

Design and Analysis of RCC Box Culvert using STAAD.Pro

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Abstract : This RCC box culverts are important cross-drainage structures used to safely convey water beneath roads and embankments while maintaining uninterrupted transportation facilities. This study presents the structural analysis and design of a **1 × 6 × 3 m single-cell RCC box culvert using STAAD.Pro**. The analysis considers the major loading conditions acting on the structure, including self-weight, earth fill, wearing coat, vehicular live load, lateral earth pressure, and hydrostatic water pressure. The structural model is developed using finite element plate elements to represent the top slab, bottom slab, and side walls of the culvert. Appropriate load combinations are considered to evaluate the critical bending moments, shear forces, axial forces, and structural response of the culvert. Manual load calculations are also carried out and compared with the STAAD.Pro analysis to verify the reliability of the numerical model. The design is carried out considering the relevant provisions of **IS 456 and IRC specifications**, with emphasis on structural safety, serviceability, durability, and economical use of materials. The study demonstrates that STAAD.Pro provides an efficient approach for analysing RCC box culverts under combined loading conditions and assists in identifying critical structural components for reinforcement design. The results indicate that the proposed RCC box culvert provides adequate structural stability and can be effectively used for cross-drainage applications.

Keywords: RCC Box Culvert, STAAD.Pro, Structural Analysis, Finite Element Analysis, Earth Pressure, Live Load, Hydrostatic Pressure, IRC Code.

INTRODUCTION

Transportation infrastructure is an essential component of economic and social development. Roads provide connectivity between cities, towns, villages, agricultural areas, and industrial regions. During the construction of roads, natural drainage channels, small streams, irrigation channels, and stormwater paths often need to be crossed. Culverts are structures constructed below roads to provide a safe passage for water while maintaining the continuity and stability of the roadway.

Among the various types of culverts, Reinforced Cement Concrete (RCC) box culverts are commonly used for drainage and water-crossing applications. An RCC box culvert consists mainly of a top slab, bottom slab, and two vertical side walls connected to form a rigid closed frame. The structural components act together to transfer the applied loads safely to the foundation. RCC box culverts are preferred because of their strength, durability, rigidity, and suitability for carrying highway traffic loads.

The design of a box culvert requires consideration of various loads acting on the structure. These include the self-weight of the RCC members, earth fill above the culvert, vehicular live load, lateral earth pressure, surcharge pressure, water pressure, and foundation reactions. The magnitude and distribution of these loads depend on factors such as soil properties, depth of earth cushion, traffic loading, groundwater conditions, and foundation characteristics. Therefore, proper structural analysis is necessary to determine the critical forces developed in each component of the culvert.

In the present study, a single-cell RCC box culvert with a clear span of 6 m and a clear height of 3 m is considered. The proposed culvert is represented as 1 × 6 × 3 m, where one represents the number of cells, 6 m represents the clear span, and 3 m represents the clear height. The structural model is developed using STAAD.Pro, a widely used computer-aided structural analysis and design software.

STAAD.Pro is used to model the structural components, define material and section properties, apply the relevant loads and load combinations, and perform structural analysis. The analysis provides important structural parameters such as bending moments, shear forces, axial forces, and support reactions. These results are used to identify the critical sections and governing load combinations for the design.

Based on the analysis results, the major structural components, including the top slab, bottom slab, and side walls, are designed using reinforced concrete design principles and applicable Indian Standard and IRC provisions. The required reinforcement is determined based on the critical design forces, while appropriate checks are considered for strength, serviceability, and structural safety.

The main aim of this study is to develop a systematic approach for the analysis and design of an RCC box culvert using STAAD.Pro. The study demonstrates the application of computer-aided structural analysis in highway engineering and provides an understanding of the structural behaviour of a box culvert under different loading conditions. The methodology can also be applied to similar RCC box culvert structures by modifying the dimensions, loading conditions, soil properties, and other site-specific parameters.

NEED OF THE STUDY.

The establishment of large RCC box culverts are important cross-drainage structures used to safely carry water beneath roads and embankments. Their structural members are subjected to different loads, including self-weight, earth fill, vehicular live load, earth pressure, and water pressure. Therefore, proper analysis and design are necessary to ensure the safety and stability of the structure.

The present study is needed to evaluate the structural behaviour of a **1 × 6 × 3 m RCC box culvert** under different loading conditions. The study uses **STAAD.Pro** to analyse the top slab, bottom slab, and side walls and to determine the critical structural responses such as bending moments and shear forces.

The study also aims to compare the results obtained from STAAD.Pro with selected manual calculations. This comparison helps to verify the analytical model and provides greater confidence in the structural design. The design considers relevant **IS and IRC provisions** to achieve a safe, serviceable, durable, and economical RCC box culvert.

Main objectives of the study

1. To analyse the RCC box culvert under different critical loading conditions.
2. To determine bending moments, shear forces, and structural responses.
3. To study the effect of earth pressure, water pressure, and vehicular live load.
4. To analyse the structure using STAAD.Pro.
5. To compare STAAD.Pro results with manual calculations.
6. To develop a safe and economical structural design.

I. Data and Sources of Data

For this study second The data required for the analysis and design of the RCC box culvert were collected from site-related information, survey data, traffic data, hydrological and geological information, and relevant design standards. The collected data were used to determine the appropriate dimensions, loading conditions, and structural parameters for the proposed **1 × 6 × 3 m RCC box culvert**.

1. Site Data

Site investigation data were considered to understand the existing site conditions, road alignment, drainage characteristics, soil conditions, and other factors affecting the proposed culvert. The investigation helps in selecting suitable structural dimensions and foundation requirements.

2. Survey and Topographical Data

The following survey information was considered:

- Index map
- Site plan
- Contour survey
- Topographical map
- Catchment area map
- Geological map

These data assist in identifying the location, drainage pattern, ground levels, catchment characteristics, and geological conditions of the proposed culvert site.

3. Traffic Data

Traffic information was considered for determining the vehicular loading acting on the culvert. The report includes classified traffic volume count and axle load data. Traffic projections may also consider normal, diverted, and generated traffic.

4. Structural and Material Data

The structural analysis considers the following parameters for the RCC box culvert:

- Clear span: 6.00 m
- Clear height: 3.00 m
- Top slab thickness: 300 mm
- Bottom slab thickness: 350 mm
- Earth cushion: 1.0 m
- Unit weight of soil: 18 kN/m³
- Unit weight of RCC: 25 kN/m³
- Wearing coat: 80 mm
- Live load: IRC Class A
- Safe Bearing Capacity: 200 kN/m²

5. Sources of Data

The principal sources used for the study are:

- Site investigation and survey information
- Traffic volume and axle-load data
- Hydrological and catchment information
- Geological and soil information
- IS 456:2000
- IRC:6
- IRC:112
- IRC:SP:13
- IRC:SP:19
- IRC:78
- STAAD.Pro analysis and design results

II. Theoretical framework

The theoretical framework of the present study is based on the **structural analysis and design principles of Reinforced Cement Concrete (RCC) box culverts**. An RCC box culvert is a rigid structural system consisting of a top slab, bottom slab, and side walls, which act together to transfer the applied loads safely to the supporting soil.

The structural behaviour of the box culvert is evaluated by considering the major loads acting on the structure, including **self-weight, earth fill, wearing coat, vehicular live load, lateral earth pressure, and hydrostatic water pressure**. These loads generate bending moments, shear forces, axial forces, stresses, and deflections in the structural members.

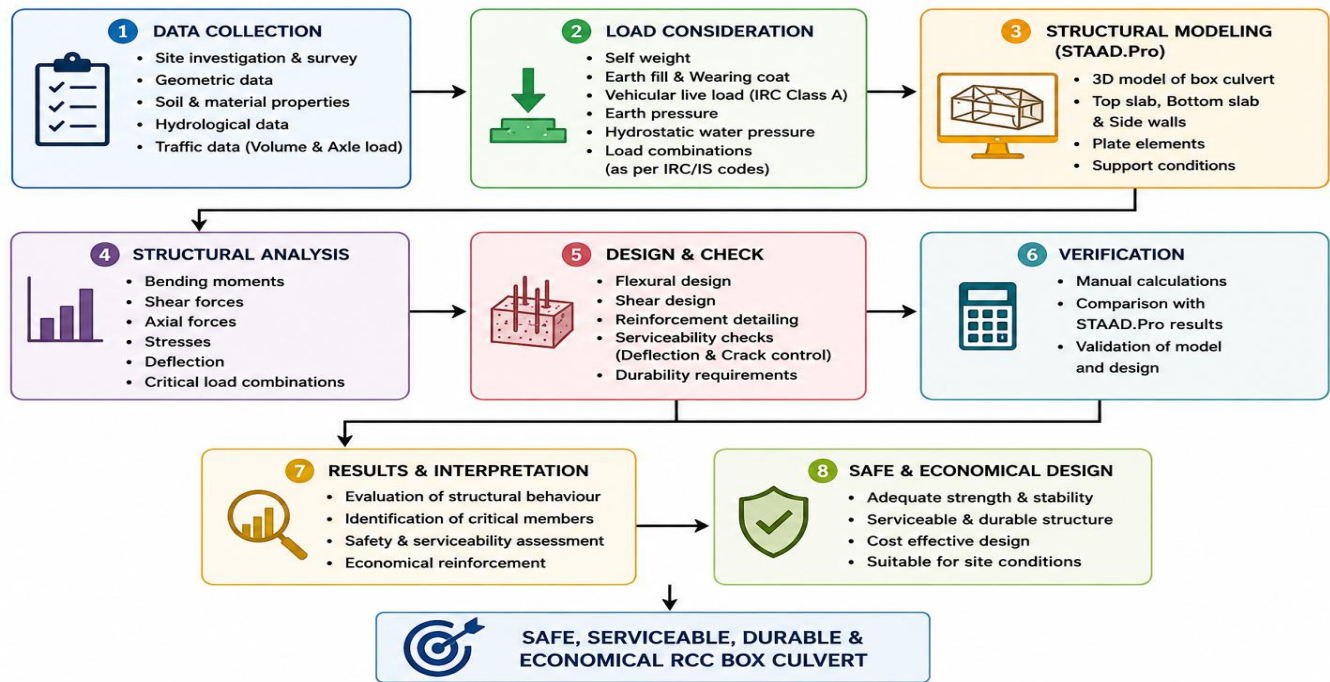
For the present study, the proposed **1 × 6 × 3 m single-cell RCC box culvert** is modelled using **STAAD.Pro**. The top slab, bottom slab, and side walls are represented using plate elements. Appropriate material properties, support conditions, load cases, and load combinations are considered for structural analysis.

The critical forces obtained from the structural analysis are used for the design of RCC members and reinforcement. Manual calculations are also used to verify selected STAAD.Pro results. The design approach considers the relevant provisions referred to in the report, including **IS 456:2000, IRC:6, IRC:112, IRC:SP:13, IRC:SP:19, and IRC:78**.

The final objective of the theoretical framework is to ensure that the proposed RCC box culvert satisfies the required **strength, stability, serviceability, durability, and economical design requirements**.

RESEARCH METHODOLOGY

THEORETICAL FRAMEWORK (RCC BOX CULVERT)



III. RESULTS AND DISCUSSION

The structural analysis and design of the proposed **1 × 6 × 3 m single-cell RCC box culvert** were carried out using STAAD.Pro. The structure was evaluated for dead load, vehicular live load, earth pressure, and hydrostatic water pressure. The results obtained from the manual calculations and STAAD.Pro analysis were used to identify the critical loading conditions and structural behaviour of the culvert.

1. Load Calculation Results

The adopted structural parameters include a 6.0 m clear span, 3.0 m clear height, 300 mm top slab thickness, 350 mm bottom slab thickness, 1.0 m earth cushion, soil unit weight of 18 kN/m³, and RCC unit weight of 25 kN/m³.

The calculated loads are:

Sr. No.	Load	Manual Calculation	Manual Result	STAAD.Pro Calculation / Input	STAAD.Pro Result
1	Top slab self-weight	$6 \times 0.50 \times 25$	75.00 kN/m	Self Weight: 0.50×25	12.50 kN/m ²
2	Earth load on top slab	18×1.0	18.00 kN/m ²	Plate pressure = 18×1.0	18.00 kN/m ²
3	Wearing coat	0.08×22	1.76 kN/m ²	Plate load = 0.08×22	1.76 kN/m ²
4	Total DL on top slab	$12.50 + 18 + 1.76$	32.26 kN/m ²	$12.50 + 18 + 1.76$	32.26 kN/m ²
5	One side-wall self-weight	$0.50 \times 3 \times 25$	37.50 kN/m	Self Weight	37.50 kN/m

Sr. No.	Load	Manual Calculation	Manual Result	STAAD.Pro Calculation / Input	STAAD.Pro Result
6	Two side walls	2×37.50	75.00 kN/m	Self Weight	75.00 kN/m
7	Bottom slab self-weight	$6 \times 0.50 \times 25$	75.00 kN/m	Self Weight	75.00 kN/m
8	Total structural self-weight	$75 + 75 + 75$	225.00 kN/m	STAAD SELFWEIGHT	225.00 kN/m
9	Class 70R Live Load	Wheel load dispersion + 25% impact	19.50 kN/m ²	Equivalent plate/area load	19.50 kN/m ²
10	Earth pressure	$0.5 \times 18 \times 3$	27.00 kN/m ²	Triangular pressure, max. at bottom	27.00 kN/m ²
11	Earth force, one wall	$\frac{1}{2} \times 27 \times 3$	40.50 kN/m	Resultant of triangular pressure	40.50 kN/m
12	Water pressure	9.81×3	29.43 kN/m ²	Triangular pressure, max. at bottom	29.43 kN/m ²
13	Water force, one wall	$\frac{1}{2} \times 29.43 \times 3$	44.15 kN/m	Resultant of triangular pressure	44.15 kN/m

These values are taken from the load calculations in the report.

2. LIMIT STATE LOAD COMBINATIONS:

For your $1 \times 6 \times 3$ m RCC Box Culvert, using the loads we established:

- Dead load, $DL = 32.26 \text{ kN/m}^2$
- Class 70R live load including impact, $LL = 19.50 \text{ kN/m}^2$
- Earth pressure at bottom, $EP = 27.00 \text{ kN/m}^2$
- Water pressure at bottom, $WP = 29.43 \text{ kN/m}^2$

Combination 1

$$\begin{aligned}
 &= 1.5(DL+LL) \\
 &= 1.5(32.26+19.50) \\
 &= 1.5(51.76) \\
 &= 77.64 \text{ KN/m}^2
 \end{aligned}$$

Combination 2

$$\begin{aligned}
 &1.5 (DL + \text{Earth Pressure}) \\
 &= 1.5(32.26+27) \\
 &= 1.5(59.26) \\
 &= 88.89 \text{ KN/m}^2
 \end{aligned}$$

Combination 3

$$\begin{aligned}
 &1.5 (DL + LL + \text{Earth Pressure}) \\
 &= 1.5 (32.26+19.50+27.00) \\
 &= 1.5 (78.76) \\
 &= 118.14 \text{ KN/m}^2
 \end{aligned}$$

Combination 4

$$\begin{aligned}
 &1.5 (DL + LL+ \text{Water Pressure}) \\
 &= 1.5 (32.26 + 19.50 + 29.43) \\
 &= 1.5(81.19) \\
 &= 121.785 \text{ KN/m}^2
 \end{aligned}$$

Combination 5

$$\begin{aligned} &1.5 (\text{DL} + \text{Earth Pressure} + \text{Water Pressure}) \\ &= 1.5 (32.26 + 27.00 + 29.43) \\ &= 1.5 (88.69) \\ &= 133.04 \text{ kN/m}^2 \end{aligned}$$

Combination	Calculation	Factored Load
1.5(DL + LL)	1.5(32.26 + 19.50)	77.64 kN/m ²
1.5(DL + EP)	1.5(32.26 + 27.00)	88.89 kN/m ²
1.5(DL + LL + EP)	1.5(32.26 + 19.50 + 27.00)	118.14 kN/m ²
1.5(DL + LL + WP)	1.5(32.26 + 19.50 + 29.43)	121.785 kN/m ²
1.5(DL + EP + WP)	1.5(32.26 + 27.00 + 29.43)	133.04 kN/m ²

3. Vertical Load on Top Slab

The report gives the total vertical load on the top slab as:

$$\begin{aligned} W &= 7.5 + 18.0 + 1.65 \\ W &= 27.15 \text{ kN/m}^2 \end{aligned}$$

Thus, the calculated vertical loading is **27.15 kN/m²**. The live load is the major component of this loading, indicating that vehicular loading has a significant influence on the top slab design.

4. Earth Pressure Result

The active earth pressure at the bottom of the 3 m high side wall is:

$$\begin{aligned} P &= K_a \gamma H \\ P &= 0.33 \times 18 \times 3 \\ P &= 17.82 \text{ kN/m}^2 \end{aligned}$$

The resultant lateral force is:

$$\begin{aligned} R &= \frac{1}{2} \times 17.82 \times 3 \\ R &= 26.73 \text{ kN/m} \end{aligned}$$

and it acts at:

$$H/3 = 3/3 = 1.0 \text{ m}$$

above the base.

5. Hydrostatic Pressure Result

For a maximum water depth of 3 m:

$$\begin{aligned} P_w &= 9.81 \times 3 \\ P_w &= 29.43 \text{ kN/m}^2 \end{aligned}$$

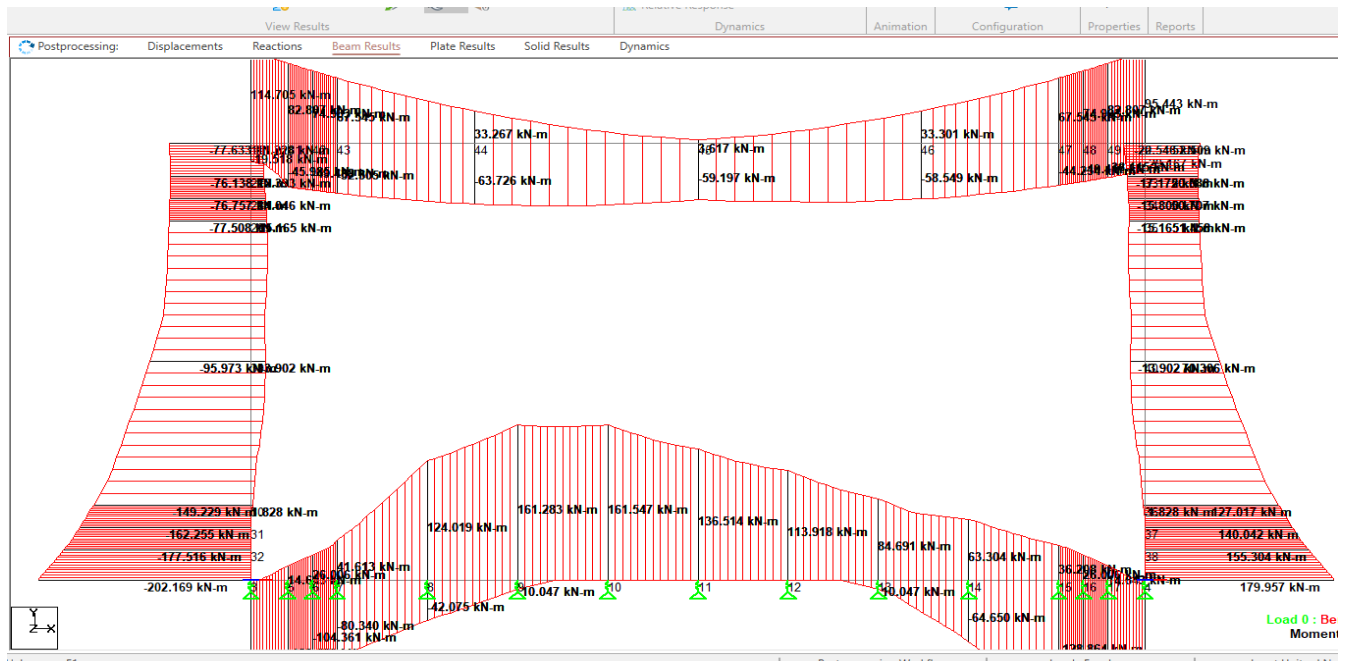
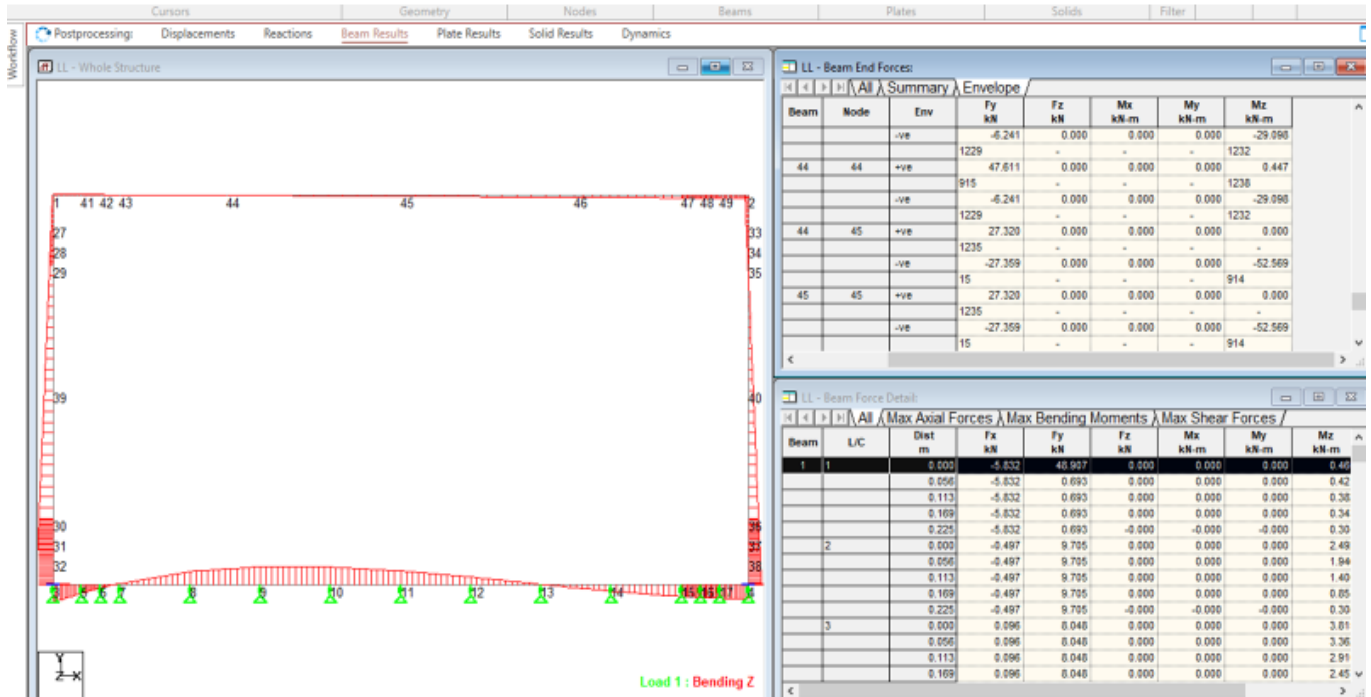
The corresponding resultant force is:

$$\begin{aligned} R_w &= \frac{1}{2} \times 29.43 \times 3 \\ R_w &= 44.15 \text{ kN/m} \end{aligned}$$

The water-pressure resultant is therefore greater than the calculated earth-pressure resultant, showing the importance of considering hydrostatic loading in the structural assessment.

Load Calculation and Design using Staad Pro.

Ultimate Limit State _TOP Box _MIDSPAN _BENDING MOVMENT



IV. Structural Behavior

The STAAD.Pro analysis indicates that the **top slab develops maximum positive bending moments under vehicular loading**, while negative bending moments occur near the slab-wall junctions due to rigid frame action. Higher shear forces occur near the supports and slab-wall connections. The side walls primarily resist lateral earth pressure and axial compression.

The bottom slab contributes to the stability of the structure against uplift and distributes foundation reactions. The report states that the calculated deflections were within the permissible limits and that adequate reinforcement was provided based on the critical bending moments and shear forces.

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REFERENCES

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