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PARAMETRIC STUDY ON THE BEHAVIOUR OF POST-TENSIONED RECTANGULAR AND TRAPEZOIDAL BOX-GIRDER BRIDGES USING FEM AND CLASSICAL METHODS

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ABSTRACT

Box-girder bridges, characterized by their hollow box-shaped sections, are widely used in modern infrastructure due to their high torsional rigidity, flexural strength, and aesthetic appeal. This study investigates the structural performance of two common box-girder cross-sections—rectangular and trapezoidal—under various loading conditions. A simply supported, single-cell post-tensioned concrete box-girder of 40 m span is analyzed. Dimensions are determined as per IRC-18 and subjected to Class A and Class 70R vehicular loading as per IRC-6. Both classical beam theory and finite element method (FEM) using CSI Bridge software are employed. Results show that the rectangular section demonstrates higher torsional shear stress (by 45%) but lower deflection compared to the trapezoidal section. The bending stress in the rectangular section is 13% lower than in the trapezoidal section. Additionally, prestress loss is found to be 5% higher in the rectangular section. The FEM results closely match manual calculations, validating the modeling approach. This study provides comparative insights into the performance of typical box-girder geometries, aiding in more effective design selection for medium-span bridges.

Keywords: Box-Girder Bridge, Finite Element Method, CSI Bridge, Post-Tensioned Concrete, Trapezoidal Girder, Torsional Stress

1. INTRODUCTION

Box-girder bridges are widely preferred for medium to long-span crossings due to their structural efficiency, high torsional rigidity, and suitability for prestressing. Their closed cellular configuration enables excellent load distribution, especially under eccentric vehicular loads. The evolution of box-girder bridges has paralleled advancements in prestressed concrete technology since the 1930s. Post-tensioning in box-girders allows for longer spans and reduced dead load by balancing internal stresses. This study focuses on comparing the structural behavior of rectangular and trapezoidal single-cell box-girders using both classical and FEM approaches. This is crucial for accurate design, serviceability, and economy in real-world applications.

2. LITERATURE REVIEW

Numerous studies have addressed the structural behavior of box-girder bridges. Membrane theory and plane frame analyses have been used for simplified modeling [1]. Finite element models (FEM), particularly using shell elements, have proven superior in capturing three-dimensional behavior including warping and torsional effects [2,3].

Comparisons between AASHTO and IRC loading standards show variations in safety margins and cost implications [4]. Prestress loss and crack resistance have also been evaluated experimentally [5]. In many studies, the FEM approach using CSI Bridge or SAP2000 has provided accurate assessments of bending stress, shear stress, and deflection [6,7]. Geometrical optimization, including the number of cells and shape of box sections, significantly impacts stress distribution [8,9].

3. METHODOLOGY

A parametric study is performed on simply supported single-cell rectangular and trapezoidal box-girders of 40 m span under IRC Class A and Class 70R loading.

3.1. CLASSICAL ANALYSIS

- Flexural and torsional stresses are computed using standard beam theory.
- Longitudinal and shear stress are derived from flexural formulas.
- Torsional shear stress is computed using St. Venant's theory.

3.2. FINITE ELEMENT ANALYSIS

- CSI Bridge software is used to model both cross-sections.
- 4-noded shell elements are used with tendon profiles incorporated.
- Boundary conditions simulate simple supports; live loads applied per IRC-6.

3.3. MODEL VALIDATION

- Manual and FEM results for bending moments under Class A and 70R loading are compared.
- Differences in results are within 2%, validating the FEM model.

3.4. PARAMETERS STUDIED

- Bending moment and stress
- Shear force and stress
- Torsional shear stress
- Prestress loss
- Mid-span deflection

4. RESULTS AND DISCUSSIONS

4.1. BENDING AND SHEAR BEHAVIOR

- The trapezoidal section experiences 13% higher compressive and 3% higher tensile stress than the rectangular under DL+LL.
- Under DL+PS, these values are 4% and 13% higher respectively.
- The shear stress is 21% higher in the rectangular section.

4.2. TORSIONAL PERFORMANCE

- Torsional shear stress in rectangular section ranges from 0.24 to 0.36 N/mm^2.
- In trapezoidal section, torsional stress ranges from 0.13 to 0.2 N/mm^2.

- Rectangular section shows 45% greater torsional resistance, indicating better performance in curves or eccentrically loaded spans.

4.3. DEFLECTION AND PRESTRESS LOSS

- Trapezoidal box-girder deflects 2% more than rectangular.
- Prestress loss is 5% higher in rectangular due to longer tendon paths and stress concentrations.

4.4. VALIDATION OF FEM

- Manual bending moment for IRC Class A = 4431.1 kNm
- FEM bending moment for IRC Class A = 4467.7 kNm
- Manual and FEM shear values closely matched, confirming model accuracy.

5. CONCLUSION

This comparative study highlights the structural advantages and trade-offs between rectangular and trapezoidal box-girders. While the rectangular section provides better torsional performance and lower deflection, the trapezoidal section shows more favorable bending stress characteristics. FEM analysis using CSI Bridge software offers reliable predictions and closely matches classical methods, validating its application for complex bridge geometries. The study aids designers in selecting appropriate geometries based on structural requirements and loading scenarios.

CONFLICT OF INTERESTS

None.

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