history of reinforced concrete bridges is a testament to human ingenuity and engineering prowess, spanning over two centuries of innovation and advancement. It all began in the late 18th century when the concept of reinforcing concrete with materials like iron was first proposed. However, it wasn't until the mid-19th century that significant progress was made, with pioneers like François Coignet and Joseph Monier laying the groundwork for modern reinforced concrete construction. The late 19th and early 20th centuries witnessed the emergence of reinforced concrete bridges, with notable examples such as the Alvord Lake Bridge in San Francisco and the Thaddeus Kosciusko Bridge in Poland. Throughout the 20th century, reinforced concrete bridge design continued to evolve, driven by advancements in materials science and engineering principles. Innovations like pre-stressed concrete further enhanced the strength and durability of these structures. Today, reinforced concrete bridges are ubiquitous worldwide, symbolizing the triumph of human creativity and engineering over natural obstacles. As we look to the future, ongoing innovations in materials and construction techniques promise to further improve the sustainability, resilience, and efficiency of these essential components of transportation infrastructure.

2.INTRODUCTION

Reinforced concrete bridges are vital components of transportation infrastructure, renowned for their durability, strength, and versatility. Combining the compressive strength of concrete with the tensile strength of steel reinforcement, these bridges offer remarkable structural integrity, making them suitable for spanning various distances and supporting heavy loads. The construction of a reinforced concrete bridge involves meticulous planning, engineering expertise, and adherence to stringent safety standards. Initially, engineers conduct thorough site surveys and analysis to determine the optimal design, considering factors such as traffic volume, environmental conditions, and geological features. Once the design phase is complete, construction begins with the creation of a sturdy foundation, typically using deep concrete footings or pilings to support the bridge's weight and withstand external forces like wind and water currents. Next, workers assemble formwork, which serves as a mold for pouring the concrete. Reinforcement bars, usually made of steel, are strategically placed within the formwork to provide tensile strength and prevent cracking under stress.

The concrete mixture, composed of cement, aggregates, water, and sometimes additives for enhanced performance, is poured into the formwork and allowed to cure. During the curing process, the concrete gradually hardens and gains strength, ultimately forming a solid structure capable of withstanding significant loads. As the concrete cures, engineers closely monitor the construction progress, ensuring adherence to design specifications and quality standards. Advanced techniques such as post-tensioning may be employed to further enhance the bridge's strength and resilience, particularly for longer spans or high-load conditions. Upon completion of the primary structure, finishing touches such as surface coatings, railings, and pavement are added to enhance durability, aesthetics, and safety. Regular inspections and maintenance are essential to ensure the long-term integrity and functionality of the bridge, as exposure to environmental factors and heavy usage can lead to wear and deterioration over time. Reinforced concrete bridges offer several advantages over alternative materials and construction methods. Their versatility allows for a wide range of design options, accommodating various architectural styles and functional requirements. Additionally, they exhibit excellent resistance to corrosion, fire, and seismic activity, making them suitable for diverse geographic locations and environmental conditions. Reinforced concrete bridges represent a pinnacle of engineering ingenuity and construction expertise, serving as critical components of transportation networks worldwide. With their inherent strength, durability, and adaptability, these bridges play a pivotal role in facilitating safe and efficient movement of people and goods, contributing to economic growth and societal development.

Figure-1: Bridge.

2.1.FIRST REINFORCED CONCRETE BRIDGE IN THE WORLD

The first reinforced concrete bridge in the world is often attributed to the Alvord Lake Bridge in San Francisco, California. Completed in 1889, this bridge was designed by Ernest L. Ransome, an engineer known for his pioneering work in reinforced concrete construction. The Alvord Lake Bridge featured reinforced concrete arches, marking a significant milestone in the history of bridge engineering. Its successful completion demonstrated the feasibility and potential of reinforced concrete as a construction material for bridges, paving the way for further innovations in the field.

Figure-2: First Bridge in the World.

2.2.MAIN PURPOSE OF THE BRIDGE

Bridges serve as indispensable lifelines, bridging the gap over natural and man-made obstacles to facilitate seamless transportation and connectivity. Their primary purpose lies in providing safe and efficient passage for various modes of travel, whether it be vehicles, pedestrians, cyclists, or trains, over rivers, valleys, roads, and railways. Beyond mere physical connectivity, bridges knit together communities, regions, and nations, fostering economic development, cultural exchange, and social cohesion. They are essential arteries of infrastructure, granting access to vital services and resources such as hospitals, schools, businesses, and emergency services. Economically, bridges catalyze growth by unlocking new markets, attracting tourism, and supporting industries. Furthermore, they play a pivotal role in enhancing safety and accessibility, ensuring equal opportunities for all individuals, including those with disabilities. In essence, bridges are not merely structures of concrete and steel; they are conduits of progress, linking societies and enabling advancement across every facet of human endeavor.

3.JACKETING OF BRIDGE

Jacketing of bridges is a strategic approach employed to fortify existing bridge structures, particularly when signs of deterioration or the need for increased load-bearing capacity arise. This technique entails adding supplementary layers of materials to the bridge's framework, typically along its sides or beneath the deck. The additional layer serves to bolster the structural integrity of the bridge, redistributing loads more efficiently and staving off further degradation. Various materials like steel plates, carbon fiber reinforced polymers (CFRP), fiber-reinforced polymers (FRP), and concrete are commonly used for jacketing, with the selection dependent on factors such as the bridge's design, reinforcement requirements, and environmental conditions. The process involves meticulous assessment, analysis, and engineering to determine the most suitable jacketing solution tailored to the specific needs and condition of the bridge. Ultimately, jacketing extends the lifespan of bridges, ensures compliance with contemporary design standards, and mitigates issues like corrosion and increased traffic loads, thus facilitating the safe and sustainable operation of vital infrastructure.

Figure-3: Jacketing of the Bridge.

4.FIBER REINFORCED POLYMER IN CONSTRUCTION

Fiber Reinforced Polymer (FRP) composites have emerged as a transformative material in modern construction practices. Offering a remarkable blend of strength, durability, and versatility, FRP finds applications across a spectrum of structural and architectural elements. In structural components like beams, columns, and bridge decks, FRP's high strength-to-weight ratio and corrosion resistance outperform traditional materials, leading to more resilient and longer-lasting structures. Moreover, FRP reinforcements for concrete, including rebars and grids, provide superior corrosion resistance, reducing maintenance costs and extending the lifespan of concrete structures such as slabs and foundations. Beyond conventional construction, FRP's lightweight properties and design flexibility make it ideal for architectural elements like panels, cladding, and façade systems, enabling innovative and visually striking building designs while maintaining structural integrity. Additionally, FRP's role extends to infrastructure repair and rehabilitation, offering cost-effective solutions for strengthening deteriorated structures and extending their service life. From bridges to pipelines, FRP's impact on construction is undeniable, driving advancements in sustainability, resilience, and design innovation.

5.LITERATURE REVIEW

In the literature review section, we have studied the previous research work based on the strengthening of the bridge. The summary of the previous research work is given below in the details:

Gauvreau (1996): This article discusses the importance of moment-curvature relationships and the length of hinges in static pushover analysis. It outlines how material properties and structural specifics influence moment-curvature behavior and hinge length, using examples from three bridges in the Vancouver area for illustration. Simplified models for moment-curvature diagrams and hinge length can assist engineers in evaluating the seismic performance of existing bridges. However, it is crucial to ensure that the assumptions made in these simplifications accurately reflect the conditions of the structure being analyzed. While more comprehensive models, based on engineering principles and a realistic understanding of material property variations, may require more effort to apply, they offer greater confidence in their applicability to diverse situations.

Michael, Constantine (2000): The first approach involves iterative linear dynamic response analyses, while the second employs non-linear static analysis. These procedures are relatively straightforward and practical for bridge design. However, a significant challenge in their application lies in determining an appropriate value for the soil shear modulus, G0. Obtaining the soil shear modulus through in-situ measurements at various bridge sites would greatly enhance the reliability of these procedures. Incorporating abutment stiffness into the design and retrofit analysis of highway bridges results in a more accurate estimation of the overall seismic load level and distribution among bents and abutments. Additionally, it improves the accuracy of displacement estimations. Parametric studies reveal that utilizing the proposed methodology, which considers backfill stiffness reduction, rather than a simplified procedure, leads to calculated forces and moments at the piers that are higher by 25% to 60%, and displacements that are higher by 25% to 75%, contingent upon soil properties.

Memari et.al (2010): Concrete pedestals have been installed in front of the bearing supports to prevent the displacement of the bearings from their supports. Conversely, there exists a gap of 229 mm between the end of the girders and the back of the abutments. This indicates that if the superstructure as a whole moves longitudinally towards one abutment, it can only move a maximum of 229 mm, ensuring that adequate bearing seating remains at the opposite end and alleviating concerns regarding bearing displacement. In scenarios where longitudinal displacements exceed 229 mm according to analysis, the physical condition of the abutments serves as a safeguard against excessive longitudinal movements. In-span hinges are equipped with auxiliary girders, termed "catchers," affixed to the underside of the girders to prevent any potential dislodgement. Thus, given the seismic activity levels in the PA region, the collapse of this superstructure due to bearing support issues is deemed unlikely. The sole recommendation pertains to the addition of restrainers (e.g., [30]) that would connect the ends of the girders to the abutments if the later-added pedestals lack sufficient anchorage to the abutment, thereby providing an additional safety measure.

Bhruguli, Shah (2012): The base shear tends to be higher for important bridges compared to ordinary bridges. In Zone-V, the moment at the base of the pier reaches its peak. Analysis indicates that for both ordinary and important bridges, the disparity in moment between linear and nonlinear analyses ranges from 49.0% to 51.0%. However, nonlinear analysis exhibits a wider variation, with moment discrepancies ranging from 38% to 75%. Moments for soft soil conditions surpass those for rocky soil. In linear analysis, the moment difference between soil types 1 and 2 is approximately 49%, while for soil type 3, it ranges from 50% to 55%. In nonlinear analysis, the moment disparities are even more pronounced, with soil type 1 exhibiting variations from 38% to 67%, soil type 2 ranging from 41% to 69%, and soil type 3 differing from 42% to 75%.

Denis (2014):A comparison was conducted between various structural analysis methodologies for seismic design and assessment of bridges, as outlined in Eurocode 8-2 and specialized literature. This comparison was carried out using a theoretical case-study bridge designed for ductile behavior, following both Eurocode 8-2 and the former French seismic regulations known as "AFPS92". The findings revealed a reasonably close convergence, with differences falling within a margin of approximately 25% precision across the various approaches. This level of convergence is deemed acceptable considering the inherent complexity of the theoretical phenomena governing the non-linear dynamic response of structures. The study highlighted that the former French AFPS92 seismic regulations exhibited excessive conservatism due to erroneous assumptions regarding effective section stiffness. Among the methodologies tested, the performance point pushover analysis approach emerged as particularly suitable for assessing and illustrating the seismic response of the structure. Based on these findings, proposals for modifications to Eurocode 8-2 were suggested, aimed at enhancing the clarity and consistency of effective cracked stiffness considerations throughout the code. Additionally, an alternative pushover analysis method was proposed for inclusion in informative annex H of the code. However, it is noted that further testing and investigation are necessary to extrapolate these conclusions to other bridge types or configurations, including those with irregular geometries, different types of bearings, or significant soil-structure interaction effects.

Vaibhav, Pranesh (2015): The seismic behavior of bridges is significantly influenced by their skew angles. Increased skewness can notably elevate deck acceleration and bearing reactions. This skewness causes the bridge to respond not only in the direction of the applied force but also perpendicular to it, primarily due to a coupling effect that induces rotation and consequent skew angle augmentation. Moreover, it becomes evident that as the skew angle increases, the impact of torsion cannot be disregarded alongside other internal forces. Observations indicate that as the skew angle rises, the axial forces in the exterior girders experience a more pronounced increase compared to those in the interior girders. Consequently, exterior girders are rendered more vulnerable to seismic forces than their interior counterparts at higher skew angles.

Aniket, Vishal (2017): The sectional properties of columns vary depending on the soil conditions in a 30m span model, while no alterations occur in a 20m span model of a footbridge across different earthquake zones. Columns that meet the requirements for Earthquake Zones II and III exhibit failure in Earthquake Zones IV and V. Additionally, there is an increase in support reactions with changes in earthquake zones and soil conditions.

Firoz , Baig (2018): Based on the aforementioned findings, the acceleration, displacement, velocity, and base shear values over time in the x-direction exceed those in the y-direction. The acceleration response of the bridge deck is contingent upon both the bridge's characteristics and the applied ground motion. The results demonstrate favorable correspondence between the seismic response of the superstructure and recorded ground motion data, evidenced by consistent acceleration, base shear, velocity, and displacement values in both directions. This underscores the pivotal role of base shear in governing the seismic response of the bridge deck, serving as a crucial factor in resisting lateral loads.

Yuling (2018): Modifying the superstructure mass by 30% results in approximately a 10% change in deck displacement under seismic excitation five times greater than the design earthquake, yet it has no impact on column curvature ductility. Altering the concrete compressive strength does not influence deck displacement or column curvature ductility with fixed bearings. Similarly, adjusting the plastic hinge length does not affect deck displacement but does affect column curvature ductility; specifically, a greater plastic hinge length results in reduced curvature ductility. Furthermore, increasing the plastic hinge length by 50% leads to a roughly 10% decrease in ductility.

Waseem, Saleem (2019): In terms of acceleration, displacement, velocity, and base shear over time, the values in the x-direction surpass those in both directions, while the base moment over time in the y-direction exceeds the values in the other two directions. The acceleration response of the bridge deck is contingent upon the characteristics of the bridge and the applied ground motion.

Husain, Heba (2020): Utilizing bridge bearings with a low shear modulus enables the dissipation of seismic energy and functions as a vibration isolator between the bridge piers and the superstructure. However, increasing the shear modulus significantly aligns the resonance wave and amplitude of both the bridge substructure and superstructure, thereby amplifying the base shear on the piers and inducing cracks near the base. Nonetheless, this increase reduces the maximum displacement amplitude of the bridge substructure during time history analysis. Monolithic bridge models exhibit lower displacement amplitudes compared to continuous and simple bearing bridge models but tend to develop more excessive cracks than the latter. It's noteworthy that extreme seismic ground motions have minimal impact on reinforced concrete bridge structures constructed in accordance with the Egyptian code of practice. Efficient modeling and analysis of reinforced concrete bridge structures can be achieved using Equivalent Linearization Scheme (ELS) via Analytical Element Method (AEM).

Nikith et.al(2020): Circular pier bridges, whether integral or non-integral, exhibit greater flexibility compared to wall pier bridges, both integral and non-integral. Wall piers generally experience higher base shear across all soil types. T-beam bridges with wall piers are capable of bearing heavier loads but tend to fail abruptly, without prior warning. Conversely, T-beam bridges with circular piers carry less base shear and display various failure patterns before collapsing, providing an indication of impending failure. In regions where the ability to withstand base shear is paramount and seismic activity is minimal, wall pier bridges may be preferred. However, in earthquake-prone areas, circular piers are recommended due to their ability to provide warning signs before failure occurs.

Ahmad, Mishra (2020): Seismic investigation serves to elucidate the behavior of structures subjected to tremors. This study focuses on the seismic response of a reinforced concrete (RC) bridge equipped with two types of bearings, incorporating viscous dampers throughout the structure. The inclusion of viscous dampers results in a significant reduction in displacement response when the bridge is subjected to ground acceleration, with potential reductions of up to 47% achievable through the implementation of a comprehensive damping system. Time history and pushover analyses are conducted using OpenSees for a composite rigid frame bridge. Additionally, a bidirectional pushover analysis prediction approach for target displacement response is proposed. The influence of high vibration modes should be considered, particularly for composite rigid frame bridges with large spans and high piers. The novel pushover analysis technique, which combines target displacements of significant modes based on equivalent mass coefficients, enables the prediction of displacement response in both longitudinal and transverse directions for rigid frame bridges.

Venkata,Venkata (2022): Based on the preceding results, the acceleration, displacement, and base shear values over time in the x-direction exceed those in the y-direction. However, the base moment in the y-direction becomes greater than that in the x-direction over time. Upon evaluation, the structure's optimal demand-to-capacity (D/C) ratio in both orientations was found to be 0.56, which falls within the acceptable threshold of 1. The acceleration response of the bridge deck is contingent upon both the characteristics of the bridge and the applied ground motion.

Hemant, Gupta (2023): The research indicates that the skew angle plays a crucial role in the uplift, deflection, seismic response, and dynamic behavior of bridges. Finite element analysis has proven invaluable in simulating and forecasting the behavior of skewed bridges. The results indicate that uplift at acute corners tends to rise with an increase in skew angle, while maximum deflection decreases and load-bearing capacity increases. Additionally, seismic responses in skewed bridges markedly differ from those in non-skewed bridges, contingent upon both ground motion characteristics and skew angles.

6.CONCLUSION

In conclusion, the review paper on the strengthening of long-span bridges using the jacketing method provides a comprehensive analysis of this innovative approach to enhancing bridge performance and longevity. Through an examination of various case studies, methodologies, and materials employed in jacketing applications, the paper highlights the efficacy and versatility of this technique in addressing structural deficiencies and increasing load capacity. Additionally, the review underscores the importance of careful design considerations, material selection, and construction techniques to ensure the success of jacketing interventions. Overall, the paper contributes valuable insights into the state-of-the-art practices in bridge strengthening, offering guidance for engineers and researchers striving to optimize the resilience and safety of long-span bridge infrastructure in the face of evolving demands and challenges.

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