



A Review on Optimization of Rectangular Box Bridge Structures under IRC Loading

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Abstract:

Rectangular box bridge structures are widely used in highway and railway transportation systems due to their high structural efficiency, durability, aesthetic appearance, and ability to accommodate heavy traffic loads. With the increasing demand for economical and sustainable infrastructure, optimization of rectangular box bridges has become an important area of research in structural engineering. This review paper presents a comprehensive study on the optimization techniques adopted for rectangular box bridge structures designed under Indian Roads Congress (IRC) loading conditions. The paper discusses various analytical and numerical approaches used for optimizing bridge parameters such as span-to-depth ratio, slab thickness, wall thickness, reinforcement detailing, and material consumption. Different optimization methods including finite element analysis, cost optimization, sensitivity analysis, and parametric studies carried out using software such as STAAD.Pro, MIDAS Civil, ANSYS, and SAP2000 are reviewed. The influence of IRC loading standards, including IRC Class A and IRC 70R loading, on the structural behavior and economy of box bridges is also examined. The review highlights the effects of bending moment, shear force, torsion, deflection, and soil-structure interaction on optimized design. From the collected literature, it is observed that optimized rectangular box bridge structures provide considerable savings in construction cost, reduction in material usage, improved load carrying capacity, and enhanced structural performance. The study concludes that the application of advanced optimization techniques along with IRC guidelines can lead to safer, durable, and economical bridge structures suitable for modern transportation networks.

Keywords: Rectangular Box Bridge, Optimization, IRC Loading, Finite Element Analysis, STAAD.Pro, Cost Optimization, Box Culvert, Structural Analysis, Parametric Study, Bridge Design, IRC Class A Loading, IRC 70R Loading, Reinforced Concrete Bridge, Soil-Structure Interaction, Structural Efficiency

1. Introduction

Bridges are one of the most important components of transportation infrastructure, providing safe and efficient passage over obstacles such as rivers, valleys, railways, and highways. With the rapid growth of road networks and increasing traffic intensity, the demand for economical, durable, and structurally efficient bridge systems has significantly increased. Among the various bridge configurations used in highway engineering, rectangular box bridge structures have gained wide acceptance due to their high structural efficiency, better load distribution characteristics, aesthetic appearance, and ease of construction. These bridges are extensively adopted for highways, railways, flyovers, underpasses, and culverts because they can effectively resist bending moments, shear forces, and torsional stresses.

[1]

A rectangular box bridge structure generally consists of a hollow reinforced or prestressed concrete section having one or more cells. The closed box configuration provides greater torsional rigidity and improved stability compared to conventional slab or girder bridges. The structural system is capable of carrying heavy vehicular loads with reduced material consumption, making it suitable for modern infrastructure projects. In addition, box bridges offer advantages such as reduced maintenance, longer service life, and better resistance against environmental effects. Due to these benefits, the application of box bridge structures in highway sectors has increased considerably over recent decades. [3]

In India, the design and analysis of bridge structures are governed by the standards and specifications developed by the Indian Roads Congress (IRC). IRC loading conditions consider different classes of vehicular loads, including IRC Class AA, Class A, and 70R loading, which represent actual traffic conditions on highways. These loading conditions play a crucial role in determining the safety, serviceability, and economy of bridge structures. Since rectangular box bridges are subjected to complex stress distributions under IRC loading, detailed structural analysis and optimization become essential for achieving safe and economical designs.[6][8]

Optimization of bridge structures is an important aspect of modern structural engineering. The primary objective of optimization is to obtain a structurally efficient design with minimum cost while satisfying all safety and serviceability requirements. In rectangular box bridges, optimization may involve variations in span length, slab thickness, wall thickness, cell configuration, reinforcement percentage, and material properties. By optimizing these parameters, engineers can reduce the self-weight of the structure, minimize material consumption, and improve overall performance without compromising structural safety. [2]

Various analytical and numerical techniques have been used by researchers for the optimization of rectangular box bridge structures. The finite element method (FEM) has become one of the most widely used techniques because it provides accurate analysis of stress distribution, deflection, bending moments, and shear forces under different loading conditions. Software tools such as STAAD.Pro, SAP2000, MIDAS Civil, and ANSYS are commonly employed for modeling and analysis of box bridge systems. Researchers have also explored optimization techniques using mathematical programming, genetic algorithms, and parametric studies to achieve economical bridge designs. The optimization of rectangular box bridge structures subjected to IRC loading conditions. The study aims to examine various research works related to structural behavior, finite element analysis, load distribution, material optimization, and cost-effective design approaches for box bridge systems. The review also highlights the influence of geometric parameters and loading combinations on the performance of rectangular box bridges. Through this study, an understanding can be developed regarding the most effective methods for achieving safe, durable, and economical bridge structures suitable for modern highway infrastructure. [10]

2.Literature review

Awad et al. (2008) This paper presents the results of a parametric study of wheel load distribution in four- sided precast concrete box culverts using three-dimensional finite element analysis (3D- FEA) as compared to the two-dimensional (2D) plane frame analysis. Maximum bending moments and deflections from the 3D-FEA results and the 2D frame analysis were computed and evaluated. Several concrete box culvert sizes were chosen with various span lengths, constant rise, and standard laying width. The culverts were subjected to various combinations of earth loading and AASHTO HS20 wheel loading applied at mid- span of the top slab. As the soil cover increases from 0 to 3 m, wheel loads are projected to the top slab using ASTM C890 procedure. The finite element results showed that the effect of wheel loading along mid-span is significant and that the edge loading condition for a single box is more critical than centre loading for soil cover less than 0.9 m. The earth loading tends to gradually dominate as the soil cover increases, which is expected based on geotechnical engineering practices. It was shown that the plane frame analysis and 3D-FEA gave similar results for long-span and non-standard box culverts. However, for short-span (3.6 m) concrete box culverts, the plane frame analysis was less conservative than the 3D-FEA by about 15% for moments; versus about 5% for long-span culvert (7.2 m). The results of this paper will assist bridge engineers in analysing and designing non-standard precast concrete box culverts and quickly replacing small bridges.

Chen et al. (2009) Concrete culverts in trenches have been widely used in expressways. Problems frequently take place because of improperly estimated vertical earth pressures on culverts. Different codes have been used in China to estimate the design load on culverts. In this study, a full-scale experiment and FEM simulation were conducted to evaluate the variation of vertical earth pressures and soil arching in backfill and to examine the accuracy of the methods recommended by different design codes including the prevailing Chinese General Code for Design of Highway Bridges and Culverts based on the linear earth pressure theory. The measured vertical earth pressures from the experiment were compared with those from the current theoretical methods. The variations of foundation pressure and settlement were also analyzed. The FEM simulation investigated the key influencing factors on the vertical earth pressures including the height of the embankment fill, the width of the trench, the slope angle of the trench, the dimensions of the culvert, the properties of the backfill, and the elastic modulus of the foundation soil. This research reveals that soil arch formed when the backfill on the culvert reached a certain height, but it was unstable. The coefficient of the vertical earth pressure on the top of the culvert was significantly different from that recommended by the Chinese General Code for Design of Highway Bridges and Culverts.

Mohankar and Ronghe (2010) Presenting on "Analysis and Design of Underpass RCC Bridge" and stating that the Underpass RCC Bridge is very rarely implemented in bridge construction but is being used for traffic movement. Presented is an analysis of the RCC bridge underpass. In this case, we take the fixed end condition into account when

analysing the RCC bridge underpass. In this study, FEM results are presented. Comparative force analysis between 3D and 2D models is provided for fixed end conditions.

Demane and Cholekar (2013) A parametric study on a RCC underpass bridge with soil structure interaction was conducted. Analysing the interaction of soil and structure during the modelling of a RCC bridge. Presented is an analysis of the RCC bridge underpass. An illustration of the interaction between soil structure and the concrete of this RCC underpass bridge is shown by considering its fixed ends and its different sections. The model is compared with results based on different forces considering a fixed end condition.

Kattimani and Shreedhar (2013) Since the road embankment cannot be allowed to hinder the natural water path, culverts must be installed underneath earth embankments for crossing watercourses such streams, Nallas, etc. The culverts are also necessary to balance the flood water on both sides of an earth embankment, which lowers the flood level on one side of the road and, in turn, lowers the water head and, in turn, lowers the threat of flooding. Culver come in a variety of shapes, including arch, slab, and box. These can be built from a variety of materials, including reinforced cement concrete or masonry (brick, stone, etc.). Expressways have historically made extensive use of concrete culverts in trenches. A box-type structure with one or more cells can be used successfully as a flyover, a grade separator, a minor bridge, and an underpass. The study of some box culvert design parameters, including the angle of live load dispersion, the impact of the earth pressure coefficient, and the depth of cushion provided on the top slab of box culverts, is the subject of this paper. The depth of the cushion, the coefficient of earth pressure for lateral pressure on the walls, the width or angle of the dispersion for live loads on boxes both with and without cushions for structural deformation are all significant factors that need to be addressed in great detail. According to studies on cushion depth, it is possible to design a box-shaped structure with a 0 metre or no cushion that will be safe for cushion loads that may one day be required due to a change in the profile of the road. According to the study, moments with no cushion are higher than moments with a 5 metre cushion.

Chen and Liang (2014). Through the use of experimental, numerical, and analytical techniques, the performance of embankment installation (EI) and trench installation (TI) culverts has been examined. Few research have been done on the effectiveness of trapezoidal TI (TTI) culverts, though. In order to better understand the complex soil-structure interaction and to serve as a guide for the design of TTI culverts, this study was carried out. The vertical earth pressure on the TTI culvert was first measured through field tests. The performance of TTI culverts was then investigated using numerical simulations. After the numerical model was verified, parametric experiments were conducted to determine the key affecting elements (such as the trench's slope angle, bottom width, culvert dimensions, and stiffness of the backfill next to the culvert) on the culvert's performance. The vertical earth pressure on the TTI culvert is found to be significantly different from that on the EI and TI culverts, according to this study. The soil arches can affect the TTI

culvert's deformation and vertical earth pressure as long as the backfill is high enough. In general, it is advised that soil arch effects be taken into account when designing TTI culverts.

Tikate and Tande (2015) Throughout the world, reinforced concrete box culverts are frequently utilised to create secure and reasonably priced structures for the transportation of water, automobiles, utilities, or pedestrians. Even though single- or multi-cell box culverts are very simple constructions, the loads placed on them during construction and throughout their useful lives can be complicated. When the weight of the cushion on the culverts is assessed incorrectly and the coefficient of ground pressure is not taken into account, problems frequently arise. Depth of cushion, coefficient of earth pressure for lateral pressures on walls, width or angle of dispersion for live loads on box culverts without cushion and with cushion for structural deformations are significant items that need to be carefully taken into account and are areas where designers' opinions differ. Therefore, an effort is made to research the impacts of cushion, earth pressure co-efficient (K_a), and width/angle of dispersion (θ) for live loads. In order to determine the impact of changing the cushion depth, earth pressure coefficient, width, or angle of dispersion on the structural behaviour of the three-dimensional box culvert and to assess the accuracy of FEM by contrasting the FEM results with IS Code methods, a finite element method simulation was carried out. When the calculated shear forces and bending moments from the FEM were compared to those from the most recent theoretical approaches, a strong correlation was found. It is advised to design a box culvert with no cushion condition, Coefficient of Earth Pressure (K_a) = 0.5, and Angle of Dispersion (θ) = 45°. This will ensure that the structure will function safely even under any increased cushion loads that may result from a change in the road's profile. This work directs engineers using IS code in assessing the behaviour of box culverts under various cushion depths so they can choose up to what cushion depth the box culvert does not need to be rebuilt during road widening. According to studies on cushion depth, it is possible to construct a box-shaped structure with a 0 metre or no cushion that will be safe for cushion loads that may one day be required owing to a change in the profile of the road.

Patil and Galatage (2016) To allow access to the natural drainage that crosses roads and railroads, box culverts were built beneath them. The thickness of the culvert section is designed depending on the weights placed on it, whereas the aperture of the culvert is decided based on the waterway needed to pass the design flood. Although culverts and bridges frequently have the same function, their size is different. For flows where hydraulic head is constrained, box culverts are the best option. Box culverts can be designed to have less of an effect on upstream water levels and downstream flow velocities than equivalent pipe structures for a given waterway area compared to circular pipes. This study focuses on box culverts made of reinforced concrete with various aspect ratios. The box culverts' cushion and no cushion loading are examined. The behaviour of the structure under the different types of loading as specified by IRC codes and their combinations that produce the worst loading effects for safe structures are the main areas of focus. On the basis of the maximum bending moments displayed for various loading cases, a comparison and conclusion are drawn.

Seo et al. (2017) In use in the US are tens of thousands of outdated bridge-class RC box culverts. This article introduces, calibrates, and applies a system-level pavement-stiffness model to a production-simplified, soil-structure interaction model used to determine load demands for in-service RC box culverts. The increased stiffness given by the pavement structure to reduce live load is taken into account by the proposed pavement-stiffness model using system-level pavement data. According to the production-simplified soil-structure interaction model, the full cover-soil depth is modelled using linear-elastic finite elements, and the additional stiffness provided by the pavement structure is modelled using beam elements across the top row of finite-element nodes. The system-level pavement stiffness model's equivalent beam-modulus values were calibrated using findings from a thorough full-pavement model that included data for a variety of pavement types. The incorporation of pavement stiffness could raise the load ratings for both concrete and asphalt pavements with an intermediate thickness, for both direct traffic and low-fill RC box culverts, according to a parametric investigation employing the suggested model. Using measured live-load moments from field live-load tests on in-service culverts, the implications of the pavement-stiffness model at the system level on anticipated live-load moment response were further investigated. These comparisons revealed that the pavement-stiffness model at the system level has increased live-load demand prediction accuracy and precision. The system-level pavement-stiffness model outperformed the production-oriented soil-structure interaction model without pavement stiffness and the AASHTO-recommended structural-frame model in load-rating analyses for an illustration sample of 24 in-service Texas RC box culverts under various pavement types. The findings of the RC box culvert load-rating are improved when the pavement stiffness is taken into account when modelling in-plane live-load attenuation. This method can be used for system-wide infrastructure management.

Alam and Patel (2018) SAP-2000 was used to analyze slab and box culverts under heavy traffic loads.. According to site, this study considers two distinct kinds of courses under substantial activity streams and water powered streams. In future working conditions, this examination work will assist in executing a more stable, practical and comparable execution.

Vasu et al. (2018) At the time of construction of roads, highways a structure is placed (commonly used) to transfer the traffic, rain water, drainage from one side to another of the road is called a culvert placed beneath the road. Due to the structural use, multiple loads are placed on the box causing various types of stress which occurs on it. The paper tries to reduce the stress occurred in the box by flaring the box partially. Culvert is an underpass provided beneath the high way which under goes various types of loading .It helps to facilities the flow of water, provide cross drainage, roadways or railways, to take electrical or other cables from one side of road to another side of the road . due construction of these high load bearing components various stress and shear gets generated in very high values the paper objects to reduce the values of the stress which have been generated for various cases.

Patel and Jamle (2019) Box culverts are the massive structures used to bridge railroad tracks, roads, etc. Flood water is balanced on both sides by embankments. Various forms of loads produced by water, traffic, cushion, soil, etc. are taken by the box. This work focuses on the manual design of a box culvert in its entirety. Design parameters examined include the impact of earth pressure, the depth of the top slab's cushion, the braking force, the impact load, the live load, the distribution of load through a tracked or wheeled vehicle, the effective width, and others. In this paper, culvert studies with and without cushions are studied for several classes of IRC loadings, and conclusions are drawn based on the bending moments and shear forces with and without cushions cases. The provisions of Indian Standards are fully discussed in this paper, along with their justifications and design-related considerations. Braking force must be taken into consideration for box culverts with no cushions in shopping malls. When necessary, it is simple to make the box length wider.

Patel and Jamle (2019) Box culverts are the structures which are used when the path of water in the natural stream crosses roads, railway lines, flyovers etc. They are normally cheaper than bridges, which make them the natural stream passes through channels. In this work, the review of various authors and their views in the design and analysis of box culvert with software approach and comparison between software and manual approach has shown. The IS standard requirements in the design manual for roads and bridges (IRC-6-2000, IS 21-2000) is used in the structural designing of concrete box culverts. In this paper study about the different classes of IRC loadings and their effect on without and with cushioning conditions imposed on box culvert. The pressure cases are then checked for both with cushioning and without cushioning loading cases. The structure designing includes the considerations of pressure cases (Box empty, Full, surcharge load) and factors such as Impact load, Braking force, Dispersal of load through fill, Effective width, Coefficients of earth pressure, Live load etc. The structural elements are designed to withstand the maximum bending moments and shear forces respectively. In the present study, this paper provides full discussion on the provisions in the codes, considerations and justifications of all the above aspects of design.

Bhujade and Gaikwad (2020) To allow access to the natural flow over highways and railroads, box culverts are the drainage structures built beneath them. The river needed to cross the design flood dictated the culvert opening. Where hydraulic head is constrained, a box culvert is an appropriate CD structure. The investigation of the limit state approach for box culverts made of reinforced concrete, both with and without a cushion on the top slab, is the subject of this research. The IRC is used to determine the thickness of the culvert section, and their combination produces the worst loading effects for safe structures. Steel structural components must be built to withstand the highest bending moment and shear force determined by analysis employing STAAD Pro. In this investigation, it was found that when a cushion was placed over a box as opposed to a box without one, the bending moment and shear force were higher. According to the rules outlined in the codes, their related results, such as the maximum bending moment and shear

force with impact for ULS combination and SLS combination, were achieved. Steel index area is investigated for both scenarios, which are depicted by a graph in the outcome analysis. For overburden structures, more steel is needed, hence the depth chosen for sections of box culvert without cushion is inappropriate for boxes with cushion. When designing, a structure could be ineffective or unsafe for supporting concrete stress. Therefore, the overburden box culvert's adopted depth of section is more than zero for safety purpose.

Kushwaha et al. (2020) The structural design of a box has further been included within the purview of this paper. The structural design takes into account several load scenarios (box empty, full, surcharge loads, etc.) as well as variables like the live load, effective width, braking force, load dispersion via fill, impact factor, and earth pressure co-efficient, among others. It is necessary to refer to the appropriate IRC codes. The structural components must be built to endure the greatest possible bending moment and shear force. The Paper contains thorough explanations of the Codes' provisions, as well as the factors that went into their development and their reasoning. Box For the purpose of allowing watercourses, such as streams and nallas, to cross the embankment, culverts must be installed underneath the earthen embankment natural water way. The culverts are also necessary to balance the flood water on both sides of an earth embankment, which lowers the flood level on one side of the road and, in turn, lowers the water head and, in turn, lowers the threat of flooding. Culverts come in a variety of shapes, including arch, slab, and box. These can be built from a variety of materials, including reinforced cement concrete or masonry (brick, stone, etc.). Since culverts pass through an earthen embankment, they experience the same traffic loads as a road and must be built to withstand those loads. Size, invert level, layout, and other factors are determined by hydraulic factors and site conditions. The cushion is based on the road profile near the culvert. The structural design takes into account several load scenarios (box empty, full, surcharge loads, etc.) as well as variables like the live load, effective width, braking force, load dispersion via fill, impact factor, and earth pressure co-efficient, among others. In the analysis and design of box culverts, the IRC Codes must be consulted. This project's goal is to use STAAD PRO software to analyse the box culvert. The box culvert's structural components are intended to endure the greatest possible bending moment and shear stress. The STAAD values are almost identical to those of manual computations. Box bridge has an extremely sturdy, safe, and rigid construction. The base slab projection of a box bridge can be increased to keep the base pressure within the safe bearing capability of the ground soil without the need for a complex foundation. Box Bridge requires almost no upkeep and is simple to build. It may contain multiple cells to accommodate discharge within a reduced embankment height. The number of cells with the desired span to depth ratio in accordance with the hydraulic parameters at the site can be chosen by the designer.

Hussein (2020) To allow for the crossing of a watercourse, such as streams, culverts are frequently needed under earth embankments. This prevents the road embankment from impeding the natural waterway. The thickness of the culvert section is designed based on the weights placed on the culvert, whereas the aperture of the culvert is decided based on the waterway needed to support the design flood. It is evident from the prior literature assessment

that the impact of the culvert's pressures on the haunch was not investigated. Therefore, the focus of this study is on how using haunches affects the culvert design's economy. This essay examines a few box culvert design factors, including the depth of fill on the top slab, the thickness of the haunch, the earth pressure coefficient, and the thickness of the box culvert. The goals demonstrate how the haunch affects the strains in the box culvert. The study looked at how pressures varied depending on the box culvert's width and cost comparisons were conducted. It shows the percentage reduction in culvert cost based on the presence of haunch. Finally, a number of important conclusions are drawn from the numerical data, with the existence of the haunch being the optimum method from an economic standpoint for reducing the values of stresses. In terms of decreasing tensions, the haunch's impact on a section with a small thickness is preferable than one with a large thickness. From an economic perspective, having a haunch is the best way to reduce the levels of stress.

Baghel and Mandaloi (2021) The culvert opening should be determined according to the maximum amount of water it will have to handle during the design flood, and the culvert section should be thick the structures must be capable of carrying those loads. The purpose of culverts and bridges is often the same, although the size of each differs. The type of material, how they carry weight, Staad Pro will show the entire study and behavior of bridge structure under different IRC loading conditions. A bridge structure can be constructed economically with the help of the software. The basic combination of loading vehicles is the most critical instance of maximum BM, since this is the loading that results in maximum BM. Load positions along a longitudinal edge affect shear stress at a reference point. As the distance between edge and 2.7 m from RHS is varied, the absolute maximum total deformation (moment) first increases, and then decreases while the distance from RHS to edge is changed. As the size of the box structure is reduced, the total deformation, and the shear stress at a reference point decreases. Bending moment reaches its highest value at the center, and shear force reaches its highest value at the support. With a cushion, the Bending Moment and Shear Force are higher than without.

Rohitkados and Chavan (2022) Box gutters are rectangular structures with four monolithic sides that give angles to lessen the impact of water pressure. Because the lower plate serves as the carpet base in this sort of gutter, no additional basis is required. We prefer blankets made of a single cell when the discharge flood is small. We only provide three sides for corridors, and they are constructed monolithically. We must expand the box's dimensions when the flood discharge is high, which results in an increase in the walls' thickness. There may be a non-economic autopsy as a result. The analysis of the box culvert for various loading scenarios according to standard code makes up the current task.

Arias et al. (2022) The goal of this study project was to develop a comprehensive and adequate solution for places with heavy automobile traffic, where some watersheds exhibit a non-negligible water flow during the rainy season. In

order to provide a solution for vehicular continuity in places affected by water flows that disrupt pedestrian and vehicle traffic and endanger human life, the research involved the structural design of several geometries of box culverts. The structural plans complied with both the Colombian bridge code and the criteria set forth by the American Association of State Highway and Transportation Officials. With the use of commercial software SAP2000 and Visual Basic programming, the designs were carried out for analysis and design, enabling the establishment of a variety of geometries and boundary conditions. The structural designs showed a significant difference in the amount of labour required to build the box culverts for various geometries, with the designs made using the American Association of State Highway and Transportation Officials code requiring more concrete than those made using the Colombian bridge code. The American Association of State Highway and Transportation Officials code provides the greatest steel standards for fills more than 3.00 m, whereas the Colombian bridge code has higher steel requirements for fills under that height. This study contributes to the design of box culverts by considering several physical events, such as earth fill load, live load, over live load, dead load, water pressure, impact load, as well as other load combinations that aim to increase the capacity of the culvert effects on the structure. The American Association of State Highway and Transportation Officials standard is similar to the Colombian bridge standard, but the American standard estimates lower quantities of cubic metres of concrete, and the use of the old general technical regulation of road works provides for lower quantities of concrete, possibly as a result of ignorance of behaviour and the demand for resistance for the road works. years 1988. For fills under 3 metres, the Colombian bridge standard has stricter criteria for steel, whereas the American Association of State Highway and Transportation Officials standard has stricter requirements for fills over 3 metres.

Jain and Suryawanshi (2022) There are several uses for buried constructions. They are typically employed to transport water. They regularly offer a grade separated crossing for both automobile and pedestrian traffic. Different sorts of constructions and materials are employed. Box and pipes culverts are the most typical forms. Segmental box culverts made of precast concrete are among the most adaptable and economical pre-cast concrete products, fitting the demands of quick-moving construction projects. Cost reductions are produced through flexible design and straightforward site placement. Pre-cast concrete segmental box sections have a wide range of applications because they make building easier. Underpasses, service tunnels, subways, minor bridges, storm water culverts, cattle underpasses, etc. can all be built using these monolithic structures. These guidelines are only applicable for Precast Concrete Segmental Box Culverts. A Precast Concrete Box Culvert is an easy construction with segmental construction which is used to provide passage for roads, flowing water below roads, embankment or railways. Precast concrete segmental box culverts are popular in construction where time available for construction is less. With today's technology these precast box culvert can be constructed unto 40 - 60 m length of per day with precast sections available at site. To achieve this productivity at site these segments of finished section of required shape must be available in precast yard. Big size box culverts having transportation issue shall be transported as one unit are constructed from one 'U' sections and top slab casted separately; for on-site assembly. Sometimes two 'U' shapes s

also are getting used. These are given rebated joints/V notched to permit sections to be laid open or sealed. Precast head walls and wing walls can also be provided for Precast Concrete Box culverts.

Hrishikesh Yadav et al (2023) Was study a comprehensive overview of the research carried out on T-beam bridges, emphasizing their structural analysis, design methodologies, optimization techniques, and overall performance under various loading and environmental conditions. T-beam bridges are widely used in highway and railway infrastructure because of their structural efficiency, durability, and economical construction. A major focus of the reviewed studies is the application of the Finite Element Method (FEM), which has become one of the most reliable and accurate tools for analyzing bridge behavior. Unlike conventional one-dimensional analysis methods, FEM enables engineers to simulate the actual three-dimensional behavior of bridge components, resulting in more optimized, safe, and economical designs. Researchers have also explored different optimization approaches, including mathematical programming, evolutionary algorithms, and MATLAB-based computational models, to minimize construction costs while maintaining structural safety and serviceability. The literature further discusses the use of pre-stressed concrete T-beams, which improve load-carrying capacity, reduce cracking, and increase span length, making them suitable for modern bridge construction. Composite construction techniques, where concrete decks are combined with steel or pre-stressed girders, have also been studied for enhancing strength, stiffness, durability, and construction efficiency. Different forms of T-beam bridges, such as straight T-beam bridges, box girder bridges, and curved bridges, have been analyzed to understand their behavior under dead loads, live loads, seismic forces, and torsional effects. Important structural parameters including bending moments, shear forces, deflection, torsional rigidity, stress distribution, vibration characteristics, and material consumption have been evaluated to compare the efficiency and suitability of various bridge configurations. Studies indicate that box girders provide higher torsional resistance and are suitable for curved alignments, whereas conventional T-beam bridges remain more economical for moderate spans. The review also identifies several important research gaps that need further attention, such as the long-term durability and maintenance performance of T-beam bridges exposed to harsh environmental conditions like corrosion, temperature variation, moisture, and seismic activity. Additionally, sustainability aspects such as reduction of material consumption, use of recycled materials, carbon footprint assessment, and energy-efficient construction practices are still insufficiently explored in bridge engineering research. Another significant gap is the limited application of advanced computational tools such as artificial intelligence, machine learning, digital twins, and structural health monitoring systems in the design and maintenance of T-beam bridges. Addressing these research gaps will help engineers develop safer, more durable, cost-effective, and environmentally sustainable bridge systems. Overall, the findings of this literature review establish a strong foundation for future studies and practical engineering applications by highlighting current advancements, existing limitations, and emerging opportunities in the field of T-beam bridge engineering.

Narendra Singh et al (2023) A bridge is a structural system constructed to provide safe passage over obstacles such as rivers, valleys, railways, or roads, and among the various bridge types, prestressed concrete (PSC) bridges are widely preferred due to their high strength, durability, economy, and superior riding comfort. Prestressed concrete bridges possess excellent structural characteristics such as reduced cracking, high torsional rigidity, improved load-carrying capacity, and continuous span behavior, which significantly minimize traffic-induced vibrations and improve serviceability. One of the most important advantages of PSC bridges is that their natural frequency generally does not coincide with the frequency generated by moving vehicles, thereby reducing resonance effects and ensuring structural stability and passenger comfort. Because of these advantages, PSC bridges are extensively used in highways, flyovers, expressways, and modern metro rail systems. Since bridges are critical infrastructural components, they must be designed to resist not only static loads such as dead load and live load but also dynamic loads, especially earthquake-induced forces, to ensure life safety during severe seismic events. Depending on material properties and geometric configuration, bridges are classified into different types, among which PSC precast I-girder bridges and PSC box girder bridges are commonly adopted for medium- to long-span applications. In PSC box girder bridges, the main load-carrying member consists of a hollow box-shaped girder that provides high torsional stiffness and better resistance against dynamic loading, whereas PSC I-girder bridges utilize I-shaped girders that offer structural efficiency, ease of construction, and economical design. In this research study, a detailed dynamic analysis of PSC precast I-girder bridges and PSC box girder bridges has been carried out for different span ranges and parametric variations using Finite Element Method (FEM)-based software. Response Spectrum Analysis, which is an important seismic analysis method, has been employed to evaluate the structural response of bridges under earthquake excitation. Various parameters such as geometric properties, span length, bending moment, shear force, displacement, base shear, base moment, natural frequency, and time period have been analyzed according to different design code provisions. The study mainly focuses on evaluating critical responses such as base reactions, girder forces, absolute displacement, natural vibration characteristics, and seismic performance of bridge structures, as these parameters play a vital role in determining the safety, stability, and serviceability of bridges under dynamic loading conditions.

Nilesh.R.Navale et al (2024) The main advantage of IRC type double box cell bridges lies in their high torsional stiffness, which is achieved due to the closed box-shaped cross-section. This high torsional rigidity enables the bridge to effectively resist twisting forces caused by eccentric loading, curved alignment, wind forces, seismic effects, and uneven live loads, thereby providing excellent structural stability and efficient load distribution. Because of these characteristics, double box cell bridges are widely adopted in highways, flyovers, metro rail systems, and long-span bridges throughout the world. The double box cell configuration also offers improved resistance against heavy earthquake forces and dynamic live loads when compared with conventional girder bridges. Deflection control is one of the most important criteria in the design of double box cell bridges; therefore, the geometry and configuration of the bridge section play a vital role in achieving better performance. These bridges generally consist of hollow girders having either rectangular or trapezoidal cross-sections, which reduce the self-weight of the structure while maintaining

high strength and stiffness. In addition to structural efficiency, double box cell bridges provide better stability, improved serviceability, durability, aesthetic appearance, and overall economy due to reduced material consumption and maintenance cost. In the present research work, three different cases are considered for analysis using various bridge configurations and section shapes, including a 45-degree skew section and a single box section for comparison. In the first case, the bridge is analyzed under IRC Class A and IRC Class B loading conditions to evaluate its behavior under standard vehicular loads. In the second case, the Response Spectrum Method is adopted to study the seismic performance of the bridge under earthquake excitation. In the third case, a combination of IRC loading and response spectrum analysis is applied to investigate the combined effect of traffic and seismic forces on the structural behavior of the bridge. The modeling and analysis are carried out using ETABS software. The objective of this study is to modify the form and shape of the double box cell bridge under IRC loading conditions in order to achieve greater economy, improved structural stability, better load-carrying capacity, and enhanced overall performance.

Aayush Aggarwal et al (2025) This study focuses on the structural analysis and design of a very tall hollow circular reinforced concrete bridge pier with a height of 52.8 meters, constructed for a highway bridge near the Khellani Tunnel in the mountainous region of Jammu and Kashmir, India. Bridges in such hilly terrains face extremely challenging environmental and structural conditions because the area is characterized by steep rocky landscapes, high seismic vulnerability, strong valley winds, and difficult construction conditions. Since Jammu and Kashmir falls under one of the highest seismic risk zones in India, the pier had to be designed carefully to resist both earthquake forces and wind loads while maintaining stability, durability, and safety over its service life. To evaluate the structural behavior, advanced numerical analysis software such as STAAD.Pro and MIDAS Civil were used along with relevant Indian Road Congress (IRC) bridge design standards. The analysis examined how the pier responds to lateral forces, vibrations, bending moments, shear forces, and displacement under different loading combinations. The results showed that wind forces, particularly those acting in the transverse direction of the bridge, were significantly larger than the seismic forces, with the maximum wind load reaching approximately 765.7 kilonewtons. This finding is important because in many bridge projects earthquake effects are generally assumed to be the governing factor, but in this case the strong mountain winds controlled the structural design requirements. The study also demonstrated that the hollow circular configuration of the reinforced concrete pier provided several engineering advantages compared to a solid pier. The hollow section reduced the overall self-weight and seismic mass of the structure, thereby lowering earthquake-induced inertia forces. At the same time, the circular geometry improved aerodynamic performance against wind loading and provided uniform resistance in all horizontal directions. The hollow design also enhanced lateral flexibility and ductility, allowing the pier to deform safely during extreme loading without sudden failure. Furthermore, the pier satisfied both strength-based and serviceability-based performance criteria, meaning it possessed adequate load-carrying capacity as well as acceptable limits of deflection, vibration, and cracking during normal operation. Overall, the research highlights that hollow reinforced concrete piers are highly suitable for long-span bridge construction in mountainous and high-altitude regions where strong winds and seismic activity coexist. The

study further emphasizes that wind effects must be given equal or even greater importance than seismic forces during the design of tall bridge substructures in such regions to ensure structural resilience, economic efficiency, safety, and long-term performance.

3.Methodology

The methodology adopted for the review on optimization of rectangular box bridge structures under IRC loading involves a systematic collection, classification, analysis, and comparison of published research papers, design codes, and technical reports related to reinforced concrete and prestressed concrete box bridge structures. Initially, relevant literature is collected from journals, conference proceedings, theses, IRC publications, and design manuals focusing on the structural behavior, analysis techniques, and optimization approaches of rectangular box bridges. The review primarily considers bridges designed according to the provisions of Indian Roads Congress loading standards such as IRC Class A, IRC 70R, and other applicable loading combinations including dead load, live load, impact load, earth pressure, water pressure, braking force, and seismic effects. Different geometric parameters such as span length, box cell dimensions, slab thickness, wall thickness, aspect ratio, and support conditions are studied to evaluate their influence on bending moment, shear force, torsion, deflection, and overall structural stability. The methodology also includes reviewing analytical and numerical methods such as conventional design procedures, finite element analysis, grillage analogy, and software-based modeling using tools like STAAD.Pro, MIDAS Civil, ANSYS, and SAP2000 for obtaining accurate stress distribution and load-carrying behavior. Optimization techniques adopted by various researchers, including cost optimization, weight reduction, material efficiency, genetic algorithms, response surface methods, and parametric studies, are critically examined to identify economical and safe design alternatives. Comparative evaluation of single-cell and multi-cell rectangular box bridges is also carried out to determine the most efficient structural configuration under varying loading and boundary conditions. The reviewed studies are then analyzed based on parameters such as economy, durability, structural performance, ease of construction, maintenance requirements, and compliance with IRC guidelines. Finally, the collected information is synthesized to identify current research trends, limitations in existing studies, and future scope for improving the optimization of rectangular box bridge structures under IRC loading conditions.

4.Results and Discussion

The review on optimization of rectangular box bridge structures under Indian Roads Congress (IRC) loading conditions indicates that box-type bridges provide an efficient, durable, and economical solution for highway and railway crossings. Various researchers have analyzed the structural behavior of single-cell and multi-cell rectangular box bridges using analytical methods, finite element analysis, and software tools such as STAAD.Pro, MIDAS Civil, and ANSYS. The results obtained from different studies show that optimization mainly depends on span-to-depth ratio, cell geometry, slab thickness, load combinations, and IRC loading classes such as IRC Class A, 70R tracked,

and wheeled loading. One of the important findings from the reviewed literature is that rectangular box bridges possess high torsional rigidity due to their closed cellular section. This characteristic enables better load distribution compared to conventional slab or T-beam bridges. Under eccentric loading conditions specified by IRC standards, box sections exhibited lower differential deflection and improved stability. Researchers observed that the distribution of bending moments and shear forces becomes more uniform in box structures, reducing stress concentration at critical sections. Consequently, optimized box bridges require comparatively less reinforcement and material consumption while maintaining structural safety and serviceability. The studies further revealed that finite element analysis provides more accurate results than conventional manual methods because the bridge behaves as a three-dimensional structure. By using FEM-based software, engineers were able to evaluate stress contours, displacement patterns, and torsional effects with greater precision. Optimization studies indicated that increasing the depth of the box section significantly improves stiffness and reduces deflection. However, beyond an optimum depth, the self-weight of the structure increases considerably, leading to higher bending moments and material cost. Therefore, selecting an appropriate span-to-depth ratio becomes essential for achieving economical design.

Several researchers compared different span arrangements and found that for short and medium spans, single-cell rectangular box bridges are more economical, whereas multi-cell box structures become advantageous for larger carriageway widths and longer spans. Multi-cell arrangements provide better load sharing and reduce slab thickness requirements. The reduction in maximum bending moment and shear force due to additional cells results in lower reinforcement quantity and improved structural efficiency. However, construction complexity and formwork requirements slightly increase with multi-cell systems.

The review also highlights the importance of IRC loading combinations in optimization. Under IRC Class 70R loading, stresses and deflections were found to be significantly higher than under IRC Class A loading. Optimization techniques therefore focused on reducing dead load while maintaining sufficient resistance against heavy live loads. Researchers reported that varying slab thickness and wall thickness helped in achieving balanced structural behavior. Reduction in unnecessary concrete volume in low-stress regions contributed substantially to cost savings without compromising safety.

5. Conclusion

Rectangular Box Bridge structures have become one of the most widely adopted bridge systems in highway engineering because of their high structural efficiency, durability, torsional rigidity, and suitability for varying site conditions. The review of various studies on optimization of rectangular box bridges under IRC loading conditions indicates that the use of advanced analytical and design techniques significantly improves the economy and performance of bridge structures. Finite Element Method (FEM)-based software such as STAAD.Pro, MIDAS Civil, SAP2000, and ANSYS has enabled engineers to accurately evaluate stress distribution, bending moments, shear forces, deflection, and torsional effects under IRC Class AA, Class A, and 70R loading conditions.

The literature also reveals that optimization of geometric parameters such as span-to-depth ratio, wall thickness, slab thickness, and cell configuration plays a vital role in reducing material consumption while maintaining structural safety and serviceability requirements. Multi-cell box structures generally exhibit better load distribution and reduced deflection compared to single-cell sections, particularly for wider carriageways and heavier loading conditions. Prestressing techniques further enhance structural efficiency by minimizing tensile stresses and crack formation.

Several researchers concluded that optimized box bridge designs provide considerable savings in concrete and steel quantities without compromising strength and stability. The adoption of IRC provisions in combination with modern computational analysis ensures reliable performance under static, dynamic, seismic, and moving load conditions. Moreover, the closed-box configuration offers improved resistance against torsion and seismic effects, making rectangular box bridges highly suitable for highways, rail over bridges, urban flyovers, and culvert applications. The review establishes that optimization of rectangular box bridge structures under IRC loading leads to economical, durable, and structurally efficient bridge systems. Future research may focus on the incorporation of advanced optimization algorithms, high-performance materials, sustainability considerations, and artificial intelligence techniques to further improve the design process and long-term performance of box bridge structures.

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