

Comparative Study of an RCC Bridge Under IRC Class AA Loading and Analysis of Deflections Using Sensors

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Abstract — Bridges are critical components of transportation infrastructure, requiring accurate evaluation of their structural performance under increasing traffic demands. This study focuses on the analysis of a Reinforced Cement Concrete (RCC) bridge subjected to IRC Class AA loading, which represents one of the heaviest design load cases for national and state highways. The bridge was modelled and analysed using STAAD.Pro to determine theoretical structural responses, including bending moments, shear forces, and deflections under moving loads. To validate the analytical results, sensor-based measurements were obtained from a scaled prototype model to record real-time deflection behaviour under applied loads. A machine learning approach was further employed to process sensor data and improve prediction accuracy by identifying deviation patterns between analytical and experimental observations. The comparative analysis demonstrated that while STAAD.Pro provides conservative and reliable predictions for design, real-world measurements capture additional behavioural variations influenced by material properties and dynamic effects. The study emphasizes the importance of integrating structural health monitoring systems and data-driven models in bridge engineering to enhance safety, durability, and predictive maintenance strategies.

Keywords: RCC Bridge, IRC Class AA Loading, Structural Analysis, STAAD.Pro, Deflection, Measurement, Structural Health Monitoring (SHM), Sensor-Based Data, Machine Learning Prediction, Load Distribution, Comparative Analysis Bridge Performance, Assessment, Real-Time Monitoring

I. INTRODUCTION

Bridges form an essential element of transportation systems by enabling uninterrupted movement over geographical obstacles such as rivers, valleys, and existing roadways. With rapid urbanization and increasing industrial development in India, roadway infrastructure is subjected to progressively heavier traffic loads, especially on national and state highways that cater to freight and defence logistics. Reinforced Cement Concrete (RCC) bridges are widely adopted due to their cost-effectiveness, durability, and structural reliability under varied loading and environmental conditions. In the design of highway bridges, the Indian Roads Congress (IRC) specifies various loading classes to ensure structural safety. Among these, IRC Class AA loading represents the heaviest load case, typically applied to bridges expected to carry military tanks or multi-axle heavy transport vehicles. Although analytical modelling software such as STAAD.Pro provides theoretical estimation of bending moments, shear forces, and deflections, these predictions may not always reflect the actual behaviour of structures due to factors like dynamic loading, material variability,

environmental degradation, and construction tolerances. To overcome this limitation, modern structural health monitoring (SHM) techniques incorporate sensors such as strain gauges, accelerometers, and displacement transducers that can record real-time deformation and stresses. When combined with data-driven algorithms, these measurements allow for more accurate performance evaluation and predictive maintenance. Therefore, this project performs a comparative study between analytical deflection results obtained from STAAD.Pro and real-time sensor measurements, ultimately aiming to enhance accuracy, monitoring capability, and reliability of RCC bridge design.

A. Types Of Bridges

Bridges are categorized based on structural form, load transfer mechanism, material, and functional configuration. The selection of the bridge type depends on factors including span length, soil conditions, expected traffic flow, hydraulic requirements, aesthetics, and construction feasibility. Beam bridges are the most common bridge type for small to medium spans due to their simple design and ease of construction. They transfer loads primarily through bending and shear, making reinforcement and depth adjustments critical for mid-span strength. Arch bridges are predominantly compression-based structures that utilize curved profiles to transfer loads to abutments. Their effectiveness in long-span applications and ability to reduce bending stresses make them suitable for challenging terrains where intermediate supports cannot be constructed. Truss bridges employ a triangulated framework that distributes loads through axial forces in members, improving material efficiency and making them suitable for railway and large road bridges. Suspension and cable-stayed bridges represent advanced long-span systems where loads are carried by cables under tension. These are ideal for coastal regions, deep valleys, and locations requiring uninterrupted navigation routes. Cantilever bridges provide favorable construction advantages in deep or inaccessible locations as spans can be extended from piers without requiring temporary supports. The selection of bridge type is therefore governed by structural behavior, economic feasibility, and environmental constraints, ensuring safety and efficiency over the bridge's lifespan

1) Beam Bridge

Beam bridges consist of longitudinal girders supported at pier locations, functioning primarily under flexure. The deck transfers live load, dead load, and impact forces to the girders, which in turn transfer reaction forces to supports. The structural response is characterized by high bending moments at mid span and high shear forces near supports. To resist these stresses, reinforcement is provided in the tension zone, while compression is resisted either through concrete or prestressed tendons depending on design type.



Fig. 1.1: Beam Bridge

Beam bridges are typically economical for spans ranging from 10 m to 30 m and can be configured using RCC, PSC, or composite steel-concrete sections. For highway bridges, design is performed using influence line analysis to determine critical loading conditions such as maximum bending and shear from moving vehicles. Their modular nature, repetitive structural configuration, and ease of construction make them widely preferred in national highway projects.

2) Arch Bridge

In arch bridges, the curvature allows loads to be distributed along the arch axis as compressive forces while horizontal thrust is resisted by the abutments. This reduces bending stresses, making arch bridges structurally superior where foundation supports are strong and soil conditions permit horizontal force transfer. Modern arch bridges may employ reinforced concrete, prestressed concrete, or steel ribs with composite decking.

These bridges also offer aesthetic benefits and are often preferred for iconic structures in urban and natural settings. Their durability under repetitive loading and minimal deformation make them suitable for railway and highway applications where long-term performance is critical. Unlike beam bridges, however, arch bridges require precise design of abutments and may involve complex construction techniques such as temporary centering or segmental erection. Typical indicators of ASR might be any of the following: a network of cracks; closed or spalled joints; relative displacements of different parts of a structure; or fragments breaking out of the surface of the concrete. Because ASR deterioration is slow, the risk of catastrophic failure is low. However, ASR can cause serviceability problems and can exacerbate other deterioration mechanisms such as those that occur in frost, deicer, or sulphate exposures.



Fig. 1.2: Arch Bridge

3) Truss Bridge

A truss bridge is a structural system characterized by its triangulated framework, which consists of interconnected members arranged in triangular units. This configuration provides inherent stability because triangles prevent deformation.



Fig. 1.3: Truss Bridge

B. IRC Class AA Loading

IRC Class AA loading comprises two standard loading cases—tracked and wheeled vehicles. Tracked loading simulates military tanks with high axle loads distributed over metal tracks, while the wheeled configuration represents heavy commercial vehicles with concentrated wheel loads. The tracked vehicle imposes approximately 700 kN total load, whereas the wheeled configuration imposes around 400 kN, making the load case considerably severe.

This loading category is applied to bridges of strategic importance such as border roads, national highways, industrial corridors, and high-density freight routes. Design under Class AA ensures the structure maintains strength, serviceability, and fatigue resistance under extreme load conditions. The loading model also influences impact factors, load distribution to girders, and slab design under wheel contact pressure.

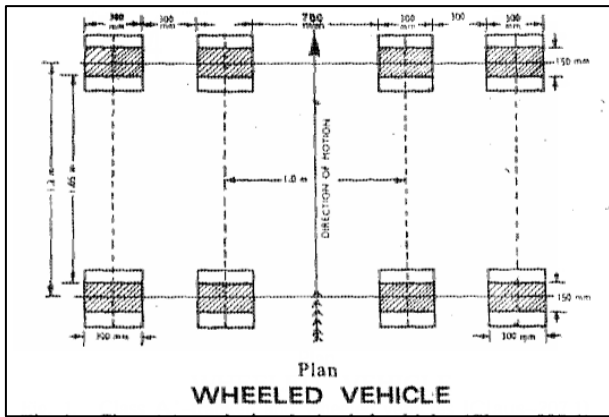


Fig. 1.4: Wheeled Vehicle

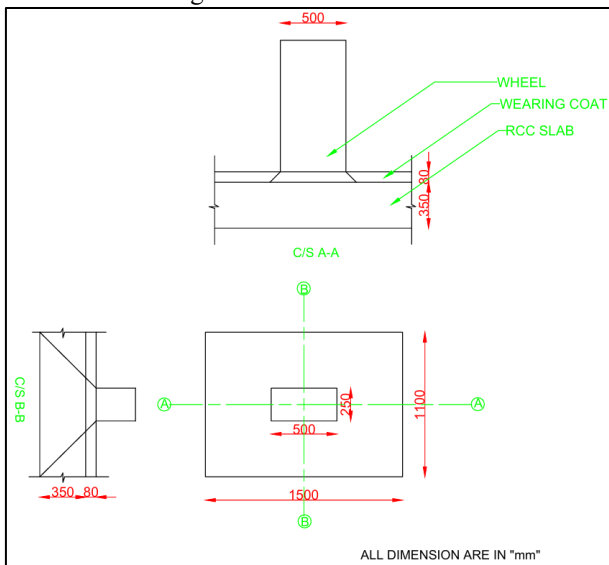


Fig. 1.5: Wheeled Vehicle Details

C. Materials Used in Bridge

Concrete grade selection directly influences durability, strength, and crack resistance of bridge elements. According to IRC specifications, minimum grade M30 is mandated for RCC components to ensure resistance against environmental exposure and repeated loading. For prestressed components, M40 or higher is required due to high compressive stresses and durability demand. Mix design must comply with IS 10262 for achieving required strength and workability.

Besides concrete, reinforcement steel of grade Fe415 or Fe500 is commonly used. For fatigue-prone regions like bridge decks, corrosion resistance and crack control become important considerations.

Minimum Concrete Grade for RCC Bridge as per IRC 21-2000:

Table 5

A) FOR BRIDGES IN PRESTRESSED CONCRETE OR THOSE WITH TOTAL LENGTH MORE THAN 60 M OR THOSE THAT ARE BUILT WITH INNOVATIVE DESIGN/CONSTRUCTION

STRUCTURAL MEMBER	MINIMUM GRADE OF CONCRETE CONDITIONS OF EXPOSURE		MIN. CEMENT CONTENT FOR ALL EXPOSURE CONDITIONS (kg/cu.m)	MAXIMUM WATER CEMENT RATIO CONDITIONS OF EXPOSURE	
	MODERATE	SEVERE		MODERATE	SEVERE
a) PCC members	M25	M30	360	0.45	0.45
b) RCC members	M30	M35	380	0.45	0.40
c) PSC members	M35	M40	400	0.40	0.40

Table 1.1: Minimum Concrete Grade for RCC Bridge

II. LITERATURE REVIEW

A. Analysis of RCC T-Frame Girder Bridge under IRC Loading (2024)

Authors: Akanksha Yadav, Vijay Kumar Shukla, Dr. R. N. Khare Et.al,
Year: 2024

This study analyzes an RCC T-frame girder bridge subjected to IRC Class AA and 70R loading using STAAD.Pro. Different span lengths (20–50 m) and varying girder thicknesses are evaluated to determine their effect on deformation, stresses, and moment distribution. The structural performance parameters such as maximum deformation, von-Mises stress, shear stress, and bending moment are compared across multiple cases. The study concludes that span length and girder thickness significantly influence bridge behaviour, and IRC loading provides reliable design response for short and long-span bridges.

B. Comparative Study of Different Types of RCC Superstructure of Bridge for Cost Optimization (2019)

Authors: Shailendra Singh Yadav, Dr. Rajeev Goel, Dr. Rakesh Mehar Et.al,
Year: 2019

This research compares four RCC superstructure types—rectangular box, trapezoidal box, I-girder, and T-girder—using STAAD.Pro for a 15 m span bridge. The aim is to determine the most economical section with and without footpaths. Results show that trapezoidal box girders are cost-efficient due to better torsional stiffness and reduced material consumption. The study highlights that box girders are more suitable for longer spans, whereas T-beams result in higher bending and displacement.

C. Planning, Analysis & Design of Reinforced Concrete Bridge Near Kanakapura (2024)

Authors: Bikram K. M., Rahul K. Y., Subhash C. Y., Tariqul I. Sani, Dr. S. Kavitha Et.al,
Year: 2024

This paper focuses on designing an RCC bridge near Kanakapura Road using STAAD.Pro for superstructure analysis and IS code manual methods for substructure design. The study analyzes deck slab performance, pier forces, abutment stability, and foundation behavior considering hydrological and soil conditions. The results show safe performance for bending, shear, and seismic deflection limits.

D. Comparative Analysis of Bridges Using RCC Deck Slab (JETIR, 2019)

Authors: Shailendra Singh Yadav, Dr. Rajeev Goel, Dr. Rakesh Mehar Et.al,
Year: 2019

This study compares different RCC bridge configurations including T-beam, I-girder, and box-girder systems. The analysis focuses on effective width method vs finite element method, using load cases such as Class 70R track, wheel, and Class A loading. Findings indicate FEM produces faster and more accurate results than traditional IRC methods. Box girders perform better for longer spans, with lower bending moments and higher torsional stiffness.

E. Comparative Study of Bridge Deck Using Different Span Cases (IJSET, 2024)

Authors: Shivani Korpe, Aisha Bendale, Siddhi Patil, Snehal Patil, Vaishnavi Et.al,

Year: 2019

This paper investigates performance variations in RCC bridge decks under different span arrangements and loading configurations. Span variations were analyzed for displacement, principal stress, and natural frequency values under Class AA loading. Longer spans recorded higher displacement and lower structural stiffness, requiring reinforcement modification. The study recommends span-dependent optimization of girder depth and slab thickness to balance cost and structural safety.

B. Methodology

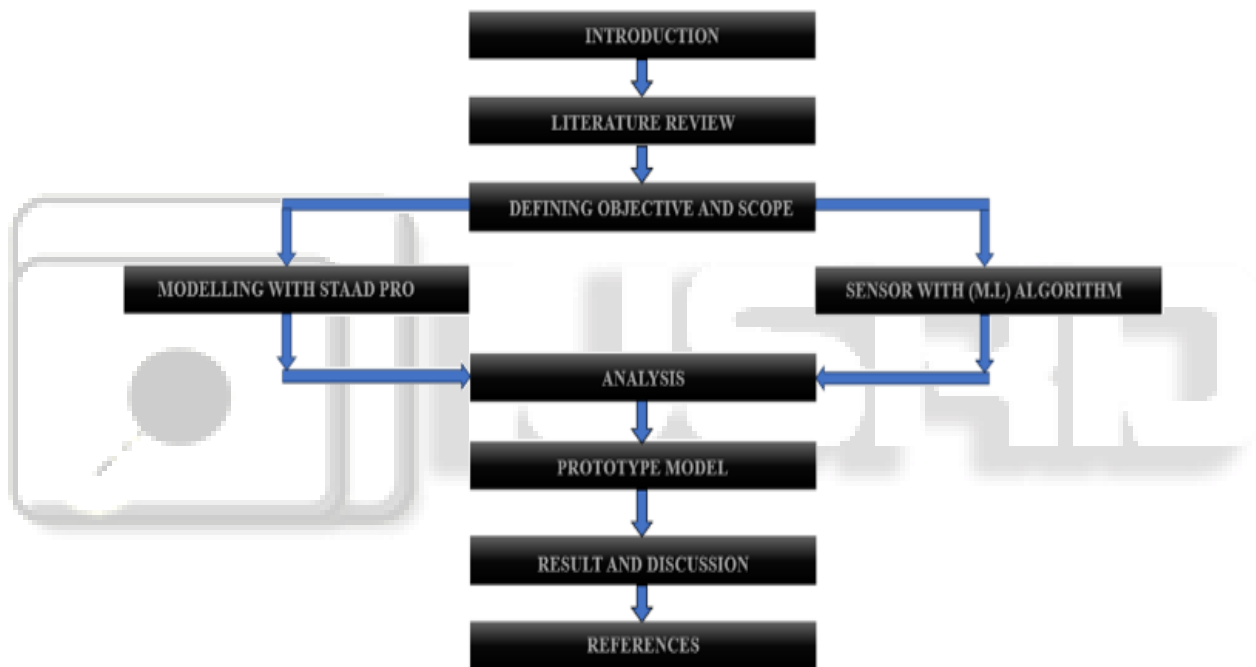


Fig. 3.1: Methodology Chart

The research begins with an Introduction, where the background, need, and importance of analyzing bridge performance under heavy loading conditions are discussed. This is followed by a Literature Review, which presents previous studies related to RCC bridge analysis, load assessment, sensor-based monitoring, and structural evaluation techniques.

Based on literature findings, the Objectives and Scope of the study are defined, ensuring clarity on analytical modelling, real-time testing, and prediction aspects. The methodology then diverges into two parallel approaches:

- 1) Modeling with STAAD.Pro, where the bridge is modeled using IRC Class AA loading to evaluate theoretical structural responses such as bending moments, shear forces, and deflections.

F. Research Gap Identification

The present research aims to fill this gap by combining STAAD.Pro analytical results with sensor-based deflection measurements and data-driven machine learning techniques, creating a more comprehensive and realistic evaluation framework for RCC bridges under IRC Class AA loading.

III. OBJECTIVES AND METHODOLOGY

A. Objectives

- 1) To analyse an RCC bridge under IRC Class AA loading using STAAD.Pro and determine theoretical deflections.
- 2) To measure actual deflections using sensors placed on the bridge model.
- 3) To compare analytical and sensor-based results and develop a machine-learning model for predicting bridge deflection more accurately.

IV. STAAD MODELING

The structural modelling of the RCC bridge was carried out using STAAD.Pro V8i, a widely used finite element software for analyzing bridge superstructures. The modelling process began by defining the geometry of the bridge based on the pre-determined span length and girder spacing. A single-span bridge of 20 m length was modeled with three longitudinal girders spaced at 4.0 m, supporting a reinforced concrete deck slab of 300 mm thickness. The geometry was developed in a wireframe format, followed by meshing the deck with plate elements to accurately simulate slab behavior under wheel loads.

Material properties were assigned according to design requirements—Concrete M30 for structural components and Fe415 grade steel for reinforcement. The density of concrete, modulus of elasticity, Poisson's ratio, and

shear modulus were defined as per IS:456 specifications. Boundary conditions were applied to simulate realistic behavior at supports. Fixed bearings were provided at the abutments, ensuring vertical restraint and preventing displacement in all degrees of freedom, while allowing rotational flexibility to simulate real support behavior.

Loading conditions were applied in accordance with IRC Class AA standards, which include both tracked and wheeled vehicle load models. Moving loads were applied along traffic lanes using influence surfaces generated in STAAD.Pro. Additional loads included self-weight (automatically computed), wearing coat as uniformly distributed load, parapet loads, and impact factors based on IRC specifications.

The model was analyzed to obtain bending moment diagrams, shear force diagrams, support reactions, deflection envelopes, and stress contours for the slab. The results were exported for manual validation and comparison with experimental readings obtained using installed sensors. These analytical results formed the baseline for validating structural performance using real-time data

A. Modelling With Staad Pro

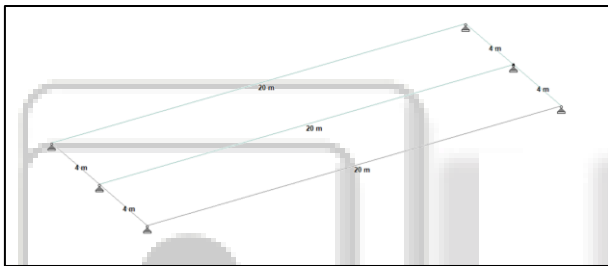


Fig. 4.1: 2D Rendering with Dimensions

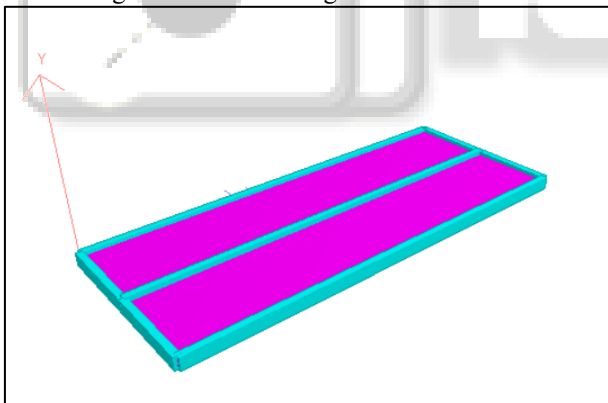


Fig. 4.2: 3D Rendering

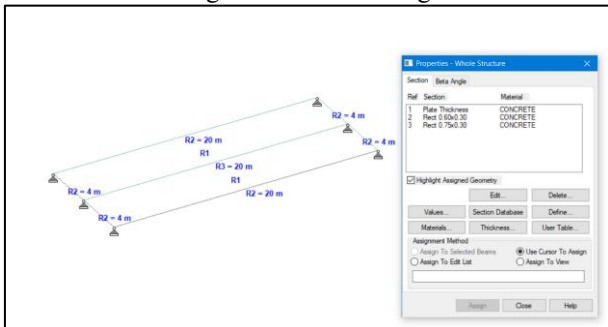


Fig. 4.3: Material Property

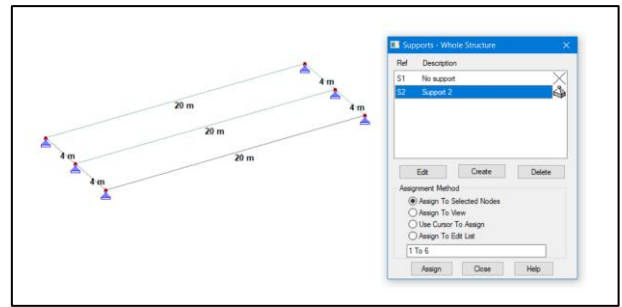


Fig. 4.4: Supports

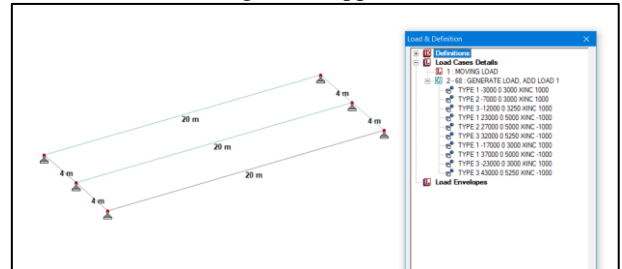


Fig. 4.5: Loading

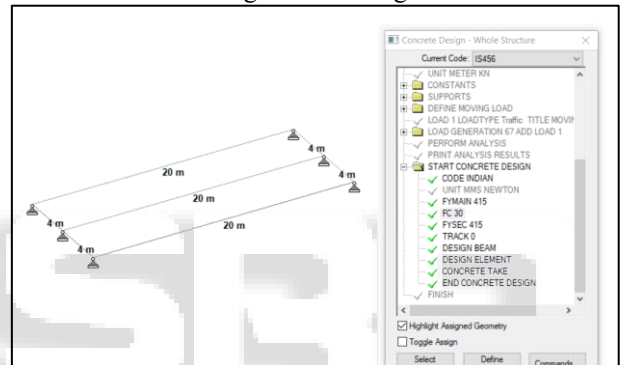


Fig. 4.6: Concrete Design

V. RESULTS & DISCUSSION

The analysis conducted in STAAD.Pro provided detailed insight into the structural response of the RCC bridge under IRC Class AA loading. The maximum bending moment was observed near the mid-span of the longitudinal girders, consistent with theoretical expectations for simply supported slabs subjected to concentrated wheel loads. Shear forces were found to be maximum near supports, requiring adequate shear reinforcement to prevent diagonal tension failures.

Deflection results obtained from STAAD.Pro were compared with the sensor-based measurements recorded during physical loading tests. While the analytical model predicted uniform behavior based on idealized material and boundary assumptions, the sensor data revealed slight variations in local deflections due to real-world factors such as micro-cracks, material imperfections, and load distribution irregularities.

The difference between analytical and sensor readings demonstrated the importance of field-based monitoring, especially for aging structures. The integration of machine learning algorithms further refined prediction accuracy by processing repeated sensor datasets, reducing the error margin between theoretical and actual deflections. Overall, the comparison validated that the analytical assumptions were largely conservative, ensuring safe design margins for serviceability and ultimate limit states.

VI. CONCLUSIONS AND FUTURE SCOPE

A. Conclusions:

- 1) The RCC bridge model analyzed under IRC Class AA loading using STAAD.Pro showed safe performance within permissible limits for bending, shear, and deflection.
- 2) Analytical results demonstrated higher mid-span deflection and maximum bending moment at critical loading positions, confirming expected structural behaviour.
- 3) Sensor-based measurements from the prototype model captured real-time deflection variations influenced by material behaviour, load distribution, and boundary conditions.
- 4) Comparison of results showed minor deviations between analytical and measured values, validating the software model while highlighting the importance of field-based monitoring.
- 5) Integration of machine learning enhanced prediction accuracy by identifying patterns in sensor data and reducing error between theoretical and experimental responses.
- 6) Overall, the study emphasizes that combining FEM-based analysis with sensor data improves reliability, safety assessment, and performance prediction of bridge structures.

B. Future Scope:

- 1) The model can be extended to multi-span or continuous bridges to study load distribution and long-span behaviour.
- 2) Real-time monitoring can be enhanced using IoT-enabled wireless sensors for continuous data collection during service life.
- 3) Machine learning models can be trained on larger datasets to predict long-term deterioration, crack growth, and fatigue behaviour.
- 4) Integration of weather, traffic frequency, and vibration data can improve predictive maintenance strategies.
- 5) Digital Twin technology can be implemented to create virtual real-time replicas of bridge structures for automated assessment.
- 6) The methodology may be applied to steel bridges, composite bridges, and cable-supported systems for broader structural application.
- 7) Advanced deep learning algorithms such as LSTM and CNN can be used for time-series prediction of structural responses under dynamic loads.

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