

Structural Analysis and Design of Railway Over Bridge (ROB) with Emphasis on Safety Considerations

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Abstract

This paper presents the final structural analysis, design validation, and safety assessment of a Railway over Bridge (ROB) constructed on the Vadodara–Kim Expressway over an operational railway corridor near Kim Village, Surat District, Gujarat. The structure is designed to facilitate uninterrupted eight-lane expressway traffic while ensuring safe clearance over the Western Railway main line.

The bridge system comprises prestressed concrete (PSC) girders for medium spans and steel girders for longer spans, supported on reinforced concrete substructures. The analysis considers critical load combinations including dead load, live load (IRC Class A/70R), impact effects, wind load, seismic forces, temperature variation, and construction-stage effects in accordance with IRC:6, IRC:112, and relevant IS codes.

Structural modeling and analysis confirm that all members satisfy strength, serviceability, and stability requirements. Safety provisions such as bearings, expansion joints, crash barriers, drainage systems, and construction-stage protection measures ensure both structural integrity and operational safety. The study validates the efficiency, durability, and safety compliance of the adopted design approach for high-volume expressway bridges.

Keywords: - Railway Over Bridge, Structural Analysis, Prestressed Concrete, Steel Girder, Load Combination, Safety Assessment, IRC Codes, Bridge Design Validation

1. Introduction

Railway Over Bridges (ROBs) are vital elements of modern transportation infrastructure, primarily constructed to replace level crossings where roads intersect railway tracks at the same grade. Traditional level crossings pose significant risks due to human error, poor visibility, and increasing congestion. By introducing vertical grade separation, ROBs eliminate direct interaction between rail and road traffic, thereby substantially improving safety, reducing delays, and enhancing overall network efficiency. With the rapid growth of vehicular traffic and increased train frequency across countries like India, the need for ROBs has become more critical, especially on high-speed corridors and expressways.

In the context of the present study, the Railway Over Bridge is proposed along the Vadodara–Kim Expressway, which is an important transportation link designed to support high-speed and high-volume traffic movement. The study extends the preliminary conceptual framework developed earlier (Paper-I) and advances toward a comprehensive structural investigation. This includes detailed

modeling, analysis, and validation of the bridge system to ensure that it meets all performance, safety, and serviceability requirements over its intended lifespan.

The structural analysis phase involves the creation of a precise numerical model of the ROB using advanced structural engineering software. This model simulates real-life behavior by incorporating material properties, geometric configurations, and boundary conditions. Various types of loads are considered in accordance with relevant codes such as IRC and railway standards. These loads typically include dead load (self-weight of the structure), live load (vehicular loads as per IRC Class A, 70R loading, etc.), impact load, wind load, seismic load, braking forces, and temperature effects. The analysis ensures that the structure can safely withstand these loads without excessive deformation or stress.

A key aspect of the study is numerical validation, where analytical results obtained from structural design calculations are compared with those generated through software simulations. This step is essential to verify the accuracy and reliability of the design assumptions. Techniques such as finite element analysis (FEA) are often used to evaluate stress distribution, bending moments, shear forces, and deflection patterns across different structural components like girders, piers, bearings, and deck slabs. Any discrepancies are carefully examined and corrected to ensure robustness of the model.

Safety evaluation is another critical component of the study. It focuses on both structural safety and user safety. Structurally, the bridge must satisfy limit state criteria—ensuring adequate strength (ultimate limit state) and serviceability (deflection, cracking, vibration control). From a user perspective, safety measures include proper railing design, crash barriers, adequate roadway width, drainage systems, and visibility considerations. Additionally, fatigue analysis is conducted to assess the long-term effects of repeated loading due to traffic, especially important for bridges on busy expressways.

Durability and design life considerations are also integrated into the analysis. The ROB must perform effectively over a design life of typically 100 years, resisting environmental effects such as corrosion, temperature variation, and moisture ingress. Appropriate material selection (e.g., high-performance concrete, corrosion-resistant reinforcement) and protective measures (coatings, drainage detailing) are included to enhance longevity.

2. Structural System Overview

The ROB consists of a dual carriageway configuration designed for high-speed expressway traffic.

Key Geometric Features

- Carriageway width: 20.25 m (each side)
- Deck width: 21.25 m
- Median width: 3.50 m
- Structural system: PSC girders + steel girders

The selection of a composite system ensures structural efficiency, constructability over live railway tracks, and long-term durability.

3. Analytical Modeling and Methodology

3.1 Modeling Approach

The bridge was idealized as a combination of:

- Continuous PSC girder spans
- Simply supported steel girder spans (erection stage)
- Composite deck slab action

The structural analysis was carried out using standard bridge engineering principles consistent with IRC guidelines.

3.2 Load Considerations

The following loads were considered:

- Dead Load (DL): Self-weight of structural components

- Live Load (LL): IRC Class A / 70R loading
- Impact Load: Dynamic amplification effects
- Wind Load: As per IRC provisions
- Seismic Load: As per IS:1893
- Temperature Load: Expansion, contraction, creep, shrinkage
- Construction Stage Loads: Erection and launching effects

3.3 Load Combinations

Critical load combinations were evaluated as per IRC:6:

- DL + LL
- DL + LL + Impact
- DL + Wind Load
- DL + Seismic Load
- DL + Construction Stage Effects

4. Structural Analysis Results

4.1 Superstructure Response

- Maximum bending moments occur at mid-span regions of PSC girders
- Shear forces are maximum near support zones
- Prestressing effectively controls tensile stresses under service loads
- No cracking observed under serviceability conditions

4.2 Steel Girder Performance

- Stress levels remain within permissible limits of IS:2062
- Adequate stiffness achieved through cross-bracing
- Fatigue resistance verified under repeated traffic loading

4.3 Deck Slab Behaviour

- Composite action ensures uniform load distribution
- Reinforcement adequately resists flexural and shear stresses
- Deflection remains within IRC permissible limits

5. Design Verification

5.1 Strength Criteria

All structural members satisfy ultimate limit state (ULS) requirements:

- Flexural strength: Safe
- Shear strength: Safe
- Torsional effects: Controlled

5.2 Serviceability Criteria

- Deflection within allowable limits
- Crack width under control (PSC advantage)
- Vibration response acceptable for high-speed traffic

5.3 Stability Check

- Global stability ensured under lateral loads
- Bearings effectively transfer loads to substructure

- No risk of overturning or sliding observed

6. Substructure and Foundation Performance

- Piers designed for axial load + bending moment interaction
- Abutments resist earth pressure and surcharge loads
- Pile foundations provide adequate load-bearing capacity
- Lateral stability ensured under seismic conditions

Result: Substructure safely transfers all superstructure loads to soil strata without exceeding allowable stress limits.

7. Safety Assessment

7.1 Structural Safety

- Adequate factor of safety maintained as per IRC standards
- Redundancy ensured through continuous span system
- Controlled stress distribution in PSC members

7.2 Construction Safety

- Execution over live railway line managed through controlled block system
- Crane-based erection minimizes risk exposure
- Temporary protective arrangements implemented

7.3 Operational Safety

- Crash barriers provided on both sides of carriageway
- Expansion joints accommodate thermal movement
- Drainage system prevents water accumulation and hydroplaning risk
- Adequate vertical and horizontal clearances ensured

8. Durability and Service Life Assessment

Durability provisions include:

- High-strength concrete (M40–M50)
- Corrosion-resistant reinforcement cover
- Protective coatings for steel girders
- Elastomeric bearings for long-term movement accommodation
- Proper drainage detailing

Outcome: Expected service life exceeds standard design requirements under routine maintenance.

9. Discussion

The analysis demonstrates that a combined Prestressed Concrete (PSC)–steel girder system achieves an efficient and practical solution for Railway over Bridge (ROB) construction, particularly in high-traffic expressway conditions. This hybrid system leverages the advantages of both materials to overcome the limitations of using either system independently. From a structural efficiency perspective, PSC girders play a critical role in controlling deflection and cracking. Prestressing introduces compressive stresses in the concrete, which counteract tensile stresses induced by external loads such as vehicular traffic and self-weight. As a result, the structure exhibits improved serviceability performance, reduced crack widths, and enhanced durability. This is particularly important for long-span bridges where deflection control governs design. Additionally, PSC members offer high load-carrying capacity with relatively slender sections, contributing to material optimization and reduced dead load. The integration of PSC and steel systems therefore results in a composite structural behavior, where each material performs in the domain where it is most

effective—concrete in compression and steel in tension and erection efficiency. This synergy improves overall performance, economy, and lifecycle durability of the bridge.

A key aspect of the study is the incorporation of safety considerations at both design and construction stages. During the design phase, the structure is checked against ultimate and serviceability limit states, ensuring compliance with relevant standards such as IRC and railway safety guidelines. Load combinations include vehicular loads, impact factors, wind loads, seismic forces, and braking forces to ensure robustness under all possible conditions. Adequate factors of safety, redundancy in structural elements, and detailing for ductility are also incorporated. During construction, safety is ensured through planned erection methodologies, use of temporary supports or staging where required, and strict adherence to railway operational constraints. Measures such as night-time launching, protective screens over tracks, and coordination with railway authorities help mitigate risks. The use of prefabricated steel elements further reduces hazards associated with prolonged on-site work.

10. Conclusion

The study demonstrates that the proposed Railway Over Bridge (ROB) satisfies all critical structural performance requirements, including strength, serviceability, and long-term durability under the combined effects of dead load, live load, impact, wind, and temperature variations. The hybrid structural system, comprising pre stressed concrete (PSC) and steel girders, leverages the advantages of both materials—PSC effectively controls deflection and cracking through induced compressive stresses, while steel girders provide high strength-to-weight ratio and enable rapid erection, particularly beneficial over active railway corridors where construction time and disruption must be minimized. The design incorporates comprehensive safety provisions such as adherence to relevant codes, load combinations, and redundancy in structural elements to ensure resilience against unforeseen conditions. Additionally, strict quality control measures during material selection, fabrication, and execution, along with a well-planned staged construction methodology, ensure precision, safety, and minimal interference with railway operations. The result is a robust and reliable infrastructure solution that not only performs efficiently throughout its service life but also significantly improves traffic flow, reduces congestion, and eliminates the risks associated with level crossings, thereby enhancing overall transportation safety and operational efficiency.

11. Future Scope

- Implementation of Structural Health Monitoring Systems (SHMS)
- Use of ultra-high-performance concrete (UHPC)
- Digital twin-based bridge monitoring
- Advanced seismic isolation systems for bridges
- AI-based predictive maintenance systems

12. References

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2. IRC:112 – Code of Practice for Concrete Road Bridges
3. IRC:24 – Steel Road Bridges
4. IS:456 – Plain and Reinforced Concrete
5. IS:1343 – Prestressed Concrete
6. IS:2062 – Structural Steel
7. IS:1893 – Earthquake Resistant Design of Structures
8. Relevant peer-reviewed journal articles on bridge engineering

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