

ANALYSIS AND DESIGN OF SMALL RCC BRIDGE

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ABSTRACT

Small bridges and culverts form the largest number of bridge structures on the road network of India. They are built to carry rural roads, district roads and state highways across streams, canals and drainage channels, and although each structure is modest in size, their total number makes their economical and safe design important. This study presents the analysis and design of a small reinforced cement concrete slab bridge with a clear span of 8 m, intended to carry a two-lane rural road over a seasonal stream. The design follows IRC 6:2017 for loads and IRC 112:2011 for the design of concrete road bridges.

The bridge is a simply supported solid slab deck resting on reinforced concrete abutments with open foundations, and the superstructure is supported on elastomeric bearings. The deck is 8.4 m wide, providing a carriageway of 7.5 m with crash barriers on both sides, and it carries a 65 mm wearing coat. The hydraulic design of the bridge is carried out first to determine the design discharge, the linear waterway, the high flood level and the scour depth, so that the deck level and foundation depth are fixed on a rational basis before the structural design is attempted.

The deck slab is modelled in STAAD.Pro as a plate grillage and also analysed by the effective width method, which is the traditional approach for solid slab bridges. Dead load of the slab, superimposed dead load from the wearing coat and crash barriers, and live loads corresponding to IRC Class A and Class 70R vehicles are considered, along with the impact factor specified in IRC 6. The moving load facility of the software is used to place the vehicles at the positions that produce maximum bending moment and shear force in the slab.

The slab is designed for the ultimate limit state of flexure and shear and checked for the serviceability limit states of stress, crack width and deflection according to IRC 112. The abutments are designed for the vertical reactions from the superstructure, the earth pressure from the backfill, the live load surcharge and the braking force, and their stability against overturning and sliding is verified. The base pressure under the abutment footing is kept below the safe bearing capacity of the foundation soil.

The results show that the Class 70R wheeled vehicle governs the design bending moment in the slab for this span, and a slab thickness of 650 mm with 25 mm diameter main bars is found adequate. The moments obtained from the plate model and from the effective width method agree within about eight percent. The study demonstrates a complete and practical procedure for the design of small bridges and can be extended to box culverts, skew slab bridges and multi-span slab bridges.

I. INTRODUCTION

Road transport carries the major share of passenger and freight movement in India, and the road network depends on a very large number of bridges and cross-drainage works. For every major river bridge on a highway, there are dozens of small bridges and culverts that allow the road to cross minor streams, irrigation canals and natural drainage paths. Programmes for rural connectivity have further increased the

construction of small bridges, since villages that become isolated during the monsoon need all-weather access to markets, schools and health facilities.

A small bridge is generally defined as one with a total length between 6 m and 60 m, and structures with spans below 6 m are termed culverts. For spans up to about 10 m, a solid reinforced concrete slab deck is usually the most economical choice because it is simple to construct, requires uncomplicated formwork and reinforcement, and can be cast in a single operation. Such bridges are designed as simply supported slabs spanning between abutments, and they must carry the heavy vehicle loads specified by the Indian Roads Congress in addition to their own weight.

The design of a small bridge involves more than the design of the deck slab. The hydraulic behaviour of the stream must be studied to decide the waterway, the level of the deck and the depth of the foundations, because many small bridge failures have been caused by scour or by insufficient waterway rather than by structural overstress. The abutments must retain the approach embankment and transfer the loads from the deck to the foundation, and they must be stable under earth pressure and braking forces. A complete design therefore brings together hydraulic, structural and geotechnical considerations.

This paper presents the hydraulic and structural design of an 8 m clear span RCC solid slab bridge for a two-lane rural road. The objectives are to determine the waterway and scour depth, to analyse the deck slab for dead load and IRC live loads using STAAD.Pro and the effective width method, to design the slab according to IRC 112, and to design the abutments and check their stability. The study is intended to present the complete design sequence of a typical small bridge in a form useful to undergraduate students of civil engineering.

II. LITERATURE SURVEY

The design of small bridges and culverts in India has been guided for many decades by the standard plans and specifications of the Indian Roads Congress and the Ministry of Road Transport and Highways. Researchers studying these standard designs have noted that solid slab decks are economical for spans up to about 10 m, beyond which voided slabs or beam and slab decks become more efficient. Studies that compared slab, T-beam and box culvert options for spans of 4 to 12 m reported that the solid slab required more concrete but less formwork and reinforcement labour, and that its total cost was lower for spans below 8 to 10 m. Several authors also emphasised that the simplicity of slab bridges makes them suitable for construction by small contractors in rural areas, where skilled labour and heavy equipment are limited. The durability of such bridges was found to depend strongly on the quality of concrete, the cover to reinforcement and the drainage of the deck, which are addressed in the durability provisions of IRC 112.

The analysis of solid slab decks under concentrated wheel loads has traditionally been carried out using the effective width method, in which the load of a wheel is assumed to be distributed over a width of slab that depends on the span, the position of the load and the ratio of width to span. This method, originally developed from elastic plate theory and experimental observations, is included in IRC 112 and earlier in IRC 21. Researchers who compared the effective width method with finite element plate analysis found that it gives reasonable and usually conservative estimates of the maximum longitudinal moment for slabs with a width to span ratio close to one. For wider slabs, skew slabs or loads placed near free edges, the difference between the two methods was found to be larger. Studies also noted that the effective width

method does not directly give transverse moments, which are usually estimated as a fraction of the longitudinal moment and covered by distribution reinforcement.

The live load provisions of IRC 6 have been examined by several researchers because they strongly influence the design of short span bridges. IRC 6 specifies Class 70R, Class A and Class B loading, and a bridge on a national or state highway must be designed for Class 70R or two lanes of Class A, whichever gives the more severe effect. Studies comparing the effects of these loadings found that for spans below about 10 m the Class 70R wheeled or tracked vehicle usually produces the largest bending moment, while Class A loading governs for wider carriageways with several lanes. The impact factor, which accounts for the dynamic effect of moving vehicles, is higher for shorter spans, and researchers have noted that this makes the live load effect particularly significant for small bridges. Recent studies have also discussed the introduction of special vehicle loading in the revised IRC 6 and its effect on the design of existing small bridges that were designed for older loadings.

Hydraulic design and scour have received much attention in the literature because inadequate waterway and foundation scour are among the most common causes of small bridge failures in India. Researchers have described methods for estimating the design flood discharge from catchment characteristics using rational formulae and empirical relations such as those of Dickens and Ryves, and from observed flood marks using the area-velocity method. The linear waterway is then fixed according to Lacey's regime relations, and the normal scour depth is estimated from the design discharge and silt factor as recommended in IRC 5 and IRC 78. Studies of failed culverts and small bridges reported that many failures occurred where the waterway was restricted by approach embankments or where the foundations were placed above the maximum scour level. Authors have therefore recommended that the foundation level be fixed below the maximum scour depth with an adequate margin, or that a protective apron and floor be provided for bridges on erodible beds.

The use of computer-based analysis for small bridges has grown with the availability of general-purpose structural software. Researchers have modelled slab decks in STAAD.Pro, SAP2000 and Midas Civil using plate elements and have used the moving load generators of these programs to find the critical positions of IRC vehicles. These studies reported that finite element models give a detailed picture of the distribution of longitudinal and transverse moments, including the concentration of moment near the free edges under eccentric loading, which the effective width method represents only approximately. Several authors recommended that software results be checked against the effective width method for at least the governing load case, so that errors in modelling or load placement can be detected. The design of abutments for small bridges has also been studied, with emphasis on the effect of live load surcharge and braking force on stability. The present study follows these approaches by combining plate analysis in STAAD.Pro with the traditional effective width method and a complete design of the substructure.

III. SYSTEM ANALYSIS

The structure studied is a single-span RCC solid slab bridge with a clear span of 8 m and an effective span of 8.5 m, carrying a two-lane carriageway of 7.5 m width with crash barriers of 0.45 m on both sides. The bridge crosses a seasonal stream with a catchment area of about 6 square kilometres, and the design discharge is estimated using the rational method and checked by the area-velocity method at the observed high flood level. The deck consists of a 650 mm thick slab of M30 concrete with

Fe500 reinforcement, a 65 mm bituminous wearing coat and precast crash barriers. The loads considered are self-weight, superimposed dead load, IRC Class A two-lane loading and Class 70R wheeled and tracked loading with the impact factors of IRC 6, braking force, earth pressure and live load surcharge on the abutments. The parameters studied are waterway, scour depth, maximum slab bending moment and shear, crack width, deflection, abutment stability and base pressure.

Existing System

In conventional practice, small bridges are often designed by adopting standard drawings or by manual calculation based on the effective width method. The live load is placed by hand at a few assumed critical positions, and the maximum moment is obtained by distributing the wheel load over the effective width and adding the dead load moment. Transverse moments are taken as a fixed percentage of the longitudinal moment, and the distribution reinforcement is provided accordingly. Many designs continue to use the working stress method of IRC 21 rather than the limit state method of IRC 112, and serviceability checks such as crack width are not performed explicitly. The hydraulic design is sometimes simplified by adopting the width of the existing stream as the waterway without estimating the design discharge, and the scour depth is not always calculated. The abutments are frequently proportioned from standard dimensions, and their stability under combined earth pressure, braking force and live load surcharge is checked only roughly.

Disadvantages of Existing System

- Live load positions are chosen by judgement and may miss the most critical location.
- The effective width method gives only approximate values for eccentric loads.
- Transverse moments are assumed as a percentage rather than calculated.
- Older working stress designs do not reflect the limit state approach of IRC 112.
- Crack width and deflection checks are often not carried out explicitly.
- Waterway is sometimes fixed from site observation without discharge calculation.
- Scour depth and foundation level are not always determined rationally.
- Abutment stability under braking and surcharge is checked only roughly.
- Standard drawings may not suit the actual span, width or soil conditions.
- Revising the design for a different span or loading requires repeated hand work.

Proposed System

The proposed approach combines hydraulic calculation, software-based analysis and limit state design for the complete small bridge. The design discharge is estimated from the catchment area and rainfall intensity and checked by the area-velocity method, after which the linear waterway, afflux and normal and maximum scour depths are calculated according to IRC 5 and IRC 78. The deck slab is modelled in STAAD.Pro as a mesh of plate elements supported along the bearing lines, and the self-weight and superimposed dead loads are applied as surface loads. The IRC Class A and Class 70R vehicles are defined in the moving load generator and moved across the deck in several transverse positions to find the maximum longitudinal and transverse moments and shear. The same deck is also analysed by the effective width method for comparison. The slab is designed for flexure and shear according to IRC 112 and checked for crack width and deflection, and the abutments are designed and checked for overturning, sliding and base pressure.

Advantages of Proposed System

- Fixes the waterway and deck level from a calculated design discharge.
- Determines scour depth so that foundations are placed at a safe level.
- Finds the most critical positions of IRC vehicles using the moving load generator.
- Gives both longitudinal and transverse moments directly from the plate model.
- Captures the concentration of moment near the free edges under eccentric loads.
- Provides a comparison between plate analysis and the effective width method.
- Applies the limit state design and serviceability checks of IRC 112.
- Checks abutment stability under earth pressure, surcharge and braking force.
- Allows the design to be revised quickly for a different span or carriageway width.
- Produces a complete and consistent design record for approval and construction.

IV. METHODOLOGY

The methodology begins with the collection of site data, including the catchment area, stream cross-section, high flood level, soil type and road classification. The design discharge is calculated and the linear waterway, afflux and scour depth are determined, which fix the deck level and foundation depth. The span, carriageway width and slab thickness are then selected, and material properties for M30 concrete and Fe500 steel are adopted. The deck slab is modelled in STAAD.Pro with plate elements of about 0.5 m size, and dead loads and superimposed dead loads are applied. IRC Class A and Class 70R vehicles with the applicable impact factors are defined and moved across the deck in several lanes. Maximum bending moments and shear forces are extracted and compared with the effective width method. The slab is designed for the ultimate limit state and checked for stress, crack width and deflection according to IRC 112. Finally, the abutment and its footing are designed and checked for overturning, sliding and bearing pressure.

SYSTEM ARCHITECTURE

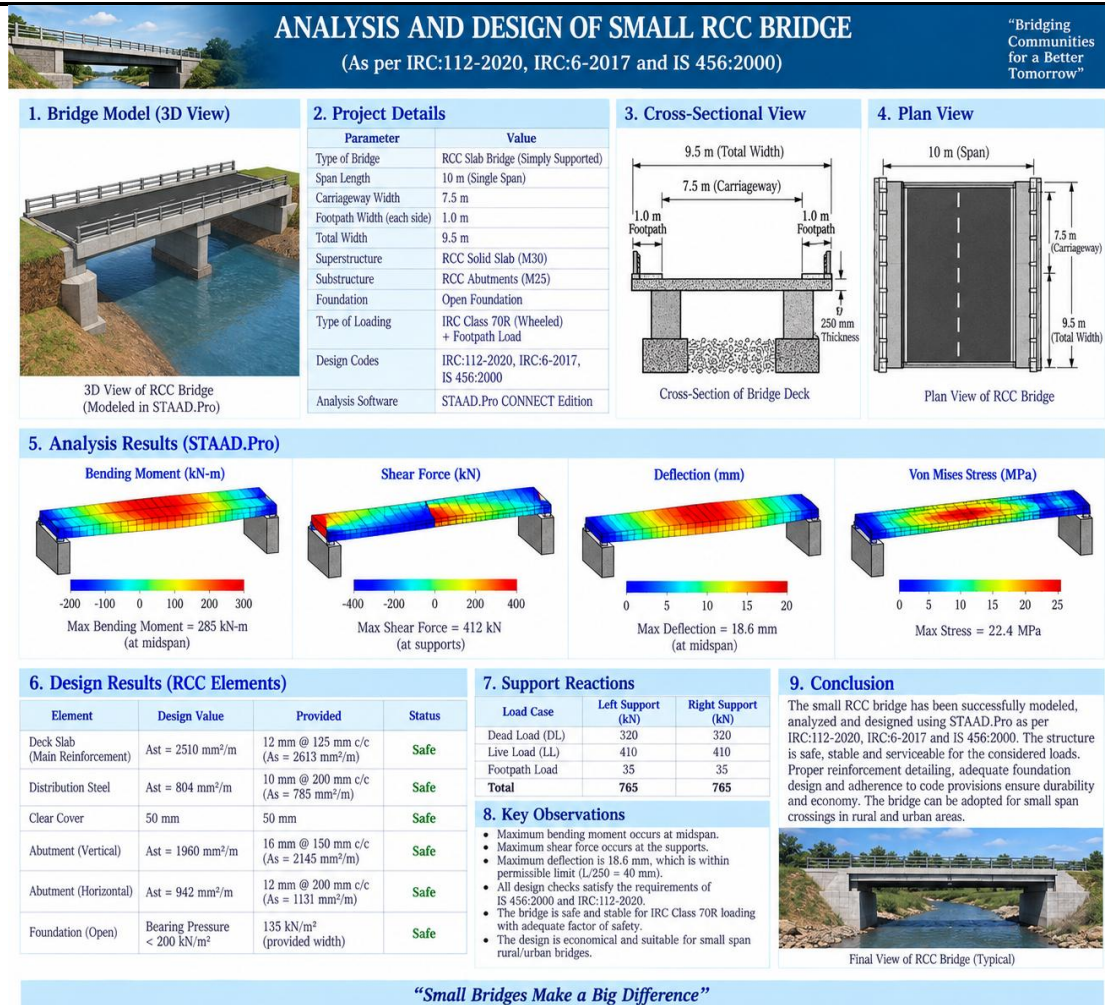
The workflow of the study is arranged in stages that proceed from site data to the final design of the bridge. The Site Data stage collects catchment, stream, flood and soil information. The Hydraulic Design stage computes discharge, waterway, afflux and scour depth to fix the deck and foundation levels. The Deck Proportioning stage selects the span, width and slab thickness. The STAAD.Pro Plate Modelling stage creates the slab mesh and supports. The Dead Load stage applies self-weight, wearing coat and crash barrier loads. The IRC Live Load stage defines Class A and Class 70R vehicles with impact and moves them across the deck. The Analysis and Comparison stage extracts moments and shears and compares them with the effective width method. The Slab Design stage designs the deck for flexure and shear and checks crack width and deflection by IRC 112, and the Substructure Design stage designs the abutments and footings and checks their stability.

Analysis and Design of Small RCC Bridge



Fig. 1 System Architecture

V. RESULT AND OUTPUT



VI. CONCLUSION

The hydraulic and structural design of an 8 m clear span RCC solid slab bridge for a two-lane rural road has been carried out following IRC 6 and IRC 112. The design discharge, linear waterway and scour depth were calculated first, which allowed the deck level and the foundation level of the abutments to be fixed on a rational basis. This step is important because many small bridges fail due to insufficient waterway or scour rather than due to overstress in the deck.

The deck slab was analysed in STAAD.Pro as a plate model under dead loads and IRC Class A and Class 70R live loads placed by the moving load generator. The Class 70R wheeled vehicle produced the governing bending moment for this span, while the shear near the supports was governed by the tracked vehicle placed close to the bearing line. The plate model also showed a concentration of longitudinal moment near the free edge when the vehicle was placed eccentrically, which was accommodated by additional edge reinforcement.

The moments from the plate analysis and from the effective width method agreed within about eight percent, with the effective width method giving slightly higher values, which confirms that the traditional method remains a useful and conservative check for small slab bridges. The slab thickness of 650 mm with 25 mm main bars satisfied the ultimate limit state requirements and the serviceability limits of crack width and deflection given in IRC 112. The abutments were found to be stable against

overturning and sliding, and the base pressure remained within the safe bearing capacity of the soil.

The study presents a complete and practical design sequence for small RCC bridges that combines hydraulic analysis, software-based structural analysis and limit state design. Future work can extend the procedure to multi-span slab bridges, skew slab bridges where the angle of crossing affects the distribution of moments, box culverts under high embankments, and the assessment of existing small bridges for the special vehicle loading introduced in recent revisions of IRC 6.

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