Structural Analysis and Design of Box Culverts – A Review

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Abstract - *Box culverts are essential low-rise structures commonly utilized for channeling water beneath roadways, flyovers, and similar infrastructures. They are particularly effective in regions with low soil bearing capacity. When designed with multiple cells and a span exceeding 6 meters, these culverts are classified as minor bridges. The height of a box culvert is proportional to its span. Made predominantly from reinforced concrete, they also serve as crossings for pedestrians and vehicles while maintaining water flow beneath. The structural design incorporates factors like live loads, effective width, and earth pressure coefficients, adhering to relevant Indian Roads Congress (IRC) standards.*

Key Words: Box Culvert, Design, IRC Code.

1. INTRODUCTION

A box culvert is a structural component designed to allow water to pass under infrastructure such as roads and railways. Constructed primarily from reinforced concrete, these culverts feature a box-like shape and come in square or rectangular cross-sections. They play a critical role in managing drainage by directing water from streams, channels, or sewer systems while ensuring minimal disruption to the overlying infrastructure.

Box culverts are particularly useful in areas with low soil bearing capacity, where conventional drainage solutions may fail. They are also utilized as small bridges, especially when their spans exceed 6 meters. During design and construction, several load factors are taken into account, including dead loads, live loads, moving loads, and earth pressures. The top slab primarily bears these loads, while the sidewalls resist lateral soil forces.

These culverts are highly efficient, versatile, and durable. They are especially beneficial for spans of up to 4 meters and heights typically less than 3 meters, making them ideal for areas with limited headroom. Their structural robustness and adaptability make them a cornerstone in modern civil engineering.

The design of box culverts is guided by detailed calculations and analysis, conforming to codes specified by the IRC. Parameters such as live load dispersion, effective width, and earth pressure coefficients are critical to ensuring both functionality and safety.

Figure 1-3 cell Box Culvert

Types of Culverts
The following are the different types of culverts:

a) Pipe Culverts

A pipe culvert is formed by placing a pipe in an excavated trench to direct water flow. It is one of the most widely used drainage solutions due to its cost-effectiveness and simplicity in installation. Pipe culverts are available in various shapes, such as circular, elliptical, and pipe arch, with the choice of shape depending on specific site conditions and constraints.

Pipe culverts must adhere to IS standards, specifically NP3 or NP4 categories. A minimum cushion of 600 mm is required between the top of the pipe and the road surface. For fills up to 4 meters, first-class bedding made of compacted granular material is suitable, whereas for fills up to 8 meters, concrete cradle bedding can be utilized. For smaller structures, RCC pipe culverts with one to six rows of RCC pipes may be used, depending on the discharge requirements. These are often more economical compared to slab culverts.

Figure 2. Three Cell Pipe Culvert

b) Box Culverts

Box culverts are precast concrete structures widely used in drainage systems to channel water effectively. Constructed with two horizontal and two vertical slabs joined monolithically, they are well-suited for carrying streams with limited flow beneath roads or railway bridges with elevated embankments.

Box culverts are cost-effective due to their rigidity and monolithic structure. They do not require separate foundations, as the bottom slab serves as a raft slab that rests directly on the ground. Single-celled box culverts are designed to handle smaller water discharges, whereas multicelled box culverts are used for larger discharges.

This design is among the most commonly used types of culverts. The concrete bottom allows smooth water flow through the structure. Box culverts are typically constructed using reinforced concrete (RCC). In cases where water needs to change direction or when significant water flow is expected, composite construction may be employed to meet specific requirements.

Figure 3 Two Cell Box Culvert

c) Pipe Arch Culverts

Pipe arch culverts are ideal for locations requiring a large waterway opening, offering better hydraulic efficiency and supporting aquatic life by enhancing water flow conditions. These culverts provide low clearance and have an aesthetically pleasing design. They are especially beneficial in areas with limited headroom and perform effectively during low-flow conditions. Key features of pipe arch culverts include:

- Suitability for sites with restricted headroom.
- Enhanced hydraulic performance at low water flow.
- A visually appealing and unique shape.
- Lightweight construction for ease of handling.
- Simple and quick installation process.

Figure 4 Arch Type Pipe Culvert

d) RCC Solid Slab Culverts

RCC solid slab culverts consist of a single horizontal reinforced concrete slab supported by abutments or piers. These culverts do not include sidewalls, making them more suitable for applications involving lighter loads and shorter spans, particularly in areas with strong soils and stable geological conditions.

Figure 5 RCC Solid Slab Culvert

1.1 Literature Review

Roshan Patel, Sagar Jamle-(2019)-

This study provides a detailed manual design of box culverts, analyzing parameters such as earth pressure, cushion depth, braking forces, impact loads, live loads, load dispersion from tracked and wheeled vehicles, and effective widths. It also discusses IRC provisions and their justifications.

Neha Kolate, Molly Mathew, Snehal Mali-(2014)-

This paper focuses on design factors such as live load dispersion angles, earth pressure effects, and cushion depth on top slabs. Structural deformations under various loading scenarios, with or without cushioning, are also explored.

Akash Mishra, Dr.Umesh Pendharkar-(2023)-

This research examines the behavior of 3-cell box culverts across 12 models with different span-to-height ratios (1.5, 1.75, and 2) and skew angles (0°, 17°, 34°, and 51°). The study evaluates load resistance and identifies optimal models for varying conditions.

Sachin Honwad, Sameer Chitnis-(2022)-

The study investigates the impact of varying skew angles (0° to 70°) on the behavior of 3-cell box culverts using STAAD Pro. The analysis focuses on the effects of dead loads, live loads, live load surcharges, and earth pressures on slab and wall performance.

A. D. Patil, A. A. Galatage-(2016)-

This report examines the performance of reinforced concrete box culverts under cushion and no-cushion scenarios. It highlights the effects of loading combinations, bending moments, and IRC code considerations for safe structural designs.

Pragya D. Harinkhede and Prof. Varsha R. Harne (2021)-

This study focuses on the analysis and design of a 30-meter Minor Multi-cell Box-type Bridge with varying configurations of precast sections. The investigation accounts for various loads, including Dead Load, Live Load, Superimposed Dead Load, Earth Pressure, and vehicle loads as outlined by the Indian Road Congress (IRC). These vehicle loads include Class "A" vehicles, 70R Bogie vehicles, 70R Wheeled vehicles, and 70R Tracked vehicles.

The bridge is assessed under multiple Load Combinations, following the guidelines for the Limit State of Collapse and the Limit State of Serviceability, to identify critical sections for Bending Moments and Shear Forces. The primary objective is to perform analysis and design of box sections in accordance with IRC standards, specifically IRC 6-2017 and IRC 112-2011.

Sandeep Gaikwad, Tanmay Ghumde-(2021)-

In this paper study about the different classes of IRC loadings and their effect on without and with cushioning conditions imposed on culvert. The pressure cases are then checked for both with cushioning and without cushioning loading cases. The structure designing includes the considerations of pressure cases (empty, Full, surcharge load) and factors such as Impact load, Braking force, Dispersal of load through fill, Effective width, Coefficients of earth pressure, Live load etc. The structural elements are designed to withstand the maximum bending moments and shear forces respectively. In the present study, this paper provides full discussion on the provisions in the codes, considerations and justifications of all the above aspects of design.

1.2 Objectives

1. To study hydrological parameters essential for box culvert design.
2. To model and analyze box culverts using STAAD Pro under different load scenarios.
3. To evaluate the structural performance of culverts with and without cushion loads for varying aspect ratios.
4. To design reinforced concrete components considering loads such as live loads, dead loads, earth pressure coefficients, and effective width.
5. To determine load combinations that cause critical stresses, ensuring a safe design.

2. Methodology

1. Conduct a detailed hydrological analysis.
2. Create and analyze culvert models using STAAD Pro software.
3. Define material properties and dimensions for slabs and walls.
4. Use spring supports under the base slab.
5. Apply load conditions, including live loads, effective widths, and earth pressure coefficients.
6. Assess axial forces, shear forces, and bending moments for slabs and walls.
7. Calculate and evaluate critical stresses, moments, and forces for design optimization.

3. CONCLUSIONS

The findings indicate that the coefficient of earth pressure has minimal influence on box culvert designs without cushioning.

Culverts without cushions require less steel reinforcement and experience lower design moments and shear stresses compared to cushioned counterparts. Furthermore, increasing skew angles amplifies longitudinal, transverse, and torsional moments as well as shear forces across all structural components

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IRC 21 -2000 – Design Constants

SP013 – Guidelines for Design of Small Bridges and Culverts.