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Analysis and Design of Minor Bridge Using STAAD Pro Software

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ABSTRACT

This research presents the comprehensive structural analysis and design of a minor reinforced concrete bridge with a span of 11.4 meters, focusing on the deck slab and abutment. The study utilizes STAAD Pro software to simulate real-life conditions, integrating Indian Road Congress (IRC) codes like IRC:5-2015, IRC:6-2017, and IRC:112-2020 for accurate modeling. Manual design calculations were performed for comparison and validation of results. Design parameters such as bending moment, shear force, crack width, and serviceability limits were checked to ensure compliance. The project emphasizes the application of engineering software for optimizing structure design, ensuring safety, durability, and economic feasibility.

Keywords: *Bridge Design, STAAD Pro, Deck Slab, IRC Guidelines, Structural Engineering, Bridge Abutment*

INTRODUCTION

A bridge is a structural element built to span physical obstacles like rivers or roads, enabling uninterrupted transportation. The primary components include the deck slab, the surface on which vehicles travel, and the abutments, which support the ends of the bridge and resist earth pressures. Historically, bridge construction has evolved from simple log structures to complex reinforced and prestressed concrete systems. Today's bridge designs follow standards set by the Indian Roads Congress (IRC), including IRC:5 for general features, IRC:6 for loads, and IRC:112 for concrete structure design. Deck slabs come in various types, including reinforced concrete slabs, voided slabs, T-sections, and box girders. Abutments are classified as gravity, cantilever, counterfort, integral, and others, based on design needs and site conditions.

Modern design approaches follow the IRC standards, including IRC:5-2015 for general design, IRC:6-2017 for loads and loading combinations, and IRC:112-2020 for concrete structures. In this study, the focus is on analyzing a solid slab deck and its abutment using STAAD Pro software and validating results with manual calculations.

LITERATURE REVIEW

Several researchers have extensively explored the application of STAAD Pro in bridge analysis and design, emphasizing its accuracy, efficiency, and compatibility with Indian standards:

1. **Pandit (2024)** emphasized the importance of deck slabs as primary load-carrying elements, analyzing their behavior under both live and dead loads, and highlighted the significance of proper stress distribution for serviceability.
2. **Ashwant (2022)** conducted a comparative study between STAAD Pro simulations and manual calculations for a solid deck slab bridge. The results demonstrated a close correlation, validating the software's reliability for design applications.
3. **Mohaliya (2021)** examined the deck slab design under various IRC 70R load conditions, validating bending moment and shear force values to ensure code compliance and structural performance.
4. **Charaniya & Prajapati (2021)** introduced a comparative approach by analyzing conventional and integral abutment systems, concluding that integral abutments reduce maintenance and improve durability in seismic zones.

5. **Shrivastava & Gautam (2020)** discussed the application of Finite Element Method (FEM), grillage method, and plate theory in bridge deck modeling, indicating FEM as the most adaptable and detailed approach for irregular geometries.
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7. **Kamble & Kadav (2019)** focused on the design of a reinforced concrete deck slab bridge across the Ulhas River using the Working Stress Method and STAAD Pro, presenting a practical workflow for rural bridge design.
8. **Gorini & Callisto (2019)** and **Kuralowicz (2016)** addressed abutment performance under seismic and lateral earth pressure conditions, proposing models for predicting displacement and optimizing abutment geometry to improve resistance and stability.

These studies underline the critical role of STAAD Pro in structural bridge design and reinforce its adoption in academic and professional practice for its accuracy and flexibility with code-based criteria.

MATERIALS AND METHODOLOGY

The methodology adopted for the analysis and design of the minor bridge integrates both manual design principles based on IRC codes and computational modelling through STAAD Pro. The project focuses on a solid slab bridge with a span of 11.4 meters and includes a detailed assessment of both the deck slab and abutment components.

1. Selection of Bridge Type

A solid deck slab type was selected for the superstructure due to its suitability for spans up to 20 meters, simplicity of reinforcement, and cost-effectiveness. The abutment is designed as a gravity wall structure supporting vertical and lateral loads while retaining the embankment.

1) **Dead Load Calculation**:
Calculated based on geometric dimensions and material unit weights.
Slab self-weight: 168.75 kN/m.
Cantilever load: 24.375 kN/m.
Wearing coat and crash barrier included under SIDL.

2) **Live Load Considerations**:
IRC Class A and Class 70R loading applied with respective impact factors (0.27 and 0.25).

3) **Load Combinations**:
Factored combinations were evaluated using Ultimate Limit State (ULS) and Serviceability Limit State (SLS) criteria as per IRC:6-2017 and IRC:112-2020.

4) **Flexural and Shear Design**:
Bending moments and shear forces were calculated manually. Reinforcement was determined based on moment capacity formulas using Fe500 steel and M35 concrete.

5) **Serviceability Checks**:
Crack width, deflection, and stress checks were performed using IRC guidelines. Crack widths were controlled under 0.3 mm, satisfying durability requirements.

3. STAAD Pro Modelling

1) A detailed STAAD Pro model of the bridge was created incorporating:
Plate elements for the deck
Beam elements for support conditions
Material properties: M35 concrete, Fe500 steel 2) Load application included:
Dead loads, live loads, SIDL
Impact factors
Seismic and earth pressure loads for the abutment 3) Analysis output provided:
Bending moments
Shear forces
Displacement and support reactions
4) Results from STAAD were cross-verified with manual design to ensure code compliance.

4. Abutment Design

Designed as a gravity abutment with a height of 9.62 m.
I. Considered:
Earth pressure, surcharge, fluid pressure
Buoyancy effects and seismic forces (Zone III conditions) I. Conducted:
Sliding and overturning checks
Load combination assessments (DL + LL + SIDL + seismic) II. Verified:
Factor of Safety > 1.5 for sliding and overturning
Bearing pressure within permissible SBC (22 t/m²)

This dual-methodology ensures structural integrity, cost-effectiveness, and practical feasibility for minor bridge projects, aligning with Indian Roads Congress standards and modern design practices.

RESULTS AND DISCUSSION

The structural design and analysis of a minor solid slab bridge and its abutments were executed using both manual calculation and STAAD Pro software. The key findings from the STAAD output and manual computations were cross-verified to ensure design consistency with IRC standards.

1.Bending Moment Comparison

The critical bending moment values derived from STAAD Pro at mid-span for the inner slab section were approximately 140.45 KNm under Ultimate Limit State (ULS). Serviceability Limit State (SLS) moments were 98.15 KNm (quasi-permanent) and 53.44 KNm (rare). For the cantilever slab section, ULS moment was 13.1 KNm and SLS moments were 9.48 KNm and 2.88 KNm, respectively. These values are in close agreement with manually computed results, validating the model accuracy.

2.Shear Force Analysis

Shear force distribution also matched the manual and STAAD results. The inner span experienced a maximum factored shear of 25.15 kN/m, translating to a total of 50.29 T (for 0.5 m width). The cantilever showed a lower shear force of 11.99 kN/m or 12.0 T total. No additional shear reinforcement was required per IRC:112-2020 Clause 10.3.2(2), indicating the section's adequacy under ultimate loads.

3. Serviceability Checks (SLS)

Stress checks confirmed compliance with IRC guidelines. Maximum permissible stress in concrete under SLS-Rare and SLS-QP were 16.8 MPa and 12.6 MPa respectively, and actual values remained within these bounds. The crack width under quasi-permanent loading was found to be 0.285 mm, which is below the IRC allowable limit of 0.3 mm. Bar spacing, reinforcement area (Ast), and crack control calculations were also found satisfactory.

4.Reinforcement Summary

The deck slab used:

Main reinforcement: 25 mm dia @ 100 mm c/c
Cantilever reinforcement: 16 mm dia @ 150 mm c/c
Distribution steel: 12 mm @ 130 mm c/c
All reinforcement areas exceeded minimum values required for strength and crack control, as per IRC:112.

5.Abutment Results

The abutment, with a height of 9.62 m, was subjected to combined loads including dead load (841.43 T), buoyancy (-855.19 T), earth pressure (462.4 T), and live load (max reaction 78.5 T). The calculated restoring moments from structural self-weight and return walls exceeded overturning moments from lateral loads. The Factor of Safety (FOS) in both sliding and overturning was greater than 1, meeting stability criteria. Live load combinations were analyzed under both Class A and Class 70R (tracked and wheeled), with impacts included as per IRC 6. Seismic loads, earth pressure, and fluid forces were considered in 14 different load cases to evaluate worst-case scenarios.

6.Shear Capacity Evaltion

Shear reinforcement requirements were checked against IRC 112:2020 Clause 10.3.2(2). STAAD Pro facilitated a faster iterative design process.

7.Stress and Crack Width Checks

Stress in steel/concrete: Within permissible limits
Max crack width: 0.285 mm < 0.3 mm (OK)
Bar spacing check: OK

8.Shear Check

Verified with IRC 112, Clause 10.3.2(2)
No additional shear reinforcement required

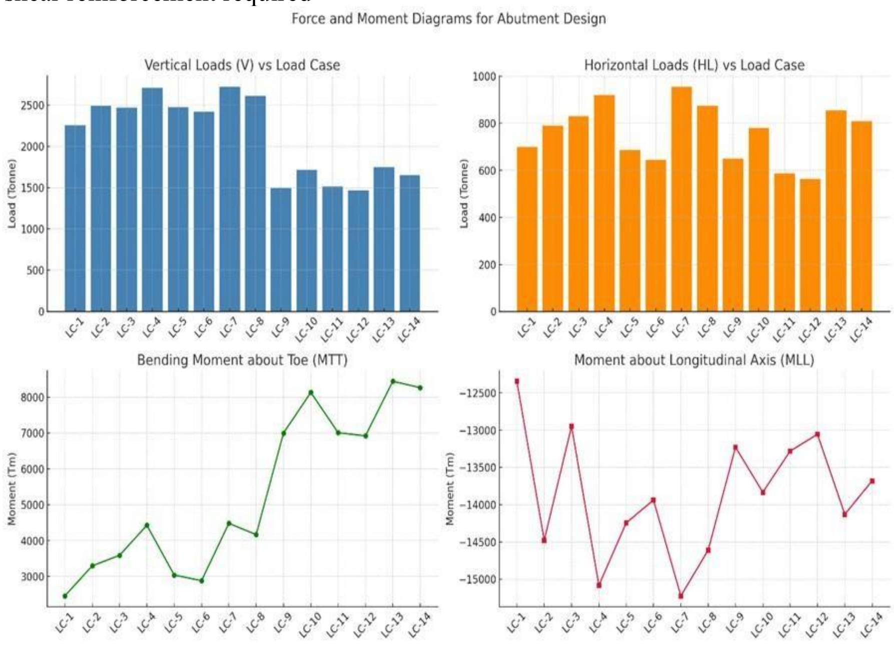

Fig.4.1force and moment diagrams for abutment design

This project focused on the detailed analysis and design of a minor bridge, including the solid deck slab and abutments, using both manual calculations and STAAD Pro software as per IRC codes (IRC 5, 6, 112). The deck was modeled as a solid slab supported over a two-span (2×10 m) bridge with an 18° skew angle, and the abutments were designed for a height of 9.62 m resting.

CONCLUSION

The project titled "Analysis and Design of Minor Bridge Using STAAD Pro Software" was successfully carried out by combining manual design calculations with STAAD Pro-based structural analysis, focusing on both deck slab and abutment design.

Key Conclusions:

I. STAAD Pro Accuracy:

STAAD Pro provided accurate and reliable outputs that were closely aligned with manual calculations under various load combinations.

It efficiently handled load applications, especially for Class A and Class 70R loadings, and supported the design with precise bending moments and shear force results.

II. Deck Slab Design:

The solid slab design was validated through both manual and software methods.

Serviceability checks like crack width, bar spacing, and stress limits met all IRC 112:2020 standards.

The maximum bending moment at ULS for the inner slab was around 140.45 kNm, and shear force was 25.15 kN/m, with no extra shear reinforcement required in most sections.

III. Abutment Design:

The abutment was analyzed under multiple critical combinations including dead load, surcharge, fluid pressure, earth pressure, and seismic forces.

Factor of safety for sliding and overturning was within permissible IRC limits, ensuring stability.

The effects of buoyancy, seismic forces, and live loads were also successfully incorporated in the design.

IV. Compliance with IRC Standards:

The complete design followed guidelines from IRC:5-2015, IRC:6-2017, and IRC:112-2020.

The structure was checked under both Working Stress Method (WSM) and Limit State Method (LSM).

V. Practical Implications:

The approach ensures that small-span bridges can be economically, safely, and efficiently designed using modern software tools.

The model can be adapted and scaled for future bridge projects in similar environmental and structural conditions.

This project demonstrates that combining engineering judgment (manual methods) with softwareassisted design (STAAD Pro) leads to accurate, code-compliant, and efficient bridge structures. It showcases a robust methodology for civil engineers aiming to enhance design precision and structural safety in minor bridge construction.

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