Contents lists available at http://qu.edu.iq

Al-Qadisiyah Journal for Engineering Sciences

Journal homepage: https://qjes.qu.edu.iq

Literature review on the evaluation of prestressed concrete box girder bridge deflection and external prestressing strengthening

Zaid Sabah Hamdi* *, *S. Z. Abeer

Roads and Transportation Engineering Department, College of Engineering, University of Al-Qadisiyah, Iraq

ARTICLE INFO

Article history:
Received 00 December 0000
Received in revised form 00 January 0000
Accepted 00 February 0000

Keywords:
Bridge
Box girder
Prestressed concrete
External tendons
Strengthening

ABSTRACT

A bridge is a man-made construction intended to enable passage across a gap, such as a river or a valley. Bridges can be provided for many purposes, such as facilitating water movement, individuals, vehicles, and railroads. The selection of the bridge's site should consider equity, effectiveness, efficiency, societal benefits, and economic ones. In structural engineering, prestressing methods are frequently used to improve structural components and systems' load-carrying capacity and serviceability performance. Increases in service loads or the end of a structure's useful life necessitate frequent maintenance and repair work. It is possible to reinforce and repair both steel and concrete buildings. The primary goal of this work is to provide a review of the literature on the assessment of prestressed concrete box girder bridges under static loads, as well as investigate the strengthening methods employed by researchers to reinforce prestressed concrete box girder bridges.

1. Introduction

Bridge structures are one of the more vulnerable components of a safe transportation system that facilitates the safe movement of individuals and vehicles. Analytical techniques are frequently employed to evaluate bridge structures, relying on structural drawings, visual examination, and loading tests. Bridges are critical infrastructure components constructed to cross large distances and widths across obstacles, including water, hills, road, and rail networks. These structures provide primary connections between various components of the transportation system. All bridges have two parts in common. A bridge's structural component is composed of three components.

To begin with, these structures can be classified as a superstructures due to their constituent parts, which include a deck, rafters or girders, pavement, expansion joints, fencing, water drainage, and bearings. These structures, which comprise abutments, piers, and pier caps, are alternatively referred to as substructures. Their primary function is to support the bridge's superstructure and facilitate the transfer of self-weight and additional loads, including those generated by vehicular traffic, to the bridge's foundation. The third component is the foundation, a pile and pile cap structure recognized as the element that transfers forces to the soil. Bridge components are normally built using concrete and materials having various responses to compression and tension action [1-10].

Concrete is a stony mass of gravel, sand, broken down stone, or other materials bound together by a cement and water paste. In practice, admixtures can be incorporated to modify properties such as workability, durability, and the duration of the hardening process. Reinforced concrete, which combines concrete and steel reinforcement, is distinguished from ordinary concrete by its tensile strength. Prestressing tendons are used in longer-span concrete bridges for delivering a compressive load, which causes compressive stress, to equalize the tensile pressure of concrete elements generated by a bending moment or different forces [11].

---

* *Corresponding author.*
E-mail address: *abeer.alkraway*@qu.edu.iq(S.. Z. Abeer)

https://doi.org/10.30772/qjes.0000.0000

A box girder is highly suitable for curve-oriented bridge components due to its exceptional rotational rigidity. Rotational deformations encountered in curved, thin-walled beams can be withstood by box girders characteristic of high rotational rigidity. Box girders can take various shapes and sizes. Box girder deck is cast-in-place units that may be built according to any intended alignment in the plan, allowing for the construction of straight-ahead, skews, and curved bridges of different kinds on the highway system. Box girders can be categorized in various ways based on their construction technique, application, and geometry. A box girder offers high torsion stiffness and strength compared to a similar open cross-section element because the distribution pattern of lengthwise flexural stresses along the entire section is almost identical. The increased flange width of the box girder allows for more significant span/depth proportions. This is advantageous if the depth of construction is constrained. It can also result in greater slender buildings that are generally considered more attractive. The confined space within the girder can be utilised to transport utilities, including but not limited to gas lines, wires, and water lines [12, 13, 14].

A box girder bridge's primary girders are hollow box girders. Steel for reinforcement, prestressed concrete, or a combination of steel and reinforced concrete comprise the box girder. Typically, these bridges are utilised to construct highway flyovers and elevated railway bridges. This bridge design frequently accommodates long spans and wide decks, which is increasingly prevalent on modern roadways owing to its robustness, flexural flexibility, and rotational rigidity. Most of these bridges' beams are composed of hollow box-shaped girders [15, 16].

Engineers have often been duped by the continuous deformation action of prestressed concrete box girder bridges when they examineof prestressed concrete box girder bridges when examining deflection angles. After examining moderate deflections, the engineer begins to makemakes assumptions and concludes that they will remain small. However, this prediction proved incorrect, as the deflections suddenly accelerated many years later. Failure to perform precise calculations may result in misidentifying the source of a rapidly escalating deformation and implementing inappropriate corrective measures, which could potentially overload the bridge and cause substantial damage. Prestressed box girder bridges often exhibit minor deflections during their first few years of operation, followed by a significant continuation of the deflection. Considerable variation in drying creep and, to a lesser extent, shrinkage variation between the upper and lower slabs of the box cross-sectional area are the primary causes. The notable discrepancy can be accounted for by the considerable range of thickness between the upper and lower slabs, in addition to the drying and shrinkage rates associated with the depth squares [17].

Reinforcement of a concrete structure involves augmenting the rigidity and flexibility of the structure's components; restoration, on the other hand, involves restoring the functionality and integrity of compromised elements. By exchanging low-quality or deficient elements for materials of higher quality, connecting materials with greater bearing loads, and redistributing loading operations via induced displacement on the construction systems, bridge frames can be strengthened [18, 19, 20].

2. Study objective

The purpose of this study is to investigate the strengthening methods researchers utilize to reinforce prestressed concrete box girder bridges and tois study aims to investigate the strengthening methods researchers utilize to reinforce prestressed concrete box girder bridges and provide an overview of the literature review concerning the structural evaluation of such bridges under static loads.

3. Past related research

3.1. Structural evaluation of bridges

Azlanet et al. (2006) introduced an alternative non-destructive method for assessing the condition of bridges in contrast to the long-standing use of optical examination. Visual inspection was found to have a significant correlation with rebound hammer strength. The determination ofDetermining the compression strength of the concrete in the bridge structure using rebounding hammer testing. The rebound hammer could be an initial assessment tool for determining the bridge's condition. The outcome of the rebound hammer assessment revealed that the mean tensile strength of the concrete in the abutment was 19 N/mm2, suggesting that the strength of the concrete was significantly deficient. In contrast, the strength of the concrete in the deck was 55 N/mm2. On the contrary, the strength of the pier was 35 N/mm2, which suggests that the concrete's strength was reasonable and stable. Figure 1 shows the location on each location sample. Figure 2 shows the distribution of rebound numbers in bridge deck, and figure 3 shows the concrete strength for simply supported and continuous bridge [21].

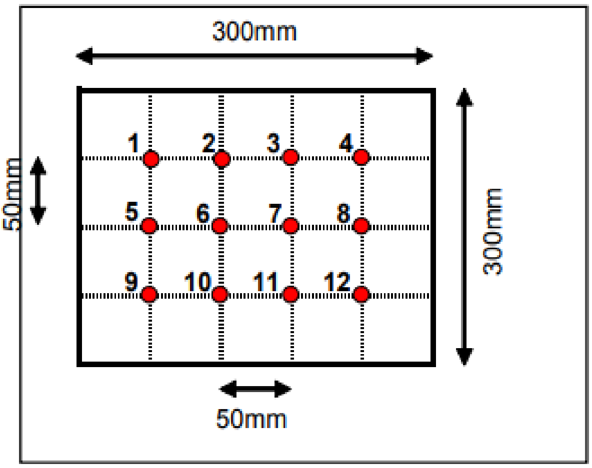


Figure 1. The location on each location sample [21]

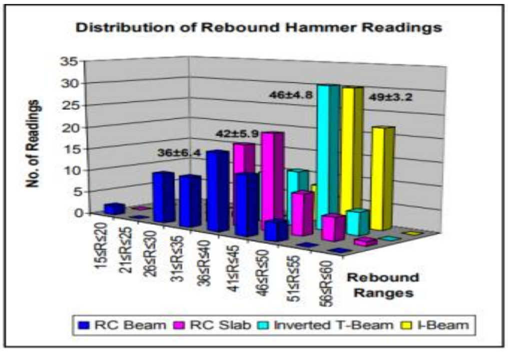
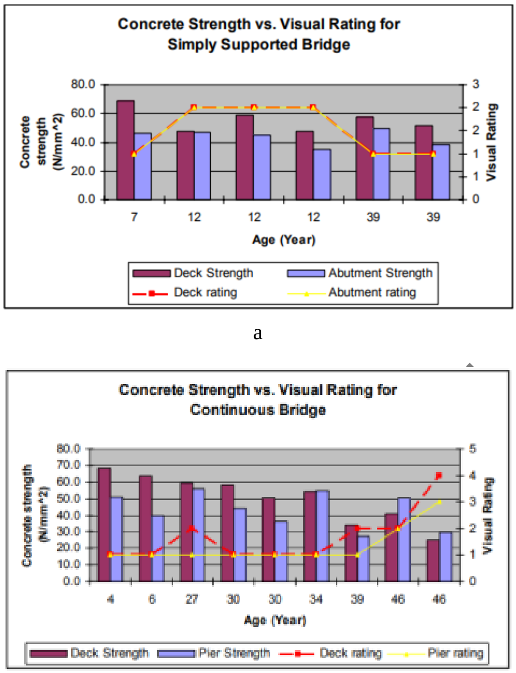


Figure 2. The distribution of rebound numbers in bridge deck [21]



a

b

Figure 3. The concrete strength for (a) simply supported, (b) continuous bridge [21]

Eltayeb et al. (2009) assessed the continuous displacement of the two bridges constructed in 1962 and 1972, respectively, in Khartoum State in 1962 and 1972, respectively. The structures in the topic are referred to as the Burri and Shambat Bridges. At this time, the primary issue with these bridges is the excessive deflection of the cantilevers at the bridge's ends. Due to prestressing steel tendons relaxing and concrete creep-induced prestressing force reduction, these deflections occurred. To calculate long-term deflection induced by dead loads, living loads, and prestressing forces, they utilized the moment area method used the moment area method to calculate long-term deflection induced by dead loads, living loads, and prestressing forces. The estimated continuous deflections will be compared to the measured live load deflections obtained from load tests conducted by a Chinese firm contracted to analyze the two bridges. There are notable discrepancies between the experimental and predicted deflection values at the extremities of cantilevers. Almost certainly, the variations stem from the foundational principles underlying the deflection computation formulas. Some modifications to long-standing deflection equations are suggested to conform computed deflections with measurable ones. Figure 4 shows the typical balanced cantilever segment in Burri Bridge and figure 5 shows the actual cross section at the root and the end of cantilever of Burri Bridge [22].

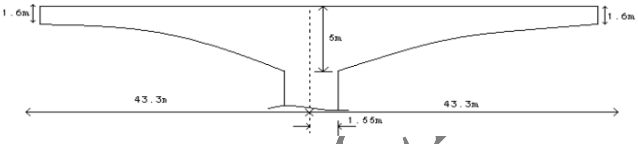


Figure 4. The typical balanced cantilever segment in Burri Bridge[22]

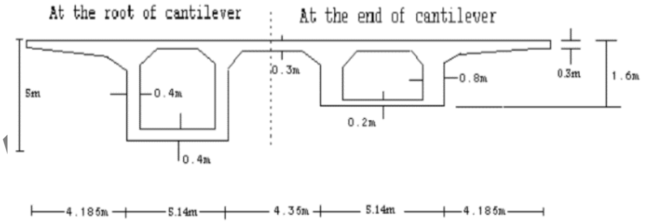


Figure 5. The actual cross-section at the root and the end of the cantilever of Burri Bridge [22]

Liu X et al. (2010) studied the continual vertical displacement characteristics of a large-span precast concrete girder bridge. To accelerate the calculation of the expression for the stress increases caused by the deflection, they established a relationship between the equivalent bending moment and the middle of span deflection by employing a corresponding moment instead of the middle point of span deflection. This was accomplished by utilizing the properties of materials axiom and the equivalent stiffness concept. As determined by the analysis results, midspan deflection had a more pronounced impact on structural stress; furthermore, the beam fractured whenever the deflection value was greater, and deflections and cracks are closely related [23].

Jianyong et al. (2010) applied a finite element model to theoretically analyze a composite continuous box girder bridge featuring corrugated steel webs. This evaluation utilized Ansys software. Both static and dynamic load tests were performed to evaluate the long-term structural integrity of the Juancheng Yellow River Highway Bridge in China. Contrasting the outcomes of the experiment and the theory. They determined that the Ansys software lacked a bridge-simulating model distinct from the CBCW model, providing bridge engineers with a practical and efficient instrument. The study results demonstrated a high degree of concordance between the theoretical predictions and the empirical data, suggesting that the CBCW model could effectively simulate these particular bridge types [24].

Ali and Wang (2011) investigated the configuration of the prestressed concrete bridge along the Jiamusi Highway. The bridge's structural performance was evaluated under both live and dead loads, and every detail regarding bridge structural element defects was documented. This study utilizes the following practical tests: depth of concrete carbonation, compressive strength of concrete, corrosion of reinforcement with steel, and static load. Except for longitudinal and diagonal cracks in the inner web of the box girders, a thorough examination of the bridge's construction reveals no significant damage. It is in satisfactory overall condition—loss, cracking, displacement, and rubber warping cause extensive damage to expansion joints. In-field tests indicate that the bridge structure's concrete is solid and devoid of carbonate and that the steel used for reinforcement is not corroded. The load-testing outcomes for vertical deformation, strain, and stress are below the predicted values. Furthermore, the crack inspection result indicates that the load test does not induce any alteration in the length of diagonal cracks present in the web structure of the box girder. This demonstrates that the bridge's structure is operational and in excellent condition. Figure 6 shows the actual structure of the Jiamusi bridge. Figure 7 shows the cross-section of the bridge in the middle and end of the span [25].

Figure 6. Actual structure of Jiamusi bridge [25]

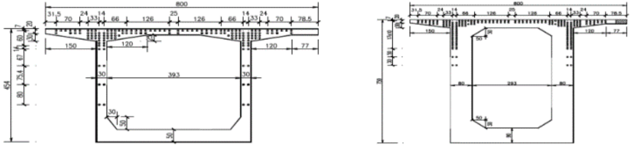


Figure 7. Cross-section of the bridge in the middle and end of the span [25]

In their study, Chang et al. (2012) analyzed the overall design characteristics of post-tensioned box girder bridges constructed with ordinary or high-strength concrete by LRFD Standards (HSC). A computer spreadsheet presentation was specifically designed to address this inquiry. The compilation of optimal design charts for such superstructures is the outcome of a cost analysis of configurations of superstructures featuring diverse geometric and material attributes. The figures are generated by considering the following parameters: span length, section depth, web spacing, tendon shape, and concrete strength. It has been observed that HSC permits significantly longer web spacing and span lengths than conventional strength concrete [26].

Ali and Wang (2013) explained that finite elements, experimental analysis, and static and dynamic evaluation are utilized for prestressed concrete box girder bridges. Their investigation aimed to detect deterioration in bridges and evaluate their structural integrity when subjected to dead alongside loads. The bridge's structural evaluation was conducted utilising the] dynamic load test and the SAP2000 Ver14.2.0 program. The results obtained from a dynamic test indicated that the measured frequency of 4.40 hertz was lower than the anticipated frequency of 4.963 hertz. The value of the variable load test coefficient was 0.88. Consequently, the resonance frequency was determined to be 5Hz by utilizing the frequency of vehicles traversing the bridge. Figure 8 shows bridge models. Figure 9 shows the layout of the cross-section of the bridge structure [27].

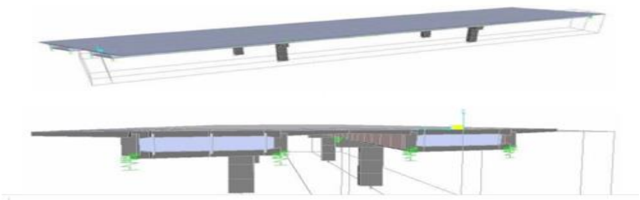


Figure 8. Bridge models

Ali (2013) investigated three box girder bridges made of prestressed concrete in China. The locations of these three bridges are in northern China. Based on the damages examination method, these structures sustained various damages, including vertical downward displacement and structural cracks. The bridge's structural integrity was assessed through experimental and theoretical analysis. He advised that bridge structures be strengthened and repaired using various strengthening technologies to restore rigidity [28].

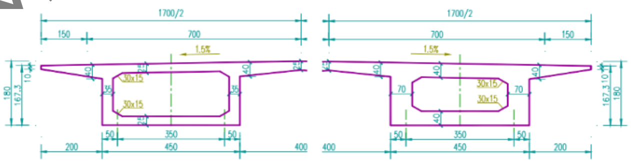


Figure 9. The layout of the cross-section of the bridge

In their study, Mayank and Saleem (2015) explored the mathematical analysis of two distinct box-girder cross-sections under comparable load conditions to ascertain which cross-section is more economically viable. By adhering to the Indian design specifications, box-girder superstructures subjected to IRC class AA loading were fabricated. Keeping both cross-sections' load and supporting parameters constant, the outcome indicates that single-cell box girders are less expensive than multi-cell box girders. It indicates that the single-cell prestressed concrete box girder is the most economical and suitable cross-section for a two-lane Indian national highway. Figure 10 shows the layout of the bridge model for 4 cell box girder and Figure 11 shows the layout of the bridge model for a cell box girder [29].

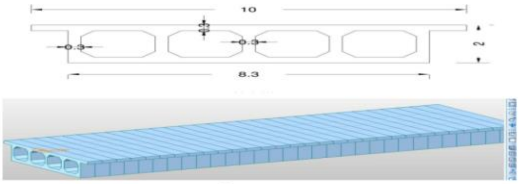


Figure 10. The layout of the bridge model for 4 cell boxes

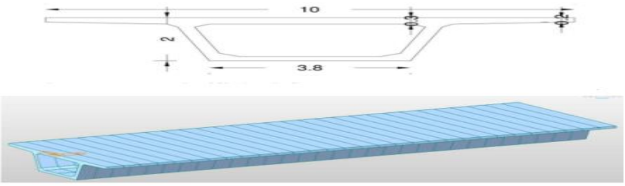


Figure 11. The layout of the bridge model for one cell box girder [29]

Paval (2015) described the design of a prestressed concrete box girder bridge superstructure and the linear and non-linear modes of time history analysis utilized in his study. A range of IRC loads are imposed on the superstructure of the bridge. The research illustrates the impact of variations in bridge geometry, damage scenarios, element properties, and bridge continuation on the redundancy of superstructures. Time history analysis is a method utilized to assess the structural response to alterations in various factors, including but not limited to boundary conditions, prestressed member damage and damage scenarios, member capacity, and non-linear effects. For this analysis, SAP2000 V15 is utilized. Periodically, the deflection varies by 30 to 40%, according to the outcomes of both linear and non-linear calculations. When comparing the outcomes of linear and non-linear studies, it is observed that the results derived from non-linear analysis are more extensive and considerably more precise than those obtained from linear analysis [30].

In their study, Chetan et al. (2015) demonstrated the analysis and design of a box girder utilizing two distinct types of covering pipes: corrugated bright metal and HDPE. A cost-effective design for a multi-cell box girder was developed by utilizing these sheathing pipes. The CSI-bridge modules program was used for analysis. Examining various losses resulting from distinct processes has encompassed elastic shortening, creep, shrinkage, friction, and wobbling loss. The study's findings indicate that the PSC multi-cell box girder design was economically viable in terms of critical bending moment and shear forces generated by various load combinations following IRC standards, in comparison to the design of an equivalent span arrangement using I girders and a cast in situ deck slab. Figure 12 shows the view of bridge mode [31].

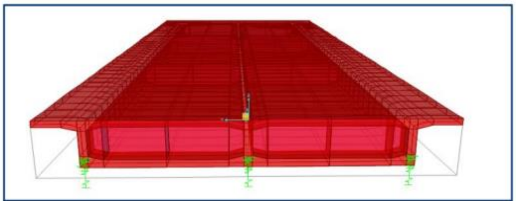


Figure 12. The view of bridge mode [31]

Amit and Savita (2017) compared various configurations of PSC box girder multi-cell bridges, including the vertically inclined, dropped, clipping, exterior girder with radius, and maximally sloping sides. The IRC Class-A load is utilized, and IRC-112 (2011) [32] is used for the analysis.

Damage inspection and structural performance evaluation of bridges were assessed by Fatimah et al. (2023). This study presented research findings from two distinct perspectives by analyzing bridge structures found in the real world. As determined by multiple investigations, Multiple investigations determined bridge structures exhibited structural defects, including cracks and vertical deflection. Throughout the damage assessment, a series of field tests were conducted. The concrete compressive strength, bridge deck leveling, the carbonation process, and steel corrosion were among these tests. In addition to the theoretical assessment, engineering applications, including SAP2000, Ansys, and Staad Pro, are utilized to conduct dynamic and static load testing. Most researchers observed that the bridge's structures had suffered significant damage and proposed a range of reinforcement and repair methods to enhance the structure's flexibility [33].

For composite box girders, Ya et al 2023 applied a finite element model of vehicle-bridge coupled vibration analysis. Advanced dynamic response analysis was performed on composite box girders with corrugated steel webs and classic concrete box girders with 30 m single boxes and single cells, as well as 50 m single boxes and multiple cells. The natural vibration frequency of the composite box girder with corrugated steel webs is lower than that of the corresponding concrete box girder, according to their research. When the bridge deck condition is bad, the composite box girder has a substantially higher dynamic impact coefficient than the concrete box girder. The dynamic impact reaction is greatly amplified when the bridge deck is in bad condition, and the difference is significant when compared to when the bridge deck is in good condition, which is greater than three times and even six times at the maximum. The dynamic impact coefficient of the composite box girder is affected by both differences in vehicle model and changes in vehicle speed. Figure 13 shows the layout of the box girder cross-section. [34]

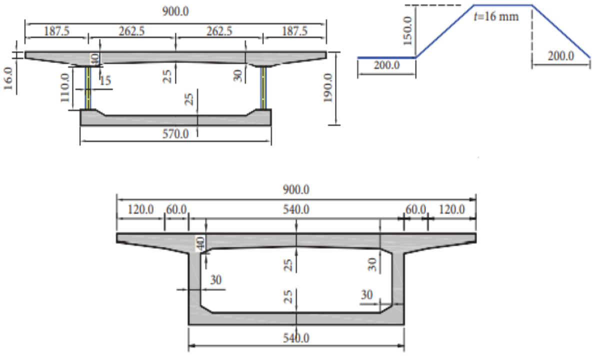


Figure 13. The layout of the box girder cross-section [34]

Vaishnavi and Mukund 2023 carried out an RCC box girder bridge having different spans but the cross-section is two or four cells. Further, this box girder is analyzed by different live load vehicle conditions such as IRC CLASS AA, CLASS 70R, and CLASS A. A comparison is made in responses obtained using CSI bridge Software. They found that reinforced concrete box girder is particularly appropriate for a span ranging between 15 to 42m. Ongoing beyond this span there is a substantial in increase in massiveness. This increase in massiveness results in a higher dead load that renders the structure relatively unsuitable for large span length. As span increases dead load increases. Live load Bending moment of IRC Class 70R is minimum because its wheel load is 100KN. When moving load increases shear force gradually increases. Figure 14 shows the bridges models. [35]

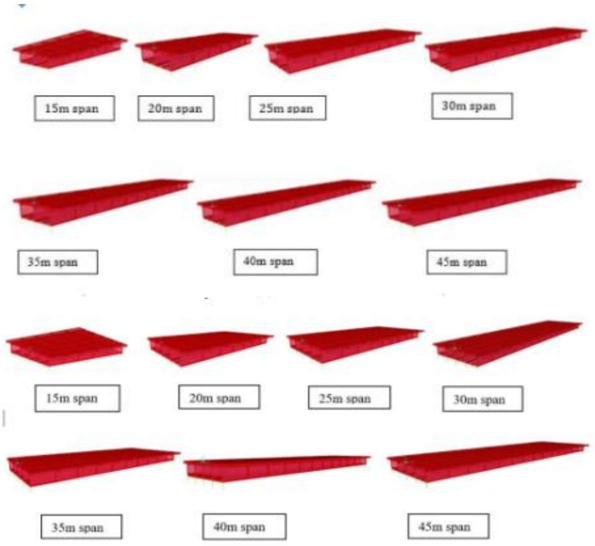


Figure 14. The bridges models [35]

3.2. Bridge Structure Strengthened `by External Prestressing Tendons *s*

The examination of external prestressing tendons as a means to reinforce concrete beams was described by Mohamed (1993). In his investigation, fatigue deformation was induced by subjecting sixteen concrete beam specimens to cyclic fatigue loading within a constant load range. These beams were reinforced with external prestressing tendons and subjected to an inversely increasing fracture load after loading. Experiment results indicated that fatigue deflections decreased by as much as 75%, and low flexural strength of beams increased by 149%. In contrast to tendons with a straight profile, external tendons featuring a reduced profile exhibited a comparatively higher degree of efficacy in enhancing flexural strength. Furthermore, both stress ranges and mean stress levels decreased during interval tension reinforcement, indicating a significant escalation in the strength fatigue rate [36].

Gregor et al. (1993) the behaviour of box girder diaphragms and intermediate slab blisters when employed for external tendon anchorage discussed. Their research aimed to create general design processes for anchoring areas in post-tensioning concrete structures, specifically to evaluate the application of strut-and-tie modelling. Three diaphragms with varied strengthening features and eight blister or rib specimens were used in the lab study. They concluded that the strut-and-tie model was a helpful and practical approach for designing and evaluating diaphragms and blisters used to anchor external tendons. Although the modelling will show where reinforcing was required for strength demands, designers must consider serviceability and crack under control [37].

Christian and Josef (1993) demonstrated the application of dynamic testing in investigating various types of external tendons and their deviation points. Dynamic tests for deviated tendons fall into two distinct classifications. The first experiment utilised full deviators to test the deviated tendon dynamically. The second experiment comprised a dynamic test in which the tendon was extended over the edge of a concrete block in order to illustrate its resistance to even a minor geometric deviation. To demonstrate the tendon's resistance to even a minor geometric deviation, the second experiment involved a dynamic test of the tendon that extended over the edge of a block of concrete. Cables with prestressing wire in a grease-filled PE tube, cables with multiple strands coated with grease and a thin PE sheathing in a grease-filled PE tube, grouted with mortar, and cables with mono-strands arranged arrow side by side in a rectangular PE cover all produced favourable results in these experiments. A relative movement occurred between the lubricated wires or strands and their direct PE-sheathing due to the dynamic displacement of the cable in PE tubes. When the wires or strands interact with the outer PE-tube or PE-cover, friction will cause the entire cable to traverse the outermost layer of the saddle [38].

Ahmed (2001) investigated the reinforcement of prestressed concrete beams with external prestressing tendons. The construction of thirteen prestressed girders involved the utilization of external prestressing strands and petroleum strands of type G, with one girder consisting solely of internally prestressing steel. They underwent two-thirds point loading to failure. The influence of six distinct variables on the behaviour of a reinforced beam was examined. These parameters consist of the following: location of the deviator, eccentricities, value of external prestressing force, stage of loading before strengthening, concrete strength, and (span/depth) ratio. A theoretical investigation was conducted to propose fundamental formulas applicable to beam analysis, specifically for accurately measuring the deflection and flexural strength of the beam. Based on the results obtained from this research, using Parafil cables for external prestressing proved to be an exceptionally efficient approach to fortifying or restoring prestressed concrete structures. By applying a minimal external prestressing force, prestressed concrete beams experienced improvements in both cracking resistance and ultimate flexural strength, while cracked girders experienced no significant reduction in ductility [39].

In their investigation, Ahmed and Sherif (2006) utilised experimental and mathematical analysis to examine the impact of external prestressing tendons on the load capacity of continuous composite steel girders. The study specifically focused on the performance of external prestressed simply supported composite steel girders subjected to positive moments. There were available half-scale specimens of continuous (two-span) composite girders. The load capacity of these samples was assessed at their maximum level. The girders that were prestressed were constructed using 7-wire-1/2-low relaxing strands. The research findings indicate that the use of using prestressed girders increases the limit of elasticity and a reduction in deflection of 15%, respectively, over non-prestressed girders. Using strands for prestressing steel girders enables the implementation of a suitable profile that effectively improves the durability of the girder [40].

In their study, Ali and Wang (2011) conducted an inspection and identification of the damages on the Jaimusi highway precast concrete box girder bridge in China. The investigation also involved a static load test to evaluate the performance of the bridge components after the reinforcement and repair of the compromised structural elements. The findings of the investigation indicate that the structural part of the bridgeinvestigation findings indicate that the bridge's structural part is in a satisfactory condition after the reinforcement and repair efforts. The mean strength of concrete, as determined by the results of the strength rebound experiment, is 46.31Mpa. The average strength of anchor beam concrete is 49.82Mpa. Based on the static load test outcomes, the recorded values for internal forces, deflection, and strain are below the predicted values. This indicates that the experimental structure satisfies the design standard for elasticity, overall deformations, and integrity. Furthermore, it demonstrates excellent operational efficiency with a suitable surplus. There is an absence of discernible alteration in the length and width of cracks under testing load, and no further cracks develop. Figure 15 shows the inspected of box girder strengthening by using external prestressing tendons [8].

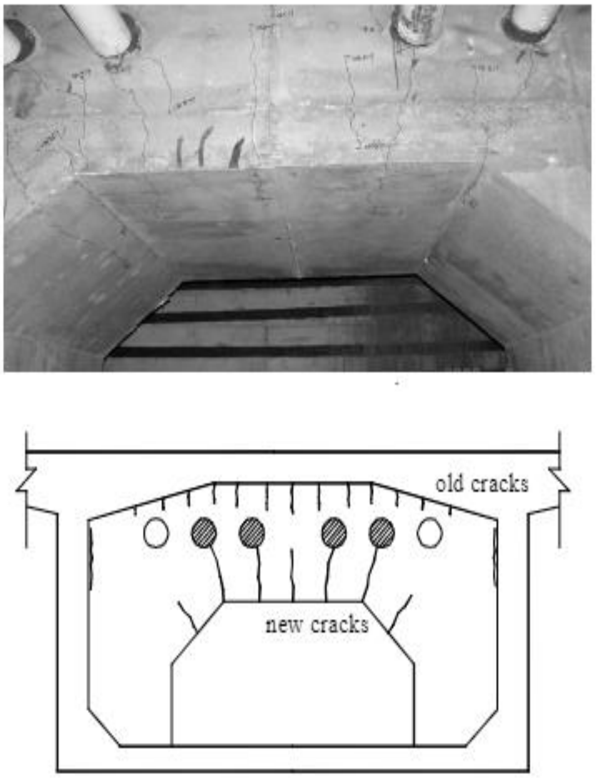


Figure 15. Box girder strengthening by using external prestressing tendons [41]

Ali and Wang (2012) reported that for the reinforcement of a prestressed concrete box girder bridge, the external prestressing tendons system was utilised. This system has been utilised in many countries since the 1950s and has been demonstrated to provide an efficient and cost-effective solution in a wide range of bridge types and situations. The primary objectives of this study are to investigate the efficacy of external prestressing tendons as a strengthening technique and to assess and analyse the Jiamusi prestressed concrete highway bridge's fixing beams. This research is comprised of three field experiments. Concrete compressive strength testing of anchor beams, tensile inspection of anchor beam re-bars, tensile testing of anchor beam structure, and tensile testing of anchor beam structure and external prestressing tendons are the experiments conducted the experiments conducted include concrete compressive strength testing of anchor beams, tensile inspection of anchor beam re-bars, tensile testing of anchor beam structure, and tensile testing of anchor beam structure and external prestressing tendons. The results obtained from field tests and analysis of external prestressing tendons and anchor beams indicate that the mean longitudinal displacement is 0.02 mm, while the axial strain fluctuates between 5 and 1 0:g. This suggests that the bending flexibility and bending capacity of the anchor beams anchor beams' bending flexibility and bending capacity are sufficient. External prestressing tendons exhibit congruent elongation readings between observation and prediction, while the measured external tensile forces are typically less than the design tensile force of 1250 kN. Figure 16 shows the view of bridge and figure 17 shows the layout of span strengthening by using external prestressing tendons. [41].

Figure 16. The view of bridge [42]

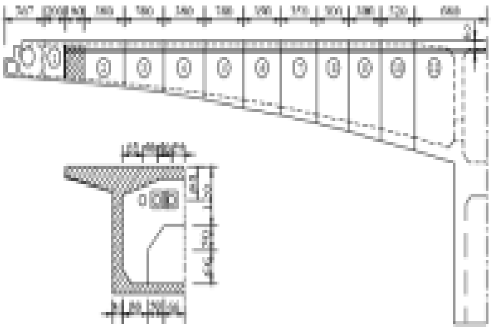


Figure 17. The layout of span strengthening by using external prestressing tendons [41]

In their study, Naser and Wang (2012) conducted an in-field load test to assess the condition of the external prestressing tendons anchoring equipment after tension forces were applied. The objective of the in-field load test was to monitor the construction process of the external prestressing tendons intended to reinforce the bridge structure. Strain and deflection measurements were taken of the anchoring equipment. Examining the cracks in the diaphragm anchorage and the deviation block devices before applying tension loads to the external tendons, measuring the deformation of the box girder when different amounts of tension forces are applied, and observing the elongation of the external tendons in each case are all components of the external prestressing tendons constructing inspection procedure. The results obtained from the observations indicate that the quantified values of deformation, elongation, and normal frequency meet the necessary criteria. Consequently, the fabrication and tension of the exterior prestressing tendons do not cause any damage. A field load test is conducted on the anchored beam, steel deviation block devices, and steel deviation cross beam. The results of the field load tests performed on the anchored equipment indicated that the deflection amounts, stresses, and strains were all below the corresponding permissible limit values as specified in the specifications. Consequently, the anchorage devices exhibit adequate strength, and the operational state becomes satisfactory upon transmission of tension loads to the exterior prestressing tendons [42].

Ali and Wang (2013) discussed the bridge structure's performance after strengthening, the analysis of static and dynamic structural response to static and dynamic loads, and the repair and reinforcement of damaged bridge members. Among the repair and strengthening methods utilized in their research are the following: crack remediation, web expansion of the box girder along the length of the bridge with internal prestressing tendons incorporated into the expanding web, and construction of reinforced concrete cross beams (diaphragms) between the two box girders. An analysis of static and dynamic structural responses after reinforcement using mathematics demonstrates a notable decrease in tension stresses, which eventually fall eventually falling below the thresholds specified in the standards. Following the process of strengthening, the values of vertical deflection diminish. The increase in the quantities of typical frequencies after the strengthening process indicates that the strengthening method effectively mitigates the resonance of the bridge structure. Consequently, the strengthening techniques exhibit efficacy in enhancing the bearing capacity and elastic behavior of the bridge structure, thereby prolonging its operational lifespan. Figure 18 shows the bridge structure after strengthening, figure 19 shows the web strengthening of box girder, and Figure 20 shows the bridge model after strengthening [43].

Figure 18. bridge structure after strengthening [43

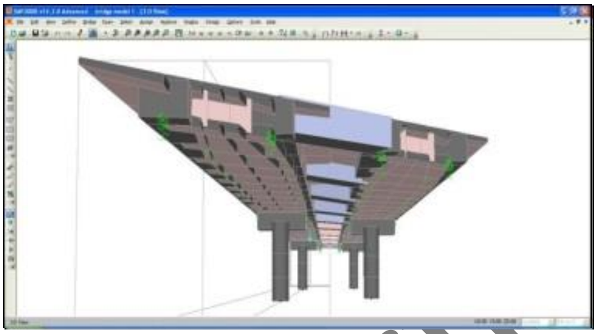


Figure 19. Web strengthening of box girder [43]

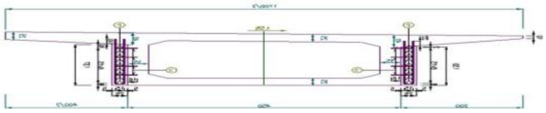


Figure 20. The bridge model after strengthening [43]

According to Hanging and Yaxun (2015), the utilization of externally prestressed bridges not only serves to restrict and diminish cracks and deformations but also enhances the structure's bearing capacity and durability, improves the stress condition of the bridge, has minimal operational impact, and offers satisfactory cost-effectiveness. The study provided a comprehensive analysis of the merits and demerits associated with the external prestressed strengthening method, as well as its calculation theory and construction technology. The conclusion of the paper identifies the deficiencies in current research [44].

In their study, Muthukumar and Balasundaram (2017) presented the results of an experimental investigation and analysis concerning external prestressing to reinforce and restore strained reinforced concrete beams. Beams subjected to varying levels of initial distress are prestressed, and their disintegration is evaluated. The effectiveness of beams in relation to initial crack load, elasticity characteristics, fracture propagation, failure load, maximum deformation, flexibility, and failure form are examined. The initial fracture in the trussed beam is delayed. The elasticity of the beam is improved. Additionally, prestressing tie bars increase their flexibility and load-bearing capacity. The repaired beam exhibits a substantial increase in load-bearing capacity, encompassing the initial crack load, operation load, and final load, compared to the parent RC beams Compared to the parent RC beams, the repaired beam exhibits a substantial increase in load-bearing capacity, encompassing the initial crack load, operation load, and final load [45].

The application of external prestressing to reinforce concrete structures was examined by Jaspal and Harpreet (2017). He determined that external prestressing simplifies design and increases the strength of structures. The implementation of external prestressing has enabled the construction of several innovative bridges comprised of lightweight concrete and significant eccentricity. External prestressing is a commonly employed technique in the building and reinforcement of new bridges. Due to the external placement of the tendons, external prestressing enhances the structural capacity to bear loads. It is one of the most straightforward and economical methods for fastening beams. It enhances the structural integrity. It is essential to research the external prestressing technique's various variables. Reinforcement with EPT enhances the ductility of structures [46].

In their study, Ganesh and Sekar (2018) conducted an analysis to determine analyzed how strain incompatibilities cause an external post-tensioning beam to behave differently than a bound prestressing beam. The impact of external tendons (in flexure and shear) on a pre-cracked or newly cracked beam is examined. The review encompasses various studies that investigate aspects such as the geometry of tendon shape parameterization, the impact of deviator blocks, the strain level in internal passive reinforcement, different loading types, the influence of initial crack widths, the combination of external prestressing and fiber wrapping up, and the increase in ultimate tendon tension [47].

The external post-tensioning technique for reinforcing RC T-girders was examined by Assefa (2019). The present investigation utilized a non-linear finite element method with two mid-third concentrated forces and Abaqus software to generate and assess ten comparable T-section RC beams with identical material properties and dimensions. An attempt was made to vary the independent variables until failure. Aside from the final beam, which serves as a control beam, nine of these girders have been fortified with external tendons. At 200mm, 225mm, and 243mm depths from the top fiber of the section, two external strands with a diameter of 12mm were affixed to each side of the web of the reinforced beams (dps). In comparison to a control beam, the load-carrying capacity of strengthened length ratios of 0.83L, 0.667L, and 0.5L and strand depths of 0.8h, 0.9h, and 0.972h was discovered to be 40.75%, 51.12%, and 62.44%, respectively [48].

Kim et al. (2021) explained that the external prestressing approach improves the accessibility and security of a structure by applying tension directly to the weak tensile area that experiences the most deflection during structure use. External prestressing is helpful in decreasing helps decrease cracks caused by applied tension and restoring restore deflection. Because the strengthening approach is used on deteriorating bridges, the strengthening impact is influenced by the current structure's state. On the other hand, research on the strengthening impact based on the degree of degradation is lacking. As a result, the performance of the bridge was studied based on its strengthening situation, and the strengthening impact was determined in this study by simulating the damaged bridge, reducing the compressive strength and reinforcement quantity, and performing a four-point loading test. The experiment confirmed a reinforcing effect of 215% crack load, 161% yield load, and the difference in behavior based on the reinforcement variables [49].

4. Conclusion

Normal and prestressed concrete box girders for highway bridges have been examined comprehensively in this study. The performance of a superstructure was dominated by the geometric shape and reinforcing techniques of the box girders. In practice, both pretension Ing and posttensioning forms of cable tension classification were applicable. Documented in the literature was the vast majority of research pertaining toThe vast majority of research was documented in the literature on the repair and reinforcement of box girders. Multiple parameters, including shape properties, repair techniques, and strengthening schemes, influence the behavior of box girders, according to the conclusion. In conclusion, multiple parameters, including shape properties, repair techniques, and strengthening schemes, influence the behavior of box girders. Therefore, in order to determine the structural efficiency of existing box girders, it is necessary to examine how the shape specifications of box girders differ based on site requirements. This study has discussed a holistic overview of normal and prestressed concrete box girders for highway bridges. The geometric shape and reinforcing methods of the box girders dominated the performance of a superstructure. Both typing of cable tension as pretension Ing and post-tensioning were applicable in practice. The majority of research concerning repairing and strengthening of box girders were documented in the literature. The conclusion that the behavior of box girders is controlled by several parameters such as shape properties, repairing methods, and strengthening schemes. So, the shape details of box girders varying according to the requirements of the site, thus must investigate the structural efficiency if existing box girders.

Authors' contribution

All authors contributed equally to the preparation of this article.

Declaration of competing interest

The authors declare no conflicts of interest.

Funding source

This study didn't receive any specific funds.

Data availability

The data that support the findings of this study are available from the corresponding author upon reasonable request

REFERENCES

[1] Hussein Abad Gazi Jaaz1, Noor Mukdam Diwood, Ali Fadhil Naser, and Marwa Foad Manher, 2023. Influence of Constructing Transverse Concrete Diaphragms in Different Distances on the Dynamic and Static Behavior of Prestressed Concrete T-Beam Bridge Structure, AIP Conference Proceedings 2776, 060014. https://doi.org/10.1063/5.0136390.

[2] Naser, A., Mohammed, H., Mohammed, A. 2022. Flexure and shear load rating evaluation of composite bridge superstructure under effect of different trucks load types, Materials Today: Proceedings, 2022: 398–407. https://doi.org/10.1016/j.matpr.2021.12.268.

[3] Naser A. F., W. Zonglin. 2011. Damage inspection and performance evaluation of Jilin highway doublecurved arch concrete bridge in China, Struct. Eng. Mech., Int. J. 39(4): 521-539. https://doi.org/10.12989/sem.2011.39.4.521.

[4] The Rev. Henry Grattan Guinness. 1911. Monthly Notices of the Royal Astronomical Society. 71(4): 257-258. https://doi.org/10.1093/mnras/71.4.257.

[5] Hussein A. G., Ali F. N., Hussam A. M, Ayad A. M. 2021. Earthquake resistance optimization and evaluation of bridge piers' structural form and dimensions based on demand-to-capacity ratio and yielding points of force-displacement, Mathematical Modelling of Engineering Problems. 8(8): 945-954. https://doi.org/10.18280/mmep.080614.

[6] Mohammed H. A., Naser, A. F. 2020. Mathematical assessment of vehicle types and loads influences on the structural performance parameters of concrete and steel bridges. Journal of Engineering Science and Technology. 15(2): 1254-1266.

[7] Naser A. F. 2018. Optimum design of vertical steel tendons profile layout of post-tensioning concrete bridges: fem static analysis. ARPN Journal of Engineering and Applied Sciences. 13(23): 9244-9256.

[8] Naser A. F., Wang Z. 2011. Experimental inspection of damage and performance evaluation after repair and strengthening of Jiamusi highway prestressed concrete bridge in China. World Academy of Science, Engineering and Technology. International Journal of Civil and Environmental Engineering, 5(1): 26-32.

[9] Naser A. F., Mohammed H. A., Mohammed A. A. 2021. Mathematical modeling of linear static and dynamic analysis for pier height effect on the structural performance of bridges structure, Mathematical Modelling of Engineering Problems. 8(4): 617-625. https://doi.org/10.18280/mmep.080415.

[10] Naser A. F. 2021. Analysis the effect of superelevationon static and dynamic properties of horizontal curvedconcrete bridge by finite element. Journal of Engineering Science and Technology. 16(5): 3669-3686.

[11] Weiwei Lin, Teruhiko Yoda, 2017. Chapter Six - Reinforced and Prestressed Concrete Bridges, Bridge Engineering Classifications, Design Loading, and Analysis Methods.v.2017: 97-110.ISBN: 9780128044322.

[12] Sonal T. Pawar, 2016. Analysis of Box Girder Bridges Using Haunches, International Journal of Scientific Research in Science, Engineering and Technology, 2(3): 473-479. IJSRSET1623133.

[13] Savio John, Reshma Prasad, 2017. An overview on box girder bridges, International Research Journal of Engineering and Technology, 4(1): 522-524.

[14] Weizhao Li, Zonglin Wang and Fadhil Naser Ali, 2011, Theoretical Analysis of Temperature and Shrinkage Stresses of Box-girder Section, Advanced Materials Research Vols. 243-249 (2011) pp 1885-1892. http://dx.doi.org/10.4028/www.scientific.net/AMR.243-249.1885.

[15] Meghana K., Sowjanya G., Mallesh T. Review Paper on Comparative Analysis of T-Beam Bridge and Box Girder Bridge, International Journal of Engineering Research & Technology, 8 (14):128-129. IJERTCONV8IS14034.

[16] Nishi Gupta, Pradeep Kumar Mehta, Rakesh Kumar, 2021, Effect of Depth on Box Girder Bridges, International Research Journal of Engineering and Technology, 8(6): 4635-4641.

[17] Vladimír Křístek, Zdeněk Bažant, Miloš Zich, and Alena Kohoutková, 2006, Box Girder Bridge Deflections, ACI Concrete International, 28(1): 55-63.

[18] Ali Fadhil Naser, Zonglin Wang, 2011. Experimental Analysis and Performance Evaluation of Fu Feng Highway Prestressed Concrete Bridge After Strengthening in China, Advanced Materials Research Vols. 189-193: 2346-2352. http://dx.doi.org/10.4028/www.scientific.net/AMR.189-193.2346.

[19] E. Naser, 2005. Repair and Strengthening of Reinforced Concrete Structure, R. V. Anderson Associated Limited, Toronto, Canada.

[20] F. Hugenschmidt, 1981. Strengthening of Existing Concrete Structures with Bonded Reinforcements, EMPA, Switzerland.

[21] Azlan, A., Sophia, C., Karim, M., 2006. "Bridge Evaluation Through Non-destructive Testing in Comparison With Visual Inspection, Proceeding of the 6th Asia-Pacific Structural Engineering and Construction Conference (APSEC-2006), 5 – 6 September, Kuala Lumpur, Malaysia.

[22] Eltayeb Hassan Onsa, Elsafi Mohamed Adam, Abdalla Khogali Ahmed, and Mohamed Elmontasir Elbagir, 2009. Long-term Deflections in Balanced Cantilever Prestressed Concrete Bridges, Journal of Engineering Science, 4(1): 1-22. https://doi.org/10.52981/fjes.v4i1.41.

[23] Liu X., Ning, Y., Huang, K., Zhang, K., and Cheng, J., 2010. "Research on the Impact of Long-Term Down Deflection From the Long-Span Concrete Girder Bridge on the Structure Stress, Proceeding of International Conference on Optoelectronics and Image Processing, 978-0-7695-4252-2/10, © 2010 IEEE.

[24] Jianyong, S., Jianming, L., Wanheng, L., and Jinquan, Z., 2010. "Finite Element Simulation of the Composite Continuous Box Girder Bridge with Corrugated Steel Web By CBCW", Proceeding of International Conference on Computing in Civil and Building Engineering, University of Nottingham. Germany.

[25] Ali F., Wang Z. 2011. Field Damage Inspection and Static Load Test Analysis of Jiamusi Highway Prestressed Concrete Bridge in China. Advanced Materials Research Vols. 163-167: 1147-1156. https://doi.org/10.4028/www.scientific.net/AMR.163-167.1147.

[26] Byungik Chang, Kamal Mirtalaei, Seungyeol Lee, and Kenneth Leitch. 2012. Optimization of Post-Tensioned Box Girder Bridges with Special Reference to Use of High-Strength Concrete Using AASHTO LRFD Method. Advances in Civil Engineering, Volume 2012. https://doi.org/10.1155/2012/673821.

[27] Naser A., Zonglin W. 2013. Finite element and experimental analysis and evaluation of static and dynamic responses of oblique prestressed concrete box girder bridge. Research Journal of Applied Sciences, Engineering and Technology. 6(19): 3642-3657. https://doi.org/10.19026/rjaset.6.3572.

[28] Ali Fadhil, 2013. Damage inspection and structural performance evaluation of prestressed concrete box girder bridges before and after strengthening-theoretical and experimental study, PhD thesis submitted to Transportation Engineering Department in Harbin Institute of Technology, Harbin City, China.

[29] Mayank Chourasia , Saleem Akhtar. 2015 .Design and Analysis of Prestressed Concrete Box Girder by Finite Element Method (4 Cells & 1 Cell , International Journal of Civil and Structural Engineering Research, 4(1):413-421.

[30] B. Paval 2015. Analysis of Multi-Cell Prestressed Concrete Box-Girder Bridge. International Journal of Engineering Technology Science and Research IJETSR, ISSN 2394 – 3386 Volume 3.

[31] Chetan T Naik , M M Achar , K Lakshmi 2015. Analysis and Design of Multi Cell Post-Tensioned PSC Box Girder. IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE), 12(4): 56-64. https://doi.org/10.9790/1684-12475664.

[32] Amit Upadhyay and Savita Maru. 2017. Comparative Study of PSC Box Girder Multi Cell (3-Cell) Bridge of Different Shapes : A Review Paper, Global Research and Development Journal for Engineering, 2(6): 141-146.

[33] Fatimah Waad Abdullah, Ali Fadhil Naser and Ali A. Aldhalemi, 2023. A review studying of damages inspection methods and structural performance assessment of bridges structures. ARPN Journal of Engineering and Applied Sciences, 18(11): 1317-1336. . https://doi.org/10.59018/0623170.

[34] Ya-N., Chi, M. , Shi-Zhong, L., and Li-Yuan, L. 3023. Study on the Dynamic Response of Composite Box Girder Bridges with Corrugated Steel Webs, Advances in Civil Engineering, Volume 2023, Article ID 5104132: 1-14. https://doi.org/10.1155/2023/5104132.

[35] Vaishnavi, P.m and Mukund, R. 2023. Analysis of box girder bridge and evaluation of equivalent udl for various spans, International Research Journal of Modernization in Engineering Technology and Science, 5(8): 251-257.

[36] Mohamed, H., 1993. Strengthening of Concrete Beams by External Pretressing PCI Journal, pp: 76-77.

[37] Gregor. P, Karen. R, John.E, Michael. E, 1993. Fretting Fatigue of External Tendons in Segmental Bridge Deviators, External Prestressing in Structures, SES, CEBTP, France.

[38] Christian. W., and Josef. E, 1993. Experiments with External Tendons, ExternalPre-Stressing in Structures, SES, CEBTP, France.

[39] Ahmed, H., 2001. "Strengthening Prestressed Beams Using Parafil Ropes as External Tendons", A Thesis Submitted in Accordance With the Requirements for the Degree of Doctor of Philosophy, School of Civil Engineering, The University of Leeds, Leeds City, England.

[40] Ahmed. E and Sherif. Y, 2006. "Use of External Prestressing to Improve Load Capacity of Continues Composite Steel Girders", Structures Congress 2006:Structure Engineering and Public Safely, ASCE, USA. https://doi.org/10.1061/40889(201)156.

[41] Ali Fadhil and Wang Zonglin. 2012. Field Tests of Anchor Beams during Strengthening of Jiamusi Prestressed Concrete Highway Bridge, Research Journal of Applied Sciences, Engineering and Technology 4(5): 475-480.

[42] Naser, A.F., Wang, Z. 2012. Experimental monitoring of the strengthening construction of a segmental box girder bridge and field testing of external prestressing tendons anchorage. Front. Struct. Civ. Eng. 6, 308–320. https://doi.org/10.1007/s11709-012-0140-3

[43] Ali F. and Wang Z. 2013. Evaluating the performance of skewed prestressed concrete bridge after strengthening, Central European Journal of Engineering, 3(2): 329-347. https://doi.org/10.2478/s13531-012-0061-x.

[44] Hanbing Zhu & Yaxun Yang. 2015. External Prestressing Bridge Reinforcement Technology Review, Web of Conferences, MATEC - 220 0 4 4 2 2.

[45] Muthukumar and Balasundaram. 2017. Rehabilitation of Distressed Concrete Beams Using External Prestressing – Experimental Study, International Journal of Applied Engineering Research 12(15):4806-4810.

[46] Harpreet Kaur and Jaspal Singh. 2017. A Review on External Prestressing In Concrete, International Research Journal of Engineering and Technology, 4(5):1801-1805. Corpus ID: 212533245.

[47] K. Ganesh and K. Sekar. 2018. A Review of Behaviour of Externally Prestressed Beams, International Journal of Civil Engineering and Technology, 9(7): 382–389.

[48] Assefa Haile. 2019. Assessment on external post tensioning to strengthen reinforced concrete t-beam, A Ph.D Thesis submitted to the School of Graduate Studies of Jimma University, Jimma, Ethiopia.

[49] Kim, S.-H.; Park, J.-S.; Jung, W.-T.; Kang, J.-Y. Strengthening Effect of the External Prestressing Method That Simulated a Deterioration Bridge. Appl. Sci. 2021, 11, 2553:1-11. https://doi.org/10.3390/app11062553.