

ANALYSIS AND DESIGN OF SIMPLY SUPPORTED RCC BRIDGE FOR VEHICLE LOADS

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ABSTRACT

Reinforced concrete T-beam bridges are among the most common superstructures used for highway spans of 12 m to 25 m in India. The deck slab and the longitudinal girders act together as flanged beams, which gives an efficient section for resisting the large bending moments produced by heavy vehicles. This study presents the analysis and design of a simply supported RCC T-beam bridge with an effective span of 20 m for a two-lane national highway, with particular emphasis on the effect of the vehicle loads specified in IRC 6:2017 on the deck slab, longitudinal girders and cross girders. The superstructure consists of three longitudinal girders spaced at 2.5 m, cross girders at the supports and at mid-span, and a 250 mm thick deck slab with cantilever overhangs carrying crash barriers. The carriageway width is 7.5 m. The main live loads considered are IRC Class A loading in two lanes and Class 70R wheeled and tracked loading, with the impact factors specified in IRC 6. Because the distribution of vehicle load among the girders strongly influences the design, the transverse distribution is studied using both the classical Courbon method and a grillage model in STAAD.Pro.

The deck slab panels between the girders are analysed for concentrated wheel loads using Pigeaud's method, which accounts for the two-way action of slabs supported on four sides. The longitudinal girders are analysed for the absolute maximum bending moment and maximum shear force under moving loads, and influence lines are used to identify the critical positions of the Class A train and the Class 70R vehicle. The grillage model, consisting of longitudinal members representing the girders and transverse members representing the slab and cross girders, is loaded with the IRC vehicles through the moving load generator of STAAD.Pro.

The girders are designed as T-beams for the ultimate limit state of flexure and shear according to IRC 112:2011, and they are checked for the serviceability limit states of stress, crack width and deflection. The deck slab and cross girders are also designed, and the reactions at the supports are used for the selection of elastomeric bearings. The results from the Courbon method and the grillage analysis are compared to assess the accuracy of the simplified method for the adopted girder spacing and cross girder arrangement.

The study finds that the Class 70R tracked vehicle governs the bending moment in the outer girder when placed eccentrically, while two lanes of Class A loading govern the moment in the central girder. The Courbon method gives outer girder moments about 9 percent higher than the grillage analysis, which shows that it is conservative for this configuration. The design results in girders of 1.6 m overall depth with a web thickness of 300 mm. The work provides a clear procedure for the design of T-beam bridges under IRC loading and can be extended to continuous and prestressed girder bridges.

I. INTRODUCTION

The rapid expansion of the national and state highway network in India has created a steady demand for bridges that can carry heavy traffic safely and economically. Highway bridges must be designed not only for their own weight but also for the loads of heavy commercial vehicles, military vehicles and special loads that may travel on the route during the service life of the structure. The Indian Roads Congress specifies standard vehicle loadings in IRC 6 that represent these vehicles in an idealised form, and the design of the superstructure depends mainly on how these loads are placed and distributed within the deck.

For spans between about 12 m and 25 m, the reinforced concrete T-beam bridge is a widely used form of superstructure. It consists of a deck slab cast monolithically with longitudinal girders, so that a part of the slab acts as the compression flange of each girder. Cross girders or diaphragms connect the longitudinal girders and help distribute concentrated loads among them. This arrangement uses concrete efficiently, since the material is concentrated in the flange and web where it is needed, and it can be constructed with conventional formwork without the specialised equipment required for prestressed concrete.

The key difficulty in the design of a T-beam bridge lies in determining the share of vehicle load carried by each girder. When a heavy vehicle travels close to one kerb, the girder nearest to it carries a much larger share of the load than the others. Classical methods such as Courbon's method assume that the cross girders are infinitely stiff, while more general methods such as the Hendry-Jaeger and Morice-Little approaches take account of the actual torsional and flexural stiffness of the deck. Grillage analysis using computer software represents the deck as a network of beams and gives a more general and flexible solution for load distribution.

This paper presents the analysis and design of a simply supported RCC T-beam bridge of 20 m span for a two-lane highway under IRC Class A and Class 70R vehicle loads. The objectives are to analyse the deck slab using Pigeaud's method, to determine the maximum bending moments and shear forces in the girders using influence lines, to compare the transverse load distribution obtained from Courbon's method and a grillage model in STAAD.Pro, and to design the slab, longitudinal girders and cross girders according to IRC 112:2011. The study aims to show students how vehicle loads govern the design of a typical highway bridge.

II. LITERATURE SURVEY

The development of standard vehicle loadings for highway bridges in India has been traced by several researchers, who describe how the loadings in IRC 6 were derived to represent the heaviest vehicles expected on Indian roads. The Class AA and later Class 70R loadings were introduced to represent military tanks and heavy trailers, while Class A represents a train of heavy commercial vehicles and Class B is used for temporary structures and lightly used roads. Studies comparing these loadings for spans of 10 m to 40 m found that the Class 70R tracked vehicle generally governs the bending moment for shorter spans because its load of 700 kN is concentrated over a length of 4.57 m, while Class A loading becomes more critical as the span increases and more axles can be placed on the span. Researchers have also studied the effect of the 2014 and 2017 revisions of IRC 6, which modified the impact factor provisions and introduced the special vehicle, and reported moderate increases in design moments for some spans. These studies emphasise that all specified loadings must be checked because the governing case depends on span and girder position.

The transverse distribution of vehicle loads among the girders of a bridge deck has been a major topic in bridge engineering research. Courbon's method, which assumes rigid cross girders and linear variation of deflection across the deck, is widely used in India because of its simplicity, and IRC practice accepts it when the span to width ratio exceeds about two and sufficient cross girders are provided. Researchers comparing Courbon's method with more rigorous approaches reported that it overestimates the share of load on the outer girder and underestimates it for the inner girder when the cross girders are relatively flexible. The Hendry-Jaeger method and the Morice-Little adaptation of the Guyon-Massonnet method account for the flexural and torsional stiffness of the deck through distribution coefficients and were found to agree well with experimental results on model bridges. Several studies concluded that Courbon's method is generally conservative for the outer girder, which usually governs the design, and therefore remains acceptable for routine design.

Grillage analysis has become the most common computer-based method for studying load distribution in beam and slab decks. In this method, the deck is idealised as a plane grid of longitudinal and transverse beam members, each with flexural and torsional properties representing the portion of the deck it models. Researchers have given detailed guidelines for the selection of member spacing, the calculation of torsional constants for T-sections, and the representation of the slab by transverse members. Studies that compared grillage results with three-dimensional finite element models found that a properly constructed grillage predicts girder moments within about five percent. The moving load generators available in STAAD.Pro and similar programs allow IRC vehicles to be moved over the grillage in several transverse positions, which makes it possible to find the governing load case for each girder systematically. Authors have cautioned, however, that the torsional stiffness of cracked concrete members should be reduced suitably, since uncracked values can overstate the load sharing between girders.

The analysis of deck slabs under concentrated wheel loads has been studied since the development of plate theory. Pigeaud's method, based on the elastic analysis of rectangular plates simply supported on four edges, provides coefficients for the moments in the short and long directions due to a load uniformly distributed over a rectangular area. This method is commonly used in India for the design of interior slab panels of T-beam bridges, with a continuity factor applied to account for the restraint provided by the girders. Researchers comparing Pigeaud's method with finite element analysis of continuous slab panels found that it gives reasonable values for the short span moment but can underestimate the moments when several wheels are placed on adjacent panels. The effective width method of IRC 112 is used for the cantilever slab and for one-way slabs. Studies have also highlighted the importance of the punching shear check under heavy wheel loads, particularly for thin deck slabs carrying the Class 70R vehicle.

The design of reinforced concrete bridge girders according to the limit state approach of IRC 112:2011 has been examined in several comparative studies. Researchers comparing designs made according to the working stress method of IRC 21 with those made according to IRC 112 reported that the limit state design generally gives a small saving in reinforcement for flexure, but the serviceability checks of stress limitation and crack width often govern the final amount of steel. The shear design provisions of IRC 112, based on the variable strut inclination method, were found to give lower shear reinforcement in many cases compared with the older method. Other studies

examined the economy of T-beam bridges for different girder spacings and numbers of girders and concluded that three or four girders with spacing between 2.4 m and 2.8 m give an economical design for a two-lane carriageway. The present work builds on these studies by applying the IRC 6 vehicle loads, comparing the Courbon method with grillage analysis, and designing all superstructure components according to IRC 112.

III. SYSTEM ANALYSIS

The structure studied is a simply supported RCC T-beam bridge with an effective span of 20 m carrying a two-lane carriageway of 7.5 m with crash barriers of 0.5 m on each side, giving an overall deck width of 8.5 m. The superstructure consists of three longitudinal girders at 2.5 m centres, each with an overall depth of 1.6 m and web thickness of 300 mm, cross girders at both supports and at mid-span, and a 250 mm deck slab with 1.25 m cantilevers. M35 concrete and Fe500 reinforcement are adopted, and the deck carries a 65 mm wearing coat. The dead loads include the self-weight of slab, girders and cross girders, wearing coat and crash barriers. The live loads are IRC Class A loading in two lanes and Class 70R wheeled and tracked vehicles, with impact factors as per IRC 6:2017. The parameters studied are the slab panel moments, the absolute maximum bending moment and shear in each girder, the transverse distribution coefficients, cross girder forces, support reactions, stresses, crack width and deflection.

Existing System

In conventional practice, the design of T-beam bridges for vehicle loads is carried out mainly by manual calculation. The deck slab panels are analysed using Pigeaud's curves read from charts, which involves interpolation and is prone to reading errors. The live load on the girders is distributed using Courbon's method, in which reaction factors are calculated for a few assumed positions of the vehicle, and the maximum moment is obtained by placing the vehicle at mid-span or by using influence lines drawn by hand. Only a limited number of vehicle positions can be examined in this way, so the absolutely critical position is sometimes missed, especially for the Class A train with its many axles. The effect of the flexibility of cross girders and the torsional stiffness of the deck on load distribution is not considered. Many existing designs still follow the working stress method of IRC 21, and the serviceability checks of IRC 112 for crack width and stress limitation are carried out only for the main girder section at mid-span.

Disadvantages of Existing System

- Reading Pigeaud's curves by hand introduces interpolation and reading errors.
- Only a few vehicle positions can be examined manually along the span.
- The absolute maximum moment under the multi-axle Class A train may be missed.
- Courbon's method assumes rigid cross girders regardless of their actual stiffness.
- Torsional stiffness of the deck is ignored in the transverse distribution.
- Separate calculations are needed for each IRC loading and girder position.
- Working stress designs do not follow the limit state approach of IRC 112.
- Crack width and stress checks are often limited to the mid-span section.
- Shear at sections near the supports is not checked at enough locations.
- Comparing alternative girder spacings requires repeating all calculations.

Proposed System

The proposed approach combines classical methods with grillage analysis in STAAD.Pro to evaluate the effect of IRC vehicle loads on a simply supported T-beam bridge. The deck slab panels are analysed using Pigeaud's coefficients for Class 70R and Class A wheel loads, and the cantilever slab is analysed by the effective width method. For the girders, influence lines for moment and shear are used with Courbon's reaction factors to obtain the design forces. A grillage model is then created in STAAD.Pro with longitudinal members representing the three girders with their effective flange widths, transverse members at about 1.0 m spacing representing the deck slab, and cross girder members with their actual properties, using reduced torsional constants for cracked concrete. The Class A and Class 70R vehicles, with impact factors from IRC 6, are defined in the moving load generator and moved along several transverse paths. The girder moments and shears from both methods are compared, and the slab, girders and cross girders are designed and checked according to IRC 112:2011.

Advantages of Proposed System

- Evaluates every IRC vehicle in several transverse positions across the deck.
- Finds the absolute maximum moment and shear using moving load analysis.
- Represents the actual flexural and torsional stiffness of girders and cross girders.
- Provides a direct comparison between Courbon's method and grillage results.
- Identifies which girder and which vehicle govern each design force.
- Gives bending moment and shear envelopes along the full length of every girder.
- Applies the limit state design and serviceability checks of IRC 112 consistently.
- Allows shear to be checked at many sections between support and mid-span.
- Makes it easy to study alternative girder spacings and cross girder layouts.
- Provides support reactions directly for the selection of bearings.

IV. METHODOLOGY

The methodology begins with fixing the span, carriageway width and girder arrangement, and with the preliminary sizing of the deck slab, longitudinal girders and cross girders using common span to depth ratios. The dead loads of the slab, girders, cross girders, wearing coat and crash barriers are calculated. The deck slab is designed first by analysing interior panels with Pigeaud's method for the Class 70R tracked and wheeled vehicles and Class A wheels, using a continuity factor for the girder restraint, and by analysing the cantilever by the effective width method. For the girders, the influence lines for bending moment and shear are used to locate the critical vehicle positions, and Courbon's reaction factors give the share of each girder. The grillage model is then built in STAAD.Pro, the vehicles are moved over it, and the girder forces are compared with the manual values. The girders are designed as T-beams for flexure and shear to IRC 112, checked for stress, crack width and deflection, and the cross girders and bearings are designed.

SYSTEM ARCHITECTURE

The workflow of the study is organised in stages that lead from the bridge configuration to the final design of the superstructure. The Configuration stage fixes the span, carriageway width, number and spacing of girders and cross girders. The Preliminary Sizing stage selects slab thickness, girder depth and web width. The Dead Load stage calculates the permanent loads on the slab and girders. The IRC Vehicle

Load stage defines Class A and Class 70R loadings with impact factors from IRC 6. The Deck Slab Analysis stage applies Pigeaud's method and the effective width method. The Influence Line and Courbon stage finds the critical vehicle positions and the girder load shares. The Grillage Modelling stage builds and loads the deck grid in STAAD.Pro with moving loads. The Comparison stage evaluates the Courbon and grillage results for each girder, and the Design stage designs the slab, girders and cross girders and checks serviceability to IRC 112.

Analysis and Design of Simply Supported RCC Bridge for Vehicle Loads

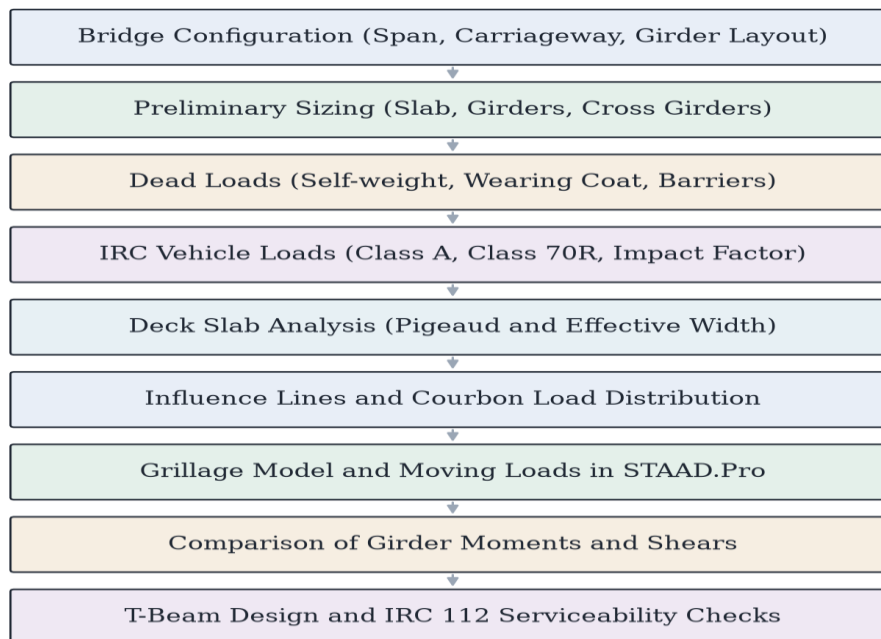


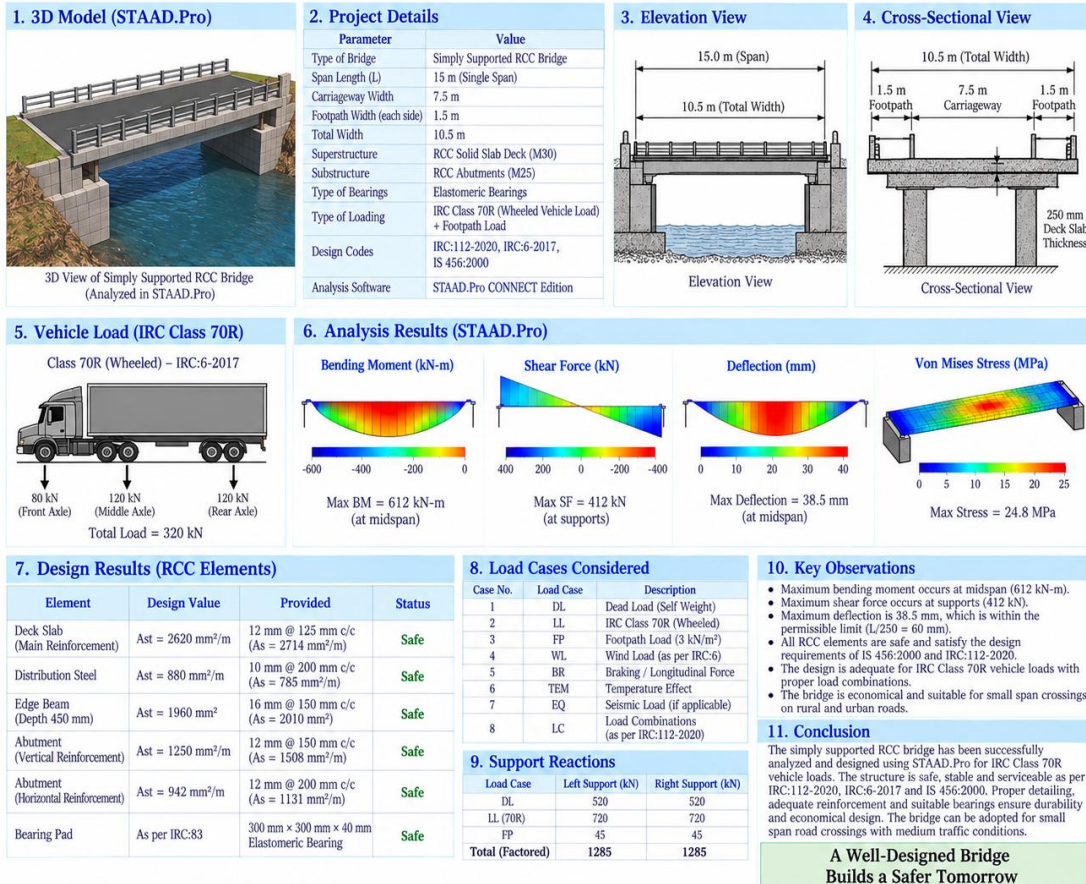
Fig. 1 System Architecture

V. RESULT AND OUTPUT

ANALYSIS AND DESIGN OF SIMPLY SUPPORTED RCC BRIDGE FOR VEHICLE LOADS

(As per IRC:112-2020, IRC:6-2017 and IS 456:2000)

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VI. CONCLUSION

The analysis and design of a simply supported RCC T-beam bridge of 20 m effective span for a two-lane highway has been carried out for IRC Class A and Class 70R vehicle loads as specified in IRC 6:2017. The deck slab, longitudinal girders and cross girders were analysed using classical methods and a grillage model in STAAD.Pro, and all components were designed according to the limit state provisions of IRC 112:2011. The study shows clearly how the type and position of the vehicle govern the design forces in each part of the superstructure.

The deck slab analysis by Pigeaud's method showed that the Class 70R wheeled vehicle governs the short span moment in the interior panels, while the punching shear under the heaviest wheel was within the permissible limit for the 250 mm slab. For the girders, the Class 70R tracked vehicle placed near the kerb produced the maximum moment in the outer girder, and two lanes of Class A loading produced the maximum moment in the central girder. The moving load analysis identified the absolute maximum moment position slightly away from mid-span for the Class A train, which is difficult to locate by manual trial.

The comparison of load distribution methods showed that Courbon's method gave outer girder moments about 9 percent higher than the grillage analysis and inner girder moments slightly lower, which agrees with the observations reported in the literature for decks with moderately stiff cross girders. The girders with 1.6 m overall

depth and 300 mm web satisfied the ultimate limit state of flexure and shear, and the stress, crack width and deflection checks of IRC 112 were also satisfied. The mid-span deflection under live load remained well within the permissible limit of span divided by 800.

The study shows that combining classical methods with grillage analysis gives a reliable and well-checked design for T-beam bridges under IRC vehicle loads. Future work can extend the study to continuous T-beam bridges, skew decks where load distribution becomes more complex, prestressed concrete girders for longer spans, and the effect of the special vehicle loading of IRC 6 on existing bridges. A three-dimensional finite element model of the deck can also be used to verify the grillage results and study local effects near the supports.

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