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# The Evolution in Design & Analysis of Prestressed Box Girder Bridge - A Review

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**Abstract:- For several decades, the utilization of pre-stressed concrete has afforded bridge engineers the capability to construct cost-effective, durable, and efficient infrastructure. This is often achieved through utilizing local resources and labor, coupled with the integration of advanced design and construction methodologies, thereby enhancing accessibility and transportation networks for surrounding communities. The assessment and planning of bridges are carried out following a range of established standard codes, providing optimal solutions that meet the needs of many design engineers. A diverse array of software applications and methodologies are employed in the design & analysis of pre-stressed box girder bridges, to gain deeper insight into the dynamics of these intricate structural systems. The primary goal of this investigation is to conduct a literature review on different optimization techniques used in the design & analysis of pre-stressed concrete box girder bridges for the past few decades including examining the structural performance, such as stresses, losses, cable configurations, modulus of elasticity and strands.**

***Keywords:-*** *Pre-Stressed Concrete, Strain, Creep, Strength, Load.*

## I. INTRODUCTION

Bridges constitute vital elements of global transportation infrastructure, playing a pivotal role in advancing national development. As a result, the need for bridges has skyrocketed in many nations recently. For instance, it is recorded that nearly 1500 bridges every year were built in the United States between 1996 and 2006.[1] As of the end of 2012, Dubai had 347 bridges.[2] The design of a bridge is intricately linked to its construction methodology, the geological composition of the underlying subsoil, and the choice of construction materials. Central to the construction of any bridge is the engineering imperative to ensure economic efficiency, structural integrity, and longevity. Pre-stressed concrete is ideal for the development of long-span and medium bridges. Since Freyssinet developed pre-stressed concrete in the early 1930s, the materials have been widely used in the development of long-span bridges, progressively overtaking reinforcement steel, which requires extensive upkeep due to the inherent drawbacks of corrosion under hostile environmental circumstances. Precast girders with cast-in-situ slabs are one of the most widely used types of superstructure in concrete bridges.[3] Concrete has a vulnerability in tension, which can be resolved with the aid of pre-stressing. This means here the impact of the added loads is in opposition to the intended level for introducing the equivalent load on the concrete element. Crack propagation can also be regulated by pre-stressing. A special variation of enhanced cement is combined with high-strength concrete in pre-trained high-force steel.[4] Pre-stressing involves applying premeasured and desired levels of permanent stress to a member before subjecting it to design loads. This pre-stress effectively counteracts or offsets the stresses induced by external loads up to the desired extent. It is a technique aimed at redistributing tension within a member to mitigate the effects of external loading. Economic viability and construction ease are paramount considerations in modern construction, achieved through the utilization of high-strength materials and advanced design methodologies.

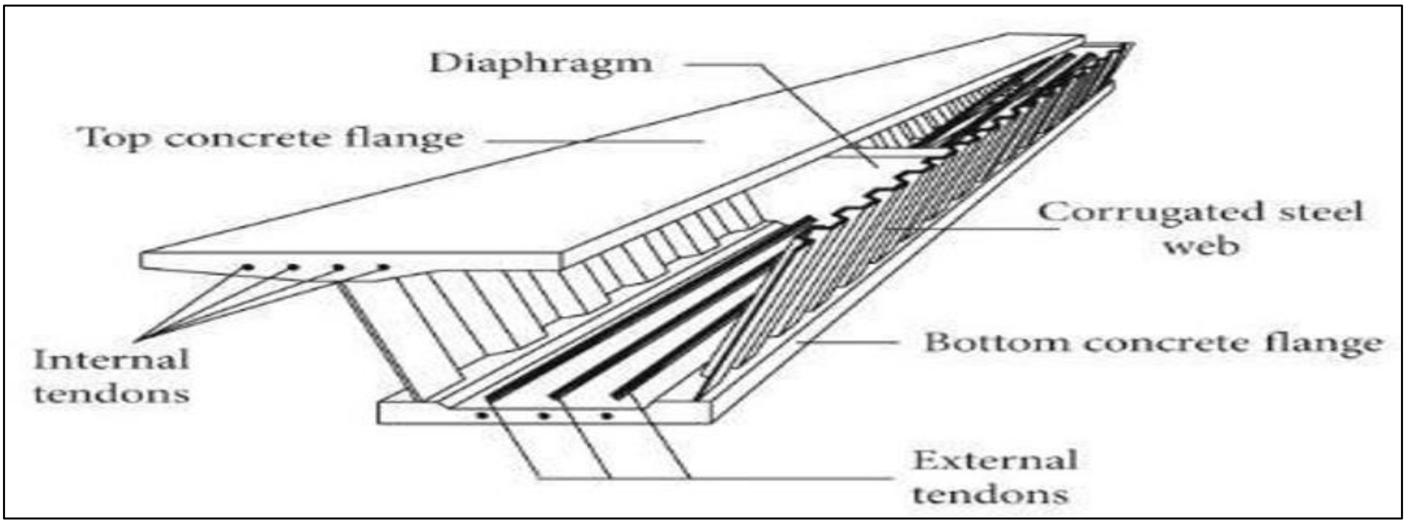


Fig 1 Components of Pre-Stressed Concrete Bridge

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Consequently, cross-sectional dimensions are reduced, leading to weight savings. These advancements are particularly significant in reinforced concrete structures; as dead load constitutes a significant amount of the overall load. Despite the low tensile strength of reinforced concrete, its compression strength is high. This ensures that the concrete portion is primarily stressed in compression during operation and, at times, even under overloading conditions. This construction method is known as pre-stressed concrete. The pre-stressing force required to meet the specific geometry and loading conditions of a given element is calculated using principles of mechanics and the stress-strain relationship. Simplification is crucial, particularly when assuming a pre- stressed beam to be homogeneous and elastic. Because of its remarkable rotational rigidity, box girders are an excellent choice for components of bridges that are oriented toward curves. High rotational stiffness box girders can withstand the rotating deformations found in curved, thin- walled beams. Box girder decks which are cast-in-place components that may be constructed along any planned orientation in the plan, enable the construction of many types of skew, straight- ahead, and curved bridges on the transportation network.

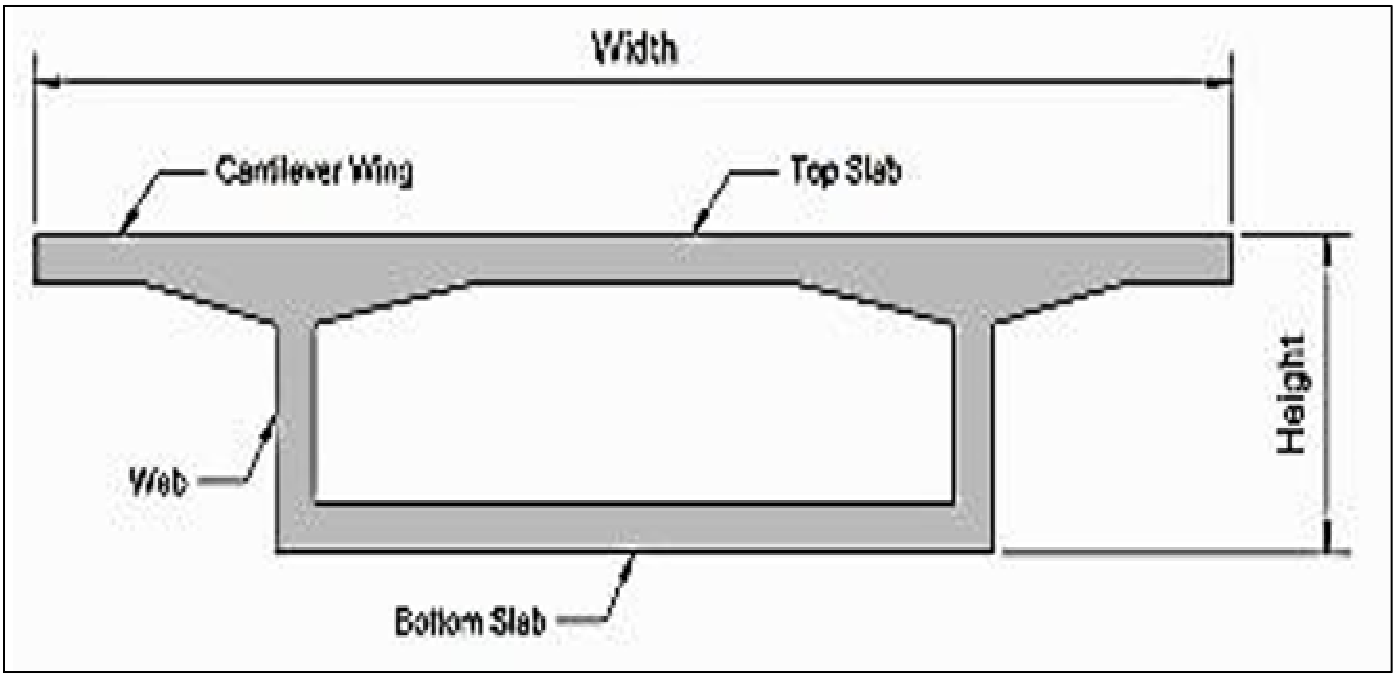


Fig 2 Cross Section of Box Girder

Because the lengthwise flexural stress distribution pattern is nearly the same throughout the whole section, a box girder provides strength and high torsion stiffness in comparison to an equivalent open cross-section member. More notable span/depth ratios are possible due to the box girder's wider flange. This is useful in cases where building depth is limited. Additionally, it may lead to slenderer, ultimately more appealing buildings. Utilities such as wires, water lines, and gas lines can be transported through the narrow opening in the girder.[5] In contrast to restoration, which focuses on restoring the integrity and usefulness of compromised pieces, reinforcement of a concrete structure entails increasing the rigidity and flexibility of its constituent parts. Bridge frames can be strengthened through the substitution of inferior or low-quality elements with superior materials, the joining of materials with larger bearing loads, and the redistribution of loading processes through induced displacement on the construction systems.[5][6] The primary goal of this study is to explore previous research on various facets of pre-stressed concrete bridges, encompassing their analysis and design, alongside optimizing the structure to reduce costs while preserving strength by following different standards and methods.

## II. PRE-STRESSED CONCRETE

It is well known that even though concrete does its best work in compression and steel in tension, we use only a small part of the potential strength and effectiveness of the materials. Pre-stressed concrete construction is an attempt to diminish concrete by utilizing the superior tensile qualities of steel and the increased compressive strength of contemporary concrete under normal loading circumstances. [7] In bridge construction, pre-stressing is typically achieved by applying forces externally to concrete using wires, bars or strands. This method significantly enhances the strength of the concrete itself.

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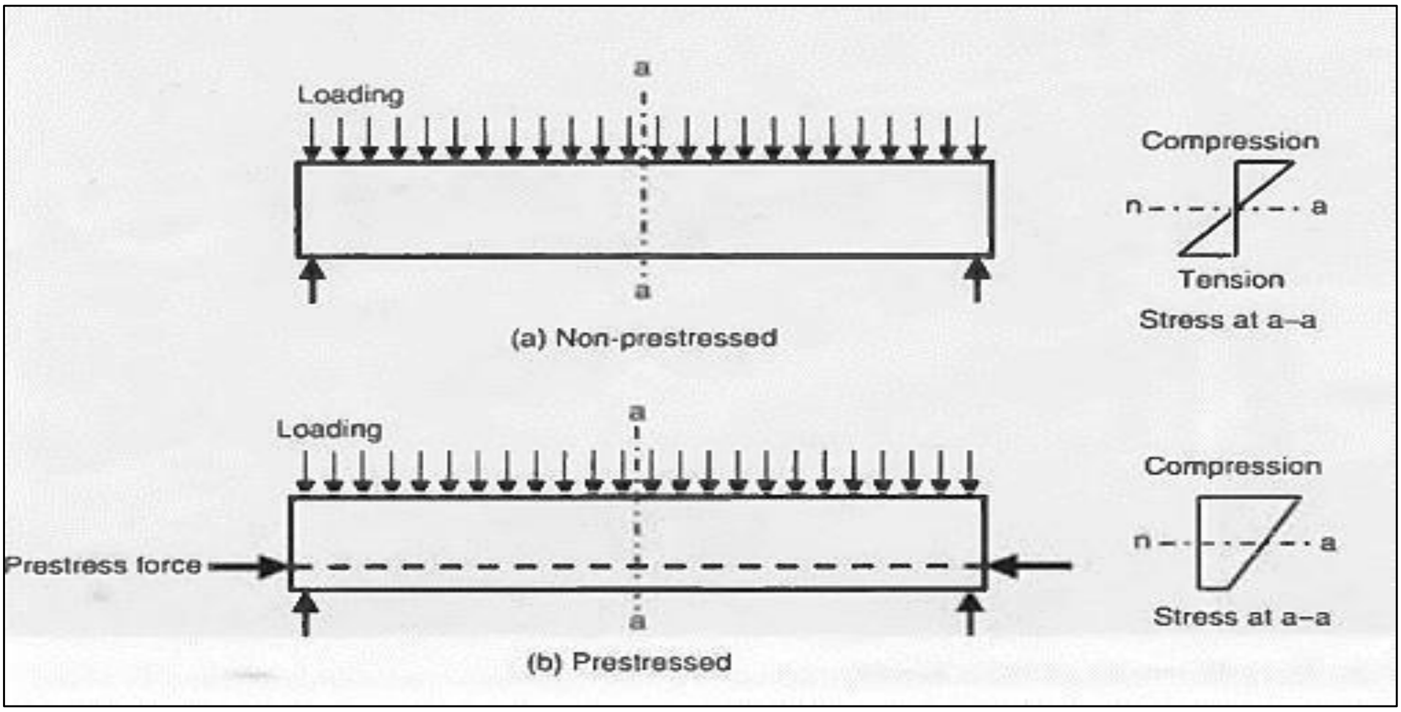


Fig 3 Change to Stresses in Beam

➢ *There are Two Pre-Stressing Methods, each Accounting for Various Types of Losses:*

- *Pre-Tensioning:*

The term "pre-tensioned" refers to the tensioning of tendons to their maximum load before concrete placement. Losses accounted for in the design process include elastic deformation in concrete, stress relaxation in steel, concrete shrinkage, and concrete creep. Prior to the concrete being poured, the tendon is pre-tensioned by jacking upon an anchor framework. When the concrete has reached a sufficient strength, the force is discharged from the anchor frame into the concrete. The tendons, which are mostly used in precast beams, are often made up of single or seven-wire strands.[8]

- *Post-Tensioning:*

Post-tensioning refers to the tensioning of tendons after concrete placement and curing. Losses accounted for in design include elastic deformation in concrete, stress relaxation in steel, shrinkage and creep in concrete, additionally friction and anchorage losses in pre-stressed concrete (PSC) girders. These considerations are particularly relevant for short to medium spans, typically under 40 meters. Post-tensioning applies to a wide range of structures, such as cable- stayed constructions, precast beams, and in situ or else precast box girders.[8]

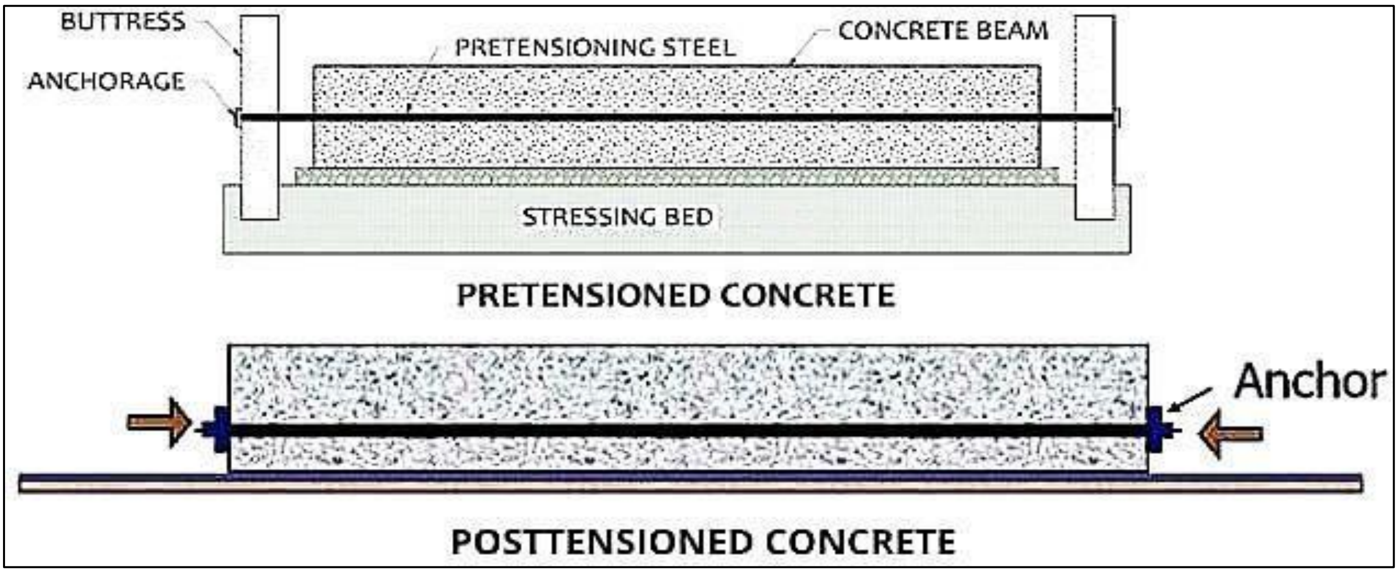


Fig 4 Pre-Tensioned Concrete and Post-Tensioned Concrete

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## III. PAST RELATED RESEARCH

The idea of pre-stressing was applied to reinforce the construction as early as 1888, but the extent of pre-stress was not taken into account. In 1888, C. F. Doering of Berlin used pre-stressed steel wires for mortar slabs, to exercise a permanent compression on the future tension zone of the concrete. J. Mandl wanted to minimize the concrete's tensile stress under load to maximize its strength. In response to this suggestion, the German M. Koenen developed a formula in 1907 for the stretching force's size, resulting in the requirement that the concrete tensile stress in the triangular straight line stress distribution, acquired for applied load, be restricted to a specific magnitude.[7]

Because of the scarcity of steel in Europe following World War II, pre-stressed concrete became popular in the reconstruction of bridges across the continent, and the 1950s saw pre-stressed concrete being used widely for bridgeworks. In this period Precast concrete bridges were still being designed by Eugene Freyssinet, whereas Gustave Magnel pioneered the method on many significant Belgian buildings. As demonstrated by Mr. Freyssinet, if the pre-stress is to be permanent, the cable in question needs to be composed of high-tensile steel. The wires have a standard limit of elasticity of approximately 170,000 lb./in$^2$ and an ultimate strength of roughly 210,000 lb./in$^2$. This allows pre-stressing to a maximum of 0.8 X 170,000 = 136,000 lb./in$^2$ or 0.6 X 210,000 = 126,000 lb./in$^2$, whichever is smaller.[9] From the early 1950s, and over the next 40 years Jean Muller carried on with Freyssinet's work in developing the art of pre-stressed concrete bridge design and construction. He introduced the technique of match-cast precast segmental concrete deck construction on the Shelton Road Bridge, USA, in 1952. In 1962 Muller used the technique on a series of motorway over bridges around Paris, the first being the Seine River's Choisy-Ie-Roi Bridge. He went on to use this approach on numerous viaducts and major bridges worldwide, with one of the most notable bridges being the Linn Cove Viaduct.[8] A study conducted in 1966 on a bridge in Dreherstown, Pennsylvania, investigated five pre-stressed concrete box girders with a deck made of reinforced concrete that was poured in place. The lateral distribution of the live load was examined using a crawl truck traveling at 2-3 mph across the span along seven evenly spaced loading lanes. Strain gauges were employed to measure strains resulting from the truck runs, aiding in the determination of distribution factors for the girders. The research aimed to enhance existing AASHTO specifications by providing real field data on spread box girder bridges' lateral static load distribution. It recommended revising the design distribution factor for girders that are both exterior and interior to reflect the precise behavior of structures of this general type. The maximum experimental live load girder moments significantly differed from the design values, with the maximum experimental values for exterior girders notably higher and those for interior girders notably lower. The superimposing of single-truck run results to achieve the effect of two-truck loading was deemed a valid procedure. The location of the neutral axis on a girder face varied with the lateral positioning of the test trucks, indicating the presence of girder torsion. The inclination of a girder's neutral axis, which also varied with the lateral position of the truck, suggested girder torsion. Finally, the girder's location for the axis which is neutral varied vertically, depending upon the truck's lateral position. [10]

Table 1 Classification of Pre-Stressed Concrete Bridges Constructed or Under Construction at the End of 1952[11]

| Constructed or Under Construction at End of 1952 | | | | | | |
|---|---|---|---|---|---|---|
| Location / Type | | | U.S. | Foreign | Totals | |
| Simple Span | Precast | Number | 92 | 269 | 361 | No 582 |
| | | Length in Miles | 4.22 | 5.75 | 9.97 | |
| | | Span Range | 20'-160' | 25'-243' | | |
| | Cast in Place | Number | 3 | 218 | 221 | |
| | | Length In Miles | 0.03 | 4.65 | 4.68 | 14.65 Miles |
| | | Span Range | 40'-60' | 19'-405' | | |
| Continuous | Precast | Number | - | 1 | 1 | No 44 |
| | | Length In Miles | - | 0.03 | 0.03 | |
| | | Span Range | - | 36'-50' | | |
| | Cast in Place | Number | - | 43 | 43 | |
| | | Length In Miles | - | 2.28 | 2.28 | 2.31 Miles |
| | | Span Range | - | 13'-515' | | |
| Totals | | Number | 95 | 531 | No. 626 | |
| | | Miles | 4.25 | 12.71 | | 16.95 Miles |

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In 1969, acknowledging this matter Daryolish Motarjemi and David A. Van Horn analyzed the live-load distribution trends on more than three hundred distinct spread box-beam bridges under different HS20 truck loading situations, leading to the development of design recommendations for determining lateral live-load distribution. The study develops an analysis method tailored for beam-slab bridges, particularly applied to spread box-beam bridges. The approach involves reducing the superstructure of the bridge to an articulating system by adding joint lines between the slab and the beams. By contrasting the theoretical analysis with the findings of four distinct spread box-beam bridge field tests, the theoretical analysis is verified. The study reveals that integrating curbs and parapets with the slab changes load distribution, lessening the load on interior girders and boosting it on exterior ones versus systems lacking these elements. Furthermore, bridge span length significantly affects load distribution, whereas beam depth has a lesser impact. Live- load distribution factors, depicted as linear functions, are notably influenced by the number of designed traffic lanes. The research advocates for revising design provisions to include curbs and parapets' effects, potentially lowering distribution factors and cutting costs in superstructure construction.[12]Before 60’s only deck joint bridges were constructed. In the 1960s several continuous highway bridges were introduced in several states of the United States. The primary motivation behind adopting continuity with precast, pre-stressed girders is the elimination of maintenance costs associated with bridge deck joints and drainage onto the substructure. Moreover, continuity enhances the appearance and riding qualities of these bridges while offering structural economy and initial economic advantages by eliminating deck joint details. Achieving continuity involves design considerations for live load and impact moments, incorporating non- pre-stressed reinforcement in the deck slab and diaphragms over piers. Although the focus has been on bridges constructed with I-beams, the design principles apply equally well to bridges with different beam shapes. Designers have the flexibility to adjust span layouts to achieve uniform pre- stressing reinforcement distribution or to address positive moments induced over piers, which arise from creep in pre-stressed girders and live loads in distant spans. Creep-induced deformations and restraint moments depend on factors such as concrete mix properties, age at loading, and volume- to-surface ratio of pre-stressed members. While laboratory testing can provide accurate creep data, available research data are often sufficient for design purposes. Adjustment of ultimate creep values and consideration of reinforcement effects on creep are essential in design analysis. Elastic analysis methods are employed to evaluate creep effects under pre-stress and dead load conditions, facilitating the calculation of adjusted moments to account for creep-induced strains in continuous bridge designs.[13] Gurdial Chadha and Konstaniin Ketchek in 1972 conducted a research on computerized analysis and design using the cantilever method of the construction. The Cantilever Method offers simplicity and economy, especially when applied to bridges with equal spans or those with different span lengths. Temporary towers may be employed to support construction over piers or sections with unequal spans. The computer program described provides comprehensive analysis for pre-stressed concrete bridges, calculating pre-stressing forces and reinforcement needs due to various acting forces like dead loads, secondary forces, and live loads. It evaluates fiber-stresses caused by both horizontal and vertical loads, including the force of centrifugal and wind. The program operates on an IBM 1130 computer and aids in designing the bridge to withstand superimposed dead loads and live loads. To address shear concerns, the program incorporates diagonal pre-stressing bars within solid webs to minimize their width and reduce dead weight, a critical aspect for large-span bridge design. It computes horizontal and torsional shear stresses at desired sections along the girder and determines principle stresses at flange-web junctions. Additionally, the program determines spacing requirements for diagonal pre-stressed reinforcement. Furthermore, it determines the ultimate flexural strength by using the 1969 AASHO requirements and the associated amount of pre-stressed reinforcing that is required. The workings of the algorithm are outlined in a flow chart, providing a systematic approach to pre- stressed concrete bridge design and analysis.[14]

In 1974, SIMPLA2, a computer-based program, was used for analyzing of a precast pre-stressed box girder bridge. Here, the object of this study was to show an analysis method and related computer-based program to enable effective analysis of segmental pre-stressed concrete box girders with constant depth throughout the whole erection process. SIMPLA2 enables designers to model the erection process within the computer, providing insights into the structural response at each step while applicable to a wide range of restraint and loading conditions such as elastic limits, diaphragms, and allows for various pre-stressing tendon profiles and stressing options. The program was successfully used by the Texas Highway Department when designing the Corpus Christi, Texas, Intracoastal Canal Bridge—the country's first segmentally constructed precast box girder bridge. Here the analysis had been done using finite segment method. SIMPLA2 facilitated checking of the final design at all erection stages and aided in assessing the feasibility of suggested tendon layout changes. Specific conclusions from example problems demonstrate that The reaction of segmentally designed, pre-stressed box girders is effectively predicted using SIMPLA2. While several irregularities in the stress were observed, they were generally insignificant except in the vicinity of anchorages. The program proved effective in practical design scenarios, such as determining tendon layout and balancing dead loads during erection sequences.[15] Y.C. Loo and A.R. Cusens employed the finite-strip procedure for analyzing the box structures, particularly for bending and in the plane stress analysis in analyzing the box structures, particularly for bending and in-plane stress analysis. This method utilizes polynomial functions and harmonic functions both in one direction in the orthogonal respectively to represent the displacement field. By solving for the undetermined coefficients in these functions, the method satisfies support conditions and allows for accurate structural analysis. To enhance the finite strip procedure’s accuracy, higher- order

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displacement functions have been developed. Two approaches the auxiliary nodal line method, and the additional boundary compatibility technique, have been introduced to accommodate higher-order analyses. These approaches improve the accuracy of the method while maintaining computational efficiency. A computer program, FISBOB, has been developed derived from the finite strip method, incorporating direct approach for force-matrix formulation and a flexibility scheme for indeterminate structures. It has been utilized for both research and practical applications, demonstrating its effectiveness in various scenarios. This program facilitates efficient structural analysis, including the analysis of pre-stressing forces and the solution of redundant forces in multi-span bridges with various support conditions. The analysis conducted using the finite strip program FISBOB encompasses several bridge structures, each serving as a case study to demonstrate the program's capabilities. Here are some of the bridges mentioned in the analysis:

- Perspex Bridge Model: A six-cell Perspex bridge model with a simply-supported span of 1830 mm., subjected to concentrated loads at different positions. This model was utilized to analyze deflection and longitudinal in-plane stress.
- Beam using Asbestos-Cement and the Model of Slab Bridge: 750 mm simply-supported slab bridge model and asbestos cement beam on a modest size intended to simulate the performance of a spine beam bridge structure's deck. The local plate bending moments were investigated with this model.
- Multi-beam Bridge Models: Three quarter-scale multi-beam bridge models, with precast pre- stressed box-type beams linked transversely. These models were evaluated to investigate load distribution properties, including the impacts of transverse joint rigidity and transversal local plate moment caused by certain loading circumstances.
- Reinforced-Concrete Voided Slab Bridge Design Model: A quarter scaled reinforced-concrete voided slab bridge design model, subjected to static and cyclic loading tests. This model was used to assess changes in longitudinal flexural rigidity and load distribution characteristics due to cracking induced by repeated loading.
- **Queen's Drive Viaduct**: A 7-span spine box girder bridge developed for the Lancashire- Yorkshire motorway M62. This bridge was analyzed to predict internal stresses under various loading conditions and to assess The impacts of various pre-stressed forces throughout the construction process.

Each bridge model serves as a unique testbed for evaluating the performance and behavior of different structural configurations under specific loading scenarios, providing valuable insights for engineering design and analysis.[16] In 1985, a study was done comparing the application among three computer programs MUPDI4, CURDI4, and CELL4MUPDI4 analyzes straight prismatic in- shape bridges using the folded plate elasticity approach, CURDI4 evaluates circularly curved prismatic in-shape bridges employing the finite strip methodology, and CELL4 analyzes bridges with arbitrary plan the geometry but constant depth using the finite element technique. These software programs allow for extensive linear elastic evaluations of an extensive variety of pre-stressed concrete box bridges in a timely and precise way, with a limited number of simplified assumptions. For simply supported straight singular cell bridges having sloping or vertical outer webs, MUPDI4 and CELL4 yield satisfactory results, particularly in displacement, longitudinal stresses, and section moments and shears. Similarly, for two-span straight four-cell bridges with vertical exterior webs, these programs offer a comprehensive understanding of the bridge's behavior under load. However, challenges arise in estimating friction losses, especially in curved bridges, leading to discrepancies between analytical and experimental results, particularly in longitudinal stresses and transverse stresses in the webs and bottom slab. Nevertheless, these programs provide valuable insights into the behavior of complex bridge structures, including circularly curved single-cell and four-cell bridges. For three-span multi-cell bridges of arbitrary plan geometry, the CELL4 program proves useful in evaluating longitudinal and transverse distributions of displacement, reactions, internal forces, moments, and stresses. While automatic pre-stressing options and other features enhance the capabilities of these programs for detailed linear elastic analyses, careful modeling and interpretation of results are essential. Overall, the programs offer a powerful tool for studying load distribution and performing static checks, enabling analysis of bridge structures that were previously challenging. The automatic integration of the element forces option facilitates static checks and enhances the understanding of load distribution within the bridge. However, attention to detail and adherence to modeling guidelines are crucial for accurate interpretation of results. [17]. In 1987 Omar Ferdjani researched aiming to elucidate both the static and dynamic behavior of a medium-span simply-supported singular cell pre-stressed concrete box bridge. The static analysis focused on investigating the bridge's strength and deformational characteristics under truck loading until structural failure occurred. In the dynamic phase, the study examined how cracking and inelasticity of concrete affected dynamic features of the mentioned structure. Experiments were carried out using a 1/10 scale detailed model of the mentioned bridge. the analytical analysis had been performed by applying the finite element method, utilizing both nonlinear programs from Carleton University and the SAP IV program in a quasi-nonlinear format. The results of the analytical study closely aligned with experimental findings. Notably, a significant reduction in the bridge's flexural stiffness was observed due to crack propagation in the webs, leading to decreased natural frequency of vibration and increased damping coefficient as the crack expanded. The study showed Finite Element Analysis (FEA) proves effective for studying the behavior of reinforced and pre-stressed box girder bridges across linear and nonlinear ranges. However, accurate input parameters accounting for concrete properties and external factors like creep and temperature variations are crucial. Quasi-nonlinear FEA is a cost-effective method for analyzing box section structures in the nonlinear range. However, precise incorporation of cracking patterns and widths is essential for accurate simulation. The studied model displayed significant

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stiffness, behaving linearly up to a load equivalent to the design load. Pre-stressed concrete box girder bridges exhibit higher ultimate capacities than simple beam theory predicts, making them suitable for medium-span bridges due to advantages like limited dead load, small deflections, and good load distribution. Cracking significantly impacts the dynamic characteristics of box girder bridges. As cracking progresses, the natural frequency decreases while the damping coefficient increases substantially, indicating altered structural behavior. While simple beam theory underestimates the ultimate capacity of pre-stressed concrete box girder bridges, it suffices for preliminary design purposes. Proper detailing of shear connectors between webs and the top slab is crucial, as observed from the failure mode of the bridge. [18] In 1988, Amar Khaled conducted research on both the dynamic and static characteristics of a medium-span, simply supported, two-cellular pre-stressed concrete box bridge. This study gives information on the functioning of pre-stressed concrete box bridges in varied loading circumstances, emphasizing on the importance of considering cracking and inelasticity effects in structural analysis and design.

Experimental tests were conducted on the $\frac{1}{7.00}$ scaled model of the bridge, and analytical analysis was performed using the finite element method with two different programs: NONLACS and SAP.

The study reveals that as the load that is applied increases, both flexural stiffness and torsional stiffness of the bridge decrease due to crack formation and concrete inelasticity. Despite significant damage, the bridge's natural frequency of vibration only decreased by 23%, while the damping coefficient increased by approximately 250%. The analytical results obtained using the NONLACS program showed excellent agreement with experimental findings, indicating its effectiveness in predicting the bridge's behavior up to failure. For intricate structural investigations like the box girder bridge, the NONLACS nonlinear finite element program is recommended. It accurately predicts nonlinear responses until failure, potentially serving as an alternative to physical testing for complex structures. SAP IV accurately predicted bridge behavior, emphasizing the importance of accurate cracking pattern data for precise simulation. Additionally, the quasi- nonlinear analysis, incorporating information about crack patterns and widths, provided reasonably accurate predictions of the bridge's behavior. The bridge exhibited linear behavior up to around double the service load, with minimal signs of cracking. At service load, the deflection was remarkably small, approximately $\frac{1}{4400}$ of the span length at mid-span. The bridge's load capacity significantly exceeded predictions by conventional ultimate strength theory, indicating conservative design practices. It sustained an ultimate load approximately 3.5 times that calculated by the Ontario Highway Bridge Design Code, failing as expected due to flexure. Torsional stiffness declined as cracking propagated, with pre-stressing steel experiencing high stress upon crack opening, leading to a 50% loss in torsional stiffness. Computed first natural frequencies of vibration closely matched physical model observations at various damage levels. While natural frequency decreased slightly with initial cracks, it decreased by only 23% near failure. The damping ratio initially measured 2.20% for the un-cracked bridge, rising to 7.64% when severely damaged. These ratios aligned well with values proposed by Newmark and Hall, indicating consistent behavior. [19]

Later, A. F. E. Moreno, and A. Fafitis used GIU programming language for a better implementation of the finite element methodology formulation of the box bridge. In the finite element technique, Large-order models using finite elements are required for detailed analysis, as well as high computational and data-management demands. Thus, an effective algorithm in a high- speed multiprocessor, led by the support of a modern high-level Parallel programming language that can efficiently execute on diverse systems may potentially provide the kind of deep analysis that was thought to be unfeasible at a fair cost. The outcome of this research is that GLU has the potential to give inexpensive performance computational power for the demanding requirements of finite element formulation in practical engineering problems. GLU has demonstrated successfully how it provides the benefits of ease of programming, in a highly architecture- independent environment. [20] The paper by Lounis, Z.Cohn, and M. Z. introduces a methodology for optimizing the preliminary design of precast pre-tensioned highway bridge girders through mathematical optimization techniques. It aims to improve cost-effectiveness for various span lengths, utilizing a three-step optimization process: girder shape, bridge deck, and pre-stressing optimization. By formulating the design problem as a nonlinear programming model, the study explores different objectives to achieve optimal bridge designs, proposing five new optimal girder sections for enhanced efficiency. The methodology considers constraints such as structural requirements and serviceability criteria while minimizing costs and material usage. Girder shape optimization investigates design objectives like minimizing superstructure cost and concrete area while maximizing section efficiency index. Results indicate a quasi-linear relationship between girder depth, span length, and spacing, with larger spacing leading to lighter superstructures. Active constraints include tensile and compressive stresses, with tensile stress at service being a key criterion for determining optimal pre-stressing force. The study proposes optimal precast girder sections and evaluates their cost-effectiveness compared to standard Canadian sections using Guyon’s efficiency index. Results demonstrate higher efficiency indices for proposed sections, indicating potential for more cost-effective bridge designs. Two design examples illustrate The effectiveness of new parts compared to standard ones, highlighting superior performance in material consumption and bridge efficiency indices. Overall, the study concludes that the proposed methodology facilitates the calculation of ideal girder shape and efficient bridge designs, offering insights about structural effectiveness and affordability. The developed computer program facilitates the generation of optimal designs and allows for sensitivity analysis, making it applicable across different design scenarios and bridge configurations.[21]

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M. Rosignoli, DrIng in his paper discusses the benefits of pre-stressed composite structures in bridge design, focusing on pre-stressed concrete box girders using plates of steel webs and concrete slabs. It highlights the importance of reducing dead load to enhance structural efficiency and reserve capacity for live loads, proposing a measure of cross-sectional efficiency based on the moment of inertia relative to material consumption. The study emphasizes pre-stressing as a key factor in optimizing cross-sectional efficiency, preventing edge decompression, and minimizing pre-stressing force. It contrasts the efficiencies of concrete and steel, noting steel's superiority in tensile efficiency but reduced compressive efficiency due to instability. Pre-stressed composite sections (PCS) are introduced as a solution, combining outward pre-stressing, plates of steel webs, and reinforced concrete slabs to improve efficiency and reduce costs. Folded-plate pre-stressed composite sections., utilizing mechanically folded plates made of steel for webs, were highlighted for their enhanced structural efficiency and practical benefits. The folding of steel plates reduces web deformation under shear forces, optimizing the cross-sectional efficiency. The concrete slabs resist axial loads, while orthogonal forces transfer shear forces, necessitating additional connectors and reinforcement in tension zones. Eccentric loads induce distortion Given the weaker transversal flexural strength of webs made of steel, concrete slabs are mostly resistant to in-plane bending. This necessitates careful reinforcement design and the use of steel bracing or diaphragms to limit distortion. Unlike stiffened-plate PCS, folded-plate PCS exhibit distinct buckling modes due to the depth and spacing of folds. The critical tangential stress evolves, and safety factors should be prudently high to accommodate post-critical behavior. Several bridge projects, such as those in Cognac, Charolles, Japan, and the Corniche Viaduct, demonstrate the practical application of folded-plate PCS. Incremental launching and segmental pre-casting methods are particularly suitable for these structures. Statistical studies comparing The structural effectiveness of folded plates pre-stressed composite sections with traditional box girders show an average increase of approximately 22%, with greater improvements observed for longer spans. The efficiency enhancement, approximately 15% for a 30-meter span and 27% for a 70-meter span underscores the potential for better performance in bridge construction. This improved efficiency opens new perspectives, with cost considerations showing The more expensive price of steel webs is offset by cheaper costs for concrete, reinforcing, and pre-stressing. Techniques for construction, adapted to specific requirements, mitigate risks associated with inexperience. Folded-plate pre-stressed composite sections are ideal for segmented pre-casting, incremental beginning, and cantilevering operations. Their adaptability includes fluctuating depth bridges and cable-stayed bridge types offering promising avenues for efficient and cost-effective bridge construction.[22] In 2004, a research investigated strains in 2 post-tensioned, pre-stressed concrete (PSC) box girder bridges during building and operation. Focusing on the Cogan and Grangetown Viaducts, part of the A4232 Road project, the study analyzes precast, post-tensioned concrete structures using a balanced cantilever technique. Instrumentation installed during construction allows monitoring of early shrinkage and creep. Vibrating wire strain gauges, selected for durability, provide data on strain development, with less than 5% proving unreliable after 16 years. Material properties, including concrete strength and composition, are crucial for predicting long-term behavior. Despite slight discrepancies in measured and design values, the study achieves satisfactory predictions using established models like the CEB-FIP Model Code. Results show variable shrinkage behavior between viaducts due to environmental conditions during construction. Curing's impact on long- term shrinkage performance is emphasized, with thorough curing essential for effective shrinkage accommodation. The analysis compares viaduct behavior with predictions, considering material properties, construction sequence, and loading. A computer program facilitates analysis, predicting stress-strain relationships and confirming compression stresses are generally higher but within design limits. The study concludes that monitoring combined with sophisticated analysis validates design code assumptions, providing reassurance to designers and scope for model refinement. Ongoing research aims to assess existing models and investigate environmental factors' influence, extending the study's value beyond data assembly.[23] Charles D. Newhouse in 2005 did a study that investigated the benefits and techniques of establishing continuity in precast, pre-stressed multi-girder bridges through continuity diaphragms. It acknowledges advantages such as reduced deflections, improved durability, and reserve load capacity, established since the late 1950s. Despite consensus on these benefits, variations exist in design methods and continuity connection details, prompting experimental and analytical research at Virginia Tech. Initially, an analytical comparison of predicted restraint moments using different design methods was conducted across commonly used systems. This analysis informed the development details for three continuous connections for testing purposes. The study phase involved testing three separate continuous connections utilizing the full depth of PCBT girders interconnected with a 6-foot-wide slab. The connections consisted of extended pre-stressing strands and bending bars at the lowest part of the girders. The results revealed that both interconnections were adequately ultimate and cyclic loads, and resisted service, with the enlarged bars connection recommended for its stiffness during cyclic loading. Additionally, a further test used a system with merely a slab placed over the tops of the girders. Throughout service testing, primary cracks occurred above the end of the girders on the joint, and no noteworthy rise in damages was noted afterward. Analytical results indicated significant positive thermal restraint moments, comparable to actual positive cracking moment capacities. Experimental findings revealed early development of restraint moments because of the thermal expansion while curing and also revealed subsequent differential shrinkage, though the values were lower than predicted by conventional analyses. Overall, the study aims to enhance knowledge regarding the behavior of precast and its design, PSC girders with casted in place slabs formed continuously, offering insights into effective continuity connection methods. The research addresses the complexity of predicting the behavior of

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composite girder-slab systems, emphasizing the importance of accurately assessing restraint moments and understanding the factors influencing different design methods. Through analytical and experimental investigations, the study provides valuable contributions to bridge design practices, facilitating informed decision- making in the construction of multi-girder bridges.[24] The research conducted by Franklin B. Angomas in 2009 focused on monitoring high-performance concrete's losses due to pre-stress in (HPC) bridge girders. The study compared measured losses with predictions from four methods of AASHTO: LRFD 2004 guideline, LRFD 2004 Refined guideline, LRFD 2007 guideline, and Lump Sum methodology. It also evaluated the method of camber prediction, including the NCHRP Report-496, PCI multiplier methodology, and Improved PCI Multiplier methodology. Girders selected from Bridge 669 near Farmington, Utah, were studied, comprising spans of 132.2, 108.5, and 82.2 feet. Monitoring occurred over three years, with fifteen girders fabricated, ten exterior spans (80 ft.) and the number of middle span is five (137 feet). The AASHTO LRFD 2004 Refined Method showed better performance in predicting loss due to pre-stress for both girder lengths, with the Lump Sum method precisely predicting loss due to pre-stress in long-term for 132-foot-long girders. Concrete characteristics: modulus of elasticity, compressive strength, as well as shrinkage, were extensively tested following ASTM standards. Freeze-thaw and chloride ion penetration tests indicated good durability across all samples. Pre-stress loss was monitored using vibrating wire strain gauges, and deflection was tracked over time using LVDTs and surveyor's levels. In conclusion, the research emphasizes the importance of accurate prediction methods for pre-stress loss and deflections in HPC girders, particularly in bridge construction. It suggests further research, particularly for short span girders, to improve prediction techniques involving both pre-stress loss & deflection models.[25] Cho et al. studied on the construction process and design of PSC box girders for the Incheon Bridge in Korea, specifically highlighting the innovative use of the Full Span Launching Method (FSLM). The viaduct spans 8,400 meters and consists of five continuous spans, each utilizing 336 PSC box-girder elements. These elements, measuring 15.7- meter-wide, 50-meter-long, and 3-meter-high, were pre-tensioned & pre-stressed at a specialized casting factory before being transported and erected using the FSLM. Key design considerations include the application of longitudinal and transverse pre-tensioning methods to reduce fabrication time and construction costs. Additionally, techniques such as holding-down equipment and additional rebar placement were employed to mitigate negative moments at support points and enhance resistance against diagonal cracks. Structural analysis utilized both 3D plate analysis and 2D frame analysis to ensure accurate results, particularly for the bottom slab where significant differences were observed. Special attention was paid to reinforcement around large openings in the girders, with reinforcement design based on 3D FEM analysis. During construction, emphasis was placed on minimizing the self-weight of carriers and girders to optimize efficiency. Lifting methods were carefully selected to ensure safety and constructability, with considerations for the reuse of lifting bars and reinforcement around buried bars. Quality control measures included fabrication in a controlled environment, the use of specified rebar sizes, and adherence to concrete strength requirements. Steam curing was applied to expedite strength development, and construction progress was carefully planned to account for space limitations and weather conditions. Transportation of girder elements involved specialized equipment and procedures due to their size and weight. The installation utilized a combination of carrier, launching girder, and under-bridge equipment, with careful attention to achieving continuous superstructure and proper load transmission. Overall, the study provides valuable insights into the construction processes and design for PSC box girders using the FSLM method, offering a reference for future bridge projects employing similar techniques.[26] Ali Fadhil Naser, and Zonglin Wan did a study focusing on the strengthening process and operational evaluation of the Fu Feng Highway PSC bridge in a city of China called Changchun. The bridge, constructed in 1997, has experienced mid-span deflection and cracks in its box girders, prompting the need for structural strengthening. The strengthening process involves three stages:

- Strengthening the floor of the box girder: ten centimeters of reinforced concrete is poured in regions with positive bending moments in the middle of the span and also the edge span.
- Strengthening the web of the box girder: plates made of steel are attached to the inside of the box girders to enhance their strength.
- Strengthening of piers 'transverse beams: Carbon-fiber sheets are Applied to strengthen the transverse beams of specified piers.

To evaluate the bridge's performance, a static load test is conducted. This test measures strain, stress, and deflection at various sections of the bridge. The measured stress values indicate a certain strength reserve within acceptable standards. However, the measured deflection values reveal a stiffness deficiency, with ratios exceeding the allowable limit. Consequently, the study recommends further strengthening of the bridge structural members using alternative technical methods and materials to improve stiffness. The analysis method involves identifying damaged structural members, implementing strengthening measures, conducting static load tests, and comparing measured values with theoretical predictions to assess structural integrity and stiffness. These findings contribute to recommendations for enhancing the bridge's performance and ensuring its long-term structural reliability. [6] The research paper of Qing-Jie Wen outlines a methodological approach for assessing the impacts of creep and shrinkage in pre-stressed concrete box girder bridges following Increasing the scope of projects. By incorporating progressive principles and energy considerations, the method aims to enhance prediction accuracy by accounting for the continuous stress changes induced by shrinkage in concrete fluctuations in Young's modulus with time. Additionally, it addresses the creep effects resulting from constrained shrinkage stress. One notable aspect of the method is its incremental approach, which allows for the consideration of stress increments due to shrinkage and creep over successive time intervals post-widening. This enables a more detailed analysis of stress variation, particularly crucial in the early stages after widening when stress redistribution is most pronounced. Furthermore, the method incorporates creep analysis by establishing a linear relationship between creep and stress, assuming its applicability as long as concrete stress levels remain below 50% of ultimate strength. By incorporating creep effects Throughout every single interval, the approach captures the continuous variation of stress caused by shrinkage. Equations are provided to calculate total strains resulting from shrinkage and variable stress, taking into account factors such as creep coefficient, Young's modulus of concrete, and Stress owing to differential shrinking between new and old bridges. Virtual work principles and finite element methods are employed to derive fixed end forces on concrete components caused by creep facilitating the determination of displacements and internal forces. A calculating program is compiled based on the proposed method, enabling validation through practical tests and offering recommendations for bridge-widening projects. The method thus presents a comprehensive approach to assessing the long-term effects of bridge widening, with a particular emphasis on shrinkage and creep factors. Overall, this methodological approach holds promise for improving the accuracy of predictions and ensuring the driving and integrity convenience of expanded bridges. Its incorporation of advanced analytical techniques and consideration of key influencing factors aligns with contemporary research in structural engineering and materials science. [27] In 2012, Naresh Dixit researched the essential aspects of bridge construction with a focus on pre-stressed concrete (PSC) bridges and deep foundation systems commonly used in civil engineering. It emphasizes the structural advantages of PSC over reinforced concrete (RC), highlighting the active combination of high-strength materials to improve the behavior of the structure and facilitate the construction of bridges with long spans. Various methods of pre-stressing concrete are described, including pre-tensioning, bonded post-tensioning, and un-bonded post-tensioning, each offering unique benefits in terms of construction efficiency and structural performance. Furthermore, the research provides detailed insights into stress analysis in PSC sections, considering factors such as pre-stressing force, bending moment, and material properties, crucial for ensuring structural integrity under different loading conditions. Design considerations for end zones in post-tensioned members are also discussed, emphasizing the importance of proper reinforcement to withstand high stresses and prevent structural failure. Additionally, it covers various deep foundation systems, including pile foundations, monopile foundations, drilled piles, and others, outlining their advantages and applications based on site conditions and project requirements. It underscores the significance of understanding these foundation options for selecting the most suitable system to ensure structural stability, durability, and cost-effectiveness in bridge construction projects. Overall, the paper provides a comprehensive overview of modern bridge construction techniques, emphasizing advanced engineering practices and material technologies essential for developing safe, durable, and efficient bridge infrastructure.[28] Miss.P.R. Bhivgade in her paper presented an analytical and design-based study of PSC box bridges, focusing on their structural behavior and design considerations. Pre-stressed concrete offers advantages for medium to long-span bridge construction, reducing maintenance costs compared to steel structures. The study evaluates a PSC box bridge with two lanes, considering Indian Road Congress (IRC) recommendations and relevant standards. Loading situations with IRC Class A include superimposed dead load, live load, and dead load, loading adopted for the analysis. The web's thickness and flanges is determined based on specifications, ensuring structural integrity and safety. Pre-stress losses and ultimate strength calculations are used to evaluate the operation of the bridge under various loading conditions. Using SAP 2000 14 Bridge Wizard, the analysis incorporates factors like pre-stress force, eccentricity, deflection, bending moment, and shear force. Results demonstrate compliance with design criteria, ensuring structural stability and serviceability. The study also validates the results through comparison with established standards and theoretical calculations. The study emphasizes the importance of proportioning concrete box girders to meet design requirements, highlighting The advantages of box bridges structurally, especially in resisting torsion. Different span-to-depth ratios are evaluated, showing that increasing depth leads to decreased pre-stress force and cable requirements while enhancing structural strength and serviceability. Overall, the paper provides fundamental principles for designing concrete box bridges, aiding engineers in the initial stages of bridge projects, and ensuring compliance with safety and performance standards.[29] In 2014, Elbadry, Mamdouh, Ghali, Amin, Gayed, and Ramez B. addressed the challenge of predicting and controlling long-term deflection in pre-stressed concrete bridges, particularly focusing on the phenomenon of creep in concrete. It highlights the discrepancy between existing prediction models, which typically extend up to 30 years, and the observed behavior of bridges, where deflection continues to increase over decades. The Bazant Baweja Model B3, unlike other models, predicts an indefinite linear rise in creep along with the logarithm of time and has been found to match observed deflection trends in long-span bridges closely**.** The paper proposes the adoption of Model B3 for predicting creep in combination with appropriate pre-stressing techniques to ensure satisfactory serviceability over an extended lifespan of 125 years. It emphasizes the importance of considering time-dependent material properties, such as concrete creep and pre-stressed steel relaxation in bridge analysis and design. The interdependence of these factors necessitates simultaneous consideration in structural analysis to ensure compatibility and equilibrium. Furthermore, the paper outlines a step-by-step analysis approach for predicting loss due to pre-stress and long-term deflection, considering factors such as concrete's shrinkage and pre-stressed steel relaxation. Design examples demonstrate how pre- stressing can be tailored to limit deflection within specified limits throughout the bridge's lifespan. The proposed design approach acknowledges the significance of non-pre-stressed steel and the shear-lag effect in mitigating excessive

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deflection, particularly in precast segmental construction. It also discusses the potential increase in pre-stressing costs associated with ensuring long-term sustainability, suggesting that the expense is justified for the sake of structural integrity. Overall, the paper contributes to the understanding of the long-term performance of PSC bridges and provides practical recommendations for designing structures that meet serviceability requirements over extended lifespans. [30] The study of Vishal et al focuses on the design & analysis of PSC girder bridges under IRC class 70 R loading conditions. The objectives include formulating the problem for multiple spans to determine the bending moment and shear force on the beams, using STAAD PRO for design and analysis, and conducting parametric analyses for pre-stressed concrete I and box girders. The study aims to validate the software by matching the outcomes with the traditional theory and calculating concrete and steel quantities based on the analysis & design outcomes. Pre-stressed concrete involves introducing internal stresses to counteract external loads, typically achieved by tensioning steel reinforcement. The function of pre-stressing is to induce compression in areas where loading creates tensile stress, thereby enhancing here the apparent tensile strength of concrete. The study illustrates how pre-stressing can prevent tension cracks and optimize material usage in bridge construction. For the design of pre-stressed concrete which was post-tensioned, permissible stresses for an I-beam slab bridge deck are evaluated based on IRC guidelines for concrete and steel grades. The design process includes determining bending moments for dead and live loads, as well as calculating total dead load and live load for various vehicle classes. A detailed literature survey informed the decision to use STAAD PRO software for analysis and design. Validation of the software's results for an I girder problem showed good agreement with analytical results. Subsequently, analysis and design were conducted for both I and box girders, with a comparative study revealing that box girders are costlier but may result in fewer losses compared to I girders. Overall, the study provides insights into the design & analysis of PSC girder bridges, demonstrating the usage of software-based tools for efficient and accurate structural engineering solutions. [31] Zuanfeng Pan and Fangchen You discussed a methodological approach to tackle excessive deflections in PSC box bridges with long-span, a common issue stemming from uncertainties in concrete properties like creeping, shrinking, and loss due to pre- stress. It proposes utilizing supplementary pre-stressing tendon, strategically tensioned over the service life of the bridge based on deflection monitoring. Initially, an uncertainty analysis is conducted employing the Latin hypercube sampling approach, analyzing for a long-time deformation at the middle span of the bridge. This analysis yields the 95 percent confidence range of mid-span distortion, which serves as the foundation for the future design of backup tendons. A quantitative approach is then employed, focusing on the discrepancy around the lower limitation and mean values of the deformation's confidence range. It evaluates various arrangements of backup tendons, identifying together the external tendons along with the girder are the most efficient for deflection management. Additionally, it addresses the limitations of current prediction models for creep and shrinkage, suggesting a modified model for enhanced accuracy. In summary, the study presents a holistic strategy to mitigate excessive deflections in long-span PSC box bridges, emphasizing the integration of uncertainty analysis, quantitative tendon design, and evaluation of arrangement schemes. It underscores the imperative of considering uncertainties in design to ensure the long-term functionality of such bridges. [32] Yu et al. did a comprehensive study aimed at understanding the local effect result of vehicles on PSC box-girder bridges, specifically the dynamic impact factor (IM) for bridge deck slabs. The research addresses an important notable gap in previous studies, which predominantly concentrated on global responses of bridge components while neglecting the specific impact on deck slabs. Using numerical simulations with a bridge-vehicle coupled model, the study investigates the dynamic responses of five standard box bridges along with different lengths of span. Parameters such as the surface condition of the road, the span length of the bridge, and vehicle speed are systematically examined to determine their influence on the IM. The analysis involves evaluating responses at specific locations on the bridge, considering both transverse bending moments and strains. Key findings highlight a distinct difference between global and local responses, with local IMs significantly affected by road surface conditions and bridge span length. Moreover, the study questions the traditional derivation of IMs from global responses and proposes the concept of local IMs tailored to deck slab dynamics for more accurate bridge designs. The paper provides detailed insights into dynamic response analyses of Bridge 3 under average road surface conditions and Load Case 2, demonstrating the dominance of different vibration modes in global and local responses. Additionally, a dynamic impact analysis explores the relationship between various parameters and the IM, revealing irregular variations in the relationship between vehicle speed and IM and linear trends between bridge span length and local IM. [33] The research conducted by Zhao et al. focuses on the practical and simulation investigation of PSC continuous box bridges, particularly examining their stress conditions and deformation behavior. Pre-stressed concrete box girders are chosen for their favorable static and dynamic properties, making them suitable for high-speed railway bridges. The study utilizes ANSYS software to construct spatial finite element models of PSC single-box, singular-chamber, and same-height continuous box girders in the program. The analysis involves assessing the general stress circumstances affect and deformation of the box girder under pre-stress, along with a specific focus on key cross-sections.

➢ *Key Findings from the Research Include:*

- Stress Analysis: The stress distribution in the box girder shows that the lower part experiences compression while the upper part is stretched, maintaining a relatively uniform stress state across the girder. Stress concentrations are observed at the support ends and anchoring sites of pre- stressing reinforcement.
- Deformation Analysis: The overall deformation of the box girder exhibits a certain degree of reverse bulging

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because of the impact of reinforcement in pre-stressing. The pre-stress applied to the girder counteracts tensile stresses induced by external loads, preventing concrete cracking.

- Control Cross-Section Analysis: Control cross-sections, including the supporting cross-section rooftop, one-fourth of the span web, and the mid-span cross-section of the bottom are chosen for in-depth stress study.

Stress concentrations are observed at stretching points of reinforcement, indicating areas of potential concern.

The study provides valuable insights into the deformation and stress response of pre-stressed concrete box bridges under pre-stress, offering technical support for stress-strain sensor arrangement in bridge monitoring systems. However, it's important to note that the equivalent load method used in the analysis may have limitations in accurately capturing the distribution and orientation of pre-stress, potentially affecting the simulation results. In summation, the research contributes to enhancing the understanding of PSC box girder behavior, which is crucial because ensuring the structural integrity and safety of bridge infrastructure. Further studies could explore alternative modeling approaches to improve the accuracy of stress and deformation predictions in such bridge systems.[34] The research conducted by Gang Zhang and colleagues addresses a critical gap in the literature by investigating the response of PSC box girders of bridges amid hydrocarbon fire circumstances. These girders, widely used in bridge construction for their advantages, face significant vulnerability to fire damage, as evidenced by past incidents like the Borui Yanjiang bridge in China and The river bridge in the U. S. named Bill Williams. To address this gap, the study develops a numerical model using ANSYS software to predict the behavior of PSC box bridge's girders exposed to hydrocarbon fire. The methodology involves three stages: calculating fire temperature, assessing cross-sectional thermal gradients, and determining mechanical performance in box girders. This approach accounts for factors like transient temperature fields, heat transfer, and deformation responses. Concrete and pre-stressing strands are incorporated into the finite element model, considering their respective material properties and responses to elevated temperatures. Through a case study, the research demonstrates the application of the numerical model in testing the fire resilience of pre-stressed concrete box girders, particularly highlighting the significant influence of different pre-stress degrees on their fire resistance. The study's findings offer valuable insights into the fire performance of pre-stressed concrete box bridge's girders and provide a methodology for assessing their fire resistance. This contributes to the understanding of structural performance under extreme conditions and may inform design and safety measures for bridge infrastructure.[35] The study conducted by Mustafa Batikha et al investigates the influence of the length of the bridge's span and also the girder type on bridge investment and life cycle expenses. Bridges play a crucial role in facilitating transportation and impacting economic growth, making their design and construction an essential aspect of civil engineering studies. The research focuses on the following kinds of girders: both post-tensioned and pre-tensioned pre-stressed concrete, and steel composite, and evaluates their cost implications across five span lengths: 20, 25, 30, 35, and 40 meters. Using structural analysis techniques, the study assesses the geometry, material properties, and loading conditions for different simple-span bridges. The analysis incorporates factors such as live loads, concrete strength, steel reinforcement properties, and pre-stressing materials to estimate the ultimate internal forces and capacity of each bridge section. Method of finite-element utilization to assess the structural response and ensure the adequacy of the selected girder configurations for various span lengths. The cost analysis comprises two aspects: initial capital expenses and 50 years' lifespan costs, including upkeep expenses. Material quantities are calculated based on the structural design, and average rates from previous projects are used to estimate the cost of materials and construction. The study presents bar-chart figures illustrating the total capital costs and life cycle costs for different girder types and span lengths. The findings reveal that while steel composite girders may offer lower initial capital costs for shorter spans (20-30 meters), pre-stressed concrete girders demonstrate lower life cycle costs over 50 years, especially for longer spans (35-40 meters). Maintenance considerations significantly impact the life cycle costs, with pre-stressed concrete girders showing a cost advantage due to their durability and reduced maintenance requirements over time. The study concludes that the choice of girder type and span length significantly influences the overall cost of bridge construction and maintenance. Pre-stressed concrete girders emerge as a cost-effective solution, particularly for longer spans, offering potential savings of up to 45% compared to steel composite girders over a 50-year life cycle. These findings provide valuable insights for decision- makers and designers in selecting the optimal girder type and span length for bridge construction projects, considering both initial capital outlay and long-term maintenance costs. [1] The study conducted by Haidong et al focuses on enhancing the preciseness of numerical modeling in assessing the long-lasting performance of PSC box girder bridges, with a specific focus on a Bridge in China named the Jiang Jin. These bridges, commonly used for spans ranging from 100 to 300 meters, have encountered challenges such as excessive vertical deflections and cracking, impacting their safety and serviceability. The research identifies shortcomings in existing modeling approaches, particularly in the Chinese standard, which inadequately predicts long-term deformations. To address this, the study proposes a model-updating approach calibrated against data obtained from operational bridges. Key components of the research include the establishment of A 3-D finite element model describing the performance of box girder portions over time, parametric investigation to discover influential factors, and the use of genetic algorithm optimization to predict realistic levels of shrinkage, creep, and loss because of pre-stress. This study underscores the critical role of accurate modeling in structural assessments and decision- making regarding repair and strengthening strategies. By aligning modeling results with historical data, the proposed approach aims to enable more precise bridge assessments, leading to safer

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strengthening interventions and cost-effective maintenance plans. In-depth structural inspections and analysis of real internal force conditions contribute to a comprehensive understanding of bridge behavior, facilitating informed decision-making for structural improvements. The study emphasizes the necessity of sophisticated modeling techniques, such as three-dimensional finite- element modeling, to capture the complex behavior of box girder bridges with larger spans accurately. Additionally, it highlights the need for more advanced creep and shrinkage to predict long-term deformations and performance better. The research provides valuable insights into increasing the precision of numerical modeling for assessing the overtime behavior of pre-stressed concrete box girder bridges, ultimately enhancing their safety, serviceability, and economical maintenance planning.[36] The research by Viqar Nazir and Mr. Sameer Malhotra in 2019 explores the analysis &design of PSC bridges using the Morice Little method, with a particular focus on the application of CSiBridge software for analysis. The Morice-Little method divides the width in effect of girders divided into parts to calculate loadings and deflections, providing insight into the behavior of pre-stressed girder elements. The study outlines the manual design process based on this method, followed by analysis using CSiBridge software. The paper highlights the importance of computer applications like CSiBridge in facilitating bridge design, construction, and maintenance. CSiBridge, developed by Computers and Structures Inc., offers features like analysis of both static and dynamic, drift control, and energy methods, making it a valuable tool for bridge engineers. The study compares results obtained from manual calculations with those from CSiBridge software, demonstrating the effectiveness of software analysis in providing detailed insights into bridge behavior under different loads. The research methodology involves designing and analyzing an 18-meter concrete bridge according to IRC guidelines and then performing analysis using CSiBridge software. Results from manual calculations and software analysis are compared, revealing differences in forces, moments, and stress distributions. While the software provides more detailed analysis and graphical representations, it may lead to higher values of reactions and forces, potentially affecting the economy of the structure. The study underscores the significance of software tools like CSiBridge in enhancing the efficiency and accuracy of bridge design and analysis processes. However, it also highlights the importance of balancing detailed analysis with considerations of structural economy.[37] The research conducted by Rao Jang Sher et al. compares the design method and analysis of between T-beam and box girder bridge superstructures through comprehensive research. This research seeks to identify the most suitable type of bridge superstructure by evaluating structural behavior, material optimization, and cost efficiency. Using SAP2000 software and manual design calculations, the researchers analyzed a 25-meter simply supported span for both types of bridge superstructures. They considered typical traffic loads outlined by AASHTO LRFD guideline provisions and conducted detailed manual design calculations for various components of the superstructure. The study employed Load and Resistance Factor Design (LRFD) methodology and compared box girder & T-beam girder bridges for both shear resistance and normal flexural, deflection for live and dead loads, optimal material usage, and economy. Results indicated that box girder bridges exhibited better structural stability & cost-effectiveness in comparison with T-beam girder bridges, also for smaller spans. Box girders showed higher torsional stiffness and strength, leading to better structural efficiency and stability. Additionally, box girder bridges required less pre-stressing steel and concrete yet more reinforcement with mild steel. This research highlighted the importance of considering both safety and economy in bridge design, with the superstructure significantly influencing overall bridge cost. Box girder bridges emerged as a better alternative concerning stability in structure and cost efficiency, challenging previous assumptions favoring T-beam girders for shorter spans. In conclusion, the study provides valuable insights into the comparative analytical and design method between T-beam and box girder bridge superstructures, emphasizing the significance of structural behavior and economic considerations in bridge engineering.[38] The research conducted by Hanwei Zhao et al. focuses on developing a data-driven technique for analyzing and forecasting premature cracking in PSC box girder bridges utilizing strain live-load information gathered by structural health monitoring (SHM) systems. This study addresses the challenge of quickly identifying cracking in concrete bridges, which can be caused by factors such as during operation, pre-stress relaxes, corrodes, and deflection. The methodology involves three main steps. First, the researchers extract features from the live-load strain data induced by passing vehicles using employing deep learning approaches, particularly long short-term memory (LSTM) networks. These networks are programmed to effectively differentiate between stationary and non-stationary portions of vehicle-induced strains, and they achieved accuracy in tests of more than 99%. Second, the system then clustered the extracted features using the Gaussian mixture, allowing for the grouping of strain data based on vehicle types. This clustering facilitates the identification of patterns and relationships between vehicular load and strain reaction. Finally, the study conducts state evaluations as well as early detection for bridge cracking based on the reliability study of massive vehicle strain clusters. By analyzing the probability distribution of the clustered data, the researchers can predict potential cracking and provide early warnings for bridge maintenance and reinforcement. The research contributes to the area of monitoring structural health by demonstrating the effectiveness of deep learning and clustering techniques in processing large-scale monitoring data and providing actionable insights for bridge maintenance and management. By leveraging live-load strain data, the proposed method offers a data-driven approach to bridge evaluation that enhances safety and reduces maintenance costs. The methodology details the use of Long Short-Term Memory aka LSTM networks for adaptive extraction of vehicle-induced strain features in pre-stressed concrete box-girder bridges. LSTM is a form of recurrent neural network aka RNN developed to overcome the issue of gradients disappearance in conventional RNN architectures. The researchers first provide an overview of RNN architecture, emphasizing its ability to capture temporal dynamics in sequences of inputs. They then introduce LSTM networks as a solution to the gradient disappearance problem, explaining the components of an LSTM unit, this includes the input gate, the cell, the output gate, and the forget gate. The LSTM network is programmed to learn and categorize non-stationary and stationary segments of strains due to vehicle in bridge monitoring data. The architecture of a Bidirectional LSTM (BiLSTM) network is presented, consisting of sequential input, hidden, fully connected, softmax, and classification output layers. The BiLSTM network's testing and training phases are explained, with a focus on the adaptive moment estimation aka Adam optimization, and manual labeling of training and test data. Once trained, The BiLSTM network successfully classifies and extracts non-stationary parts of strains due to vehicles while reducing sensor noise. A sliding window approach is employed for online classification, and the network achieves high accuracy in identifying strain features associated with different vehicle loads. Subsequently, the extracted strain features are clustered using Gaussian mixture models (GMM) to identify data clusters related to concrete cracking. The clustering boundaries are determined based on the crests of the GMM, with each cluster corresponding to a different loading effect (e.g., heavy, medium, and light vehicles). The researchers found that the strain responses from heavy vehicles can exceed concrete cracking thresholds, indicating potential structural deterioration. In summary, the methodology employs LSTM networks for adaptive feature extraction and GMM clustering for identifying strain patterns associated with concrete cracking in PSC box girder bridges. The approach demonstrates the effectiveness of deep learning techniques in analyzing structural monitoring data and predicting structural health issues. The research paper presents a comprehensive methodology for evaluating the cracking reliability and conducting advance warnings of PSC box girder bridges during operation. By leveraging LSTM deep learning and GMM-based clustering techniques, the study aims to analyze strain data due to vehicles collected through bridge monitoring systems. The LSTM network is utilized to stationary and non-stationary parts of strains due to vehicles with high accuracy, enabling the extraction of strain features such as amplitudes. These features are then clustered using GMM, revealing distinct patterns related to different vehicle loads. The correlation between vehicle weights and induced strain amplitudes is analyzed, highlighting the importance of data clustering for accurate evaluation. Through this approach, the study demonstrates the ability to conduct state evaluations and early warnings for bridge cracking based on data on strain due to vehicles. The methodology identifies heavy vehicle strains as a key factor in bridge cracking, with under strong vehicle influences, the bottom flange's longitudinal strain exhibited the highest values. This finding suggests a focus on monitoring and inspecting this component in pre-stressed concrete box-girder bridges. Overall, the research provides valuable insights into the utilization of deep learning and clustering techniques for structural health monitoring and maintenance of bridges. It emphasizes the importance of data-driven approaches in assessing structural integrity and mitigating the risk of cracking in bridge infrastructure.[39] Miranda, Suryanita, and Yuniarto conducted research on the reaction analysis of the structure of PSC box girder bridges under loads of earthquakes, focusing on Indonesia's seismic conditions. They aimed to assess displacement values on bridge piers subjected to earthquake loads, considering soil conditions: soft, medium, and hard. This study revealed significant implications for Indonesia, a country prone to seismic activity due to its location in an active tectonic zone. With a large percentage of bridges already in poor condition or damaged, understanding structural responses to earthquakes becomes critical.

Using MIDAS CIVIL software, the researchers analyzed the PSC girder bridge on the Pekanbaru- Duri Crossroad, focusing on its pier sections. They modeled various soil conditions and evaluated displacement patterns under earthquake loads. Results indicated that soil type significantly influenced displacement values, with soft soil conditions showing the highest displacement. Interestingly, the displacement pattern correlated with the peak surface soil spectrum, suggesting a direct relationship between soil type and structural response. The research also highlighted the importance of compliance with SNI 2833:2016 regulations, ensuring bridge structures withstand seismic events effectively. The study's findings contribute valuable insights into optimizing bridge designs for seismic resilience, particularly in regions prone to earthquakes like Indonesia. In summary, the study underscores the necessity of robust structural analysis and design considerations to enhance the earthquake resistance of bridge structures, ultimately improving infrastructure resilience and public safety in seismic-prone regions.[40] The research conducted by Hemalatha, James, Natrayan, and Swamynadh focused on the structural analysis and design of PSC box and RCC T-beam bridges across varying span lengths. The study aimed to assess the structural efficiency of these bridge types and their superstructures, considering factors like load- bearing capacity, material utilization, and construction economics. T-beam bridges, typically used for spans with shorter lengths, and box bridges, preferred for spans with long lengths, were chosen for analysis due to their respective advantages in economy and construction technology. The study emphasized the significance of superstructure components in resisting loads, with T-beam bridges utilizing T-shaped cross-sections for compressive force resistance and box girder bridges employing hollow box-shaped girders for structural support. Various loads, including dead loads, live loads, and moving loads such as IRC Class AA loading, were considered in the analysis. Courbon's method and Piguead's curves were employed for manual calculations of live load, dead load, shear forces, and bending moments. Design steps for the RCC T-shaped beam girder bridge included determining material strengths, calculating shear forces & bending moments, designing ultimate shear forces & moments, and checking for shear strength. Similarly, for the pre-stressed concrete box girder bridge, design steps encompassed determining permissible stresses, cross-section design, slab panel design, web girder design, and checking for ultimate flexural and shear strength. The study provided detailed insights into the analysis & design procedures for both bridge types, highlighting the importance of structural efficiency, material utilization, and load-bearing capacity in bridge construction. Overall, the research contributes valuable knowledge to bridge engineering, aiding in the optimization of design and construction practices for enhanced safety, efficiency, and cost-effectiveness.[41] The paper by Shuo et al presents a thorough investigation into the interior forces study of PSC box girder bridges, focusing specifically on the pre-stressed concrete transverse large cantilever continuous aka PCTLCC box girder bridge model. The authors use the numerical shape function aka NSF and structural stressing state theories approach to analyze the operation of these bridges under a variety of loading scenarios. The investigation begins by calculating the standardized generalized strain energy density (GSED), which is used to properly describe the bridge model's stressing condition. Using the Mann-Kendall (M-K) criteria, distinctive loads are found, such as failure load, elastic-plastic branch load, and progressive failure load. Notably, it is found that load due to failure indicates the start of the damage process instead of the final load at which the structure is completely demolished. Utilizing this NSF method, the authors expand experimental data and conduct a detailed analysis of the functioning behavior of the bridge model under different loads. They observe that the PCTLCC box girder bridge demonstrates rational operating performance, span flexibility, and structural economy, because of aspects such as the box girder section's ability to reduce self-weight and offer rigidity with high torsional value. Despite these advantages offered by these bridges, they pose challenges for analysis and design due to their complex stressing states and loading conditions. Previous research has addressed various aspects, including spatial stress analysis, cracking prevention, optimization algorithms, and web cracking probability. To address existing research gaps, the authors introduce new analytical theories and methods. They propose the notion of a stressing level and create the GSED curvature to represent the bridge's stressing condition appropriately. Additionally, they apply the M-K criterion to differentiate between stressing condition leaps and offer the NSF approach for extending restricted experimental information to examine internal force alterations throughout bridge degradation. This research provides valuable insights into the functioning behavior of the PCTLCC box bridges, offering new approaches for design and analysis. The findings contribute to advancing bridge engineering practices by enhancing understanding of structural performance and providing methods for more accurate analysis and design.[42] The study investigates curved pre-stressed concrete box girder aka CPCBG bridges' mechanical characteristics under different loading situations, using numerical shape function and the theory of the stressing state of the structure. This research aims to provide insights into the pattern for stressing state, internal forces, and strain fields of the CPCBG bridges to facilitate rational design and analysis. The paper begins by highlighting the increasing popularity of curved bridges because of their aesthetic appeal, acceptable high torsional stiffness and structural performance. Though structures made of reinforced concrete were initially favored for curved bridges which have spans with shorter lengths, the application of the CPCBG bridges has expanded due to its benefits such as long spans, high torsional stiffness, and low self-weight. However, the complicated stressing condition of the CPCBG bridges, compounded by factors such as curvature and pre-stressing, presents challenges for the precise prediction of the bearing capacity of the structure. Current analytical theories and methodologies struggle to provide precise predictions, leading to conservative design approaches to avoid potential structural failures. To address these challenges, the study employs non-sample point interpolation (NPI) techniques and the stressing state of the structure theories to analyze CPCBG bridges' stress properties during various loading circumstances. Experimental data from a 1/6 scale model of the respective bridge are utilized for investigating the pattern due to stressing state through GSED data and strain distribution patterns. The study employs interpolation with the NPI technique to show stress and strain domains in the bridge's model and to examine the stressing condition of the bending moments and cross-section of concrete including axial forces. Furthermore, torsional effects are simulated to demonstrate the behavior of the cross-sectional portion due to torsion under various loading cases. The analysis & comparison of both internal forces and strain field disclose that both have common and unique mechanical features of CPCBG bridge's models. By verifying experimental and simulation data, the study offers insights into previously undiscovered working properties of such structures, providing valuable information for the design & analysis of the CPCBG bridge and potentially other different kinds of structures. Overall, this research contributes to bridging the gap in understanding the mechanical behavior of CPCBG bridges and offers a new approach to reveal their unique characteristics, thereby aiding in the development of more accurate design and analysis methodologies for curved bridge structures.[43]

## IV. CONCLUSION

The historical evolution and recent advancements in the analysis & design of pre-stressed concrete box bridges demonstrate significant progress within the area of bridge engineering. From its inception in the late 19th century to the cutting-edge methodologies employed today, pre-stressed concrete technology has continually evolved to meet the growing demands of infrastructure development. The reviewed research papers collectively provide a comprehensive overview of various aspects related to pre-stressed concrete bridges, including methodologies for evaluating the effects of creep and shrinkage, comparative study of different bridge superstructures, innovative construction methods, and strategies for enhancing structural reliability and durability. Through the integration of advanced analytical techniques, such as finite element methods, structural health monitoring systems, and data-driven approaches, researchers have been able to enhance prediction accuracy, optimize structural efficiency, and develop proactive maintenance strategies to ensure the chronic performance of PSC bridges. Furthermore, this exploration for pre- stressed composite structures, such as folded-plate pre-stressed composite sections, highlights the

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ongoing quest for innovative solutions to optimize structural efficiency while reducing costs and environmental impact.

Overall, the collective findings from these research endeavors underscore the dynamic nature of bridge engineering, driven by a relentless pursuit of safety, efficiency, and sustainability. By bridging theoretical advancements with practical applications, these studies contribute to the continual improvement of bridge infrastructure worldwide, ensuring safer and more resilient transportation networks for generations to come.

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