ANALYSIS AND OPTIMIZATION OF THE DETAILED DESIGN OF A BOX CULVERT

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ABSTRACT

In the analysis of culverts using software, the primary focus is on understanding the structural behavior of reinforced concrete box culverts under different loading conditions. Culverts are crucial for managing water flow beneath roadways or embankments, allowing water to pass through and maintaining water levels on both sides, especially during floods. These structures are referred to as "balancers" when their function is to equalize water levels. For this analysis, the ratio of length to height (L/H ratio) and the angle of internal friction (φ) of the soil surrounding the culvert are key factors influencing its structural response. The L/H ratio defines the shape and proportions of the culvert, impacting the distribution of loads and moments across its span. The angle of internal friction of the soil determines how much resistance the soil provides against sliding or shearing along the culvert, affecting overall stability and bearing capacity.

The design of box culverts, as structural components under bridges, railway crossings, and flyovers, plays a crucial role in efficiently channeling water flow to prevent damage to the above structures. This study focuses on the detailed design of a box culvert using STAAD. Pro, following the Indian Railway Standard (IRS) CBS codes. Designed to resist dead load (DL), live load (LL), surcharge load, and impact loads. Engineered to handle the pressure from soil and water below the structure. Carry the lateral earth pressure and water pressure from the sides. The slabs and side walls are designed to resist the maximum bending moment caused by the applied loads. Designed to withstand the shear forces generated due to various loads, ensuring the structure's stability. To ensure durability and limit the crack width, the structure is analyzed for serviceability under different load conditions. This is critical to maintaining the longevity of the structure without excessive maintenance. The use of STAAD. Pro allows for precise analysis and optimization of the box culvert design, ensuring that the structural elements meet the necessary safety and performance criteria based on IRS CBS codes. The study highlights the importance of efficient design, particularly as infrastructure development continues to advance.

KEY WORDS:- Surcharge Load, Impact Loads **,** Box culvert design, Serviceability, Importance of efficient design

INTRODUCTION

Box culverts, which are typically precast concrete structures with a rectangular or square shape, are widely used in civil engineering for allowing water flow under roads, railways, and other infrastructure. Aside from their inherent strength and durability, box culverts offer several other key benefits.

Versatility: Box culverts can be used in various applications, such as drainage, underpasses, utility tunnels, and animal crossings. Their design allows for different sizes and configurations, accommodating various water flow rates and environmental needs.

Ease of Installation: Precast box culverts are prefabricated in controlled environments, ensuring quality and reducing construction time. Their modular design allows for quick and easy installation, minimizing traffic disruption.

Low Maintenance: Once installed, box culverts require minimal maintenance compared to other drainage structures. Their durability ensures long service life without significant upkeep.

Cost-effectiveness: Recasting the box culverts off-site saves time and reduces labor costs, while their long lifespan provides an excellent return on investment due to reduced repair and replacement needs.

Environmental Benefits: Box culverts help manage water flow and prevent flooding by directing storm water runoff efficiently. They also provide a controlled pathway for water, minimizing erosion and protecting surrounding ecosystems.

Design Flexibility: They can be designed to handle a wide range of load-bearing requirements, including the weight of heavy traffic, and can be reinforced or customized to meet specific project needs.

Structural Integrity: Box culverts are designed to withstand significant loads and external pressures, making them ideal for use in areas where strength and stability are paramount.

Load Distribution: The culvert must be designed to resist various types of loads, including dead loads (self-weight), live loads (traffic, water pressure), and lateral earth pressures from the surrounding soil. The analysis helps determine the moments, shear forces, and axial thrusts induced by these loads.

Moments and Shear Forces: The moments generated in the culvert frame depend on the loading conditions, L/H ratio, and culvert geometry. The design should account for maximum bending moments and shear forces, ensuring adequate reinforcement is provided for structural safety.

Thrust Analysis: Thrusts arise due to axial loads and water pressure, and their magnitude depends on the culvert's dimensions and the flow characteristics of the water. Proper distribution of these forces is critical to ensure that the culvert doesn't collapse or suffer from settlement issues.

Rigid Frame Design: Box culverts are typically designed as rigid frames, where the interactions between the top slab, side walls, and bottom slab are considered in the analysis. This helps in understanding how the structure behaves as a whole under various loading scenarios.

Software Simulation:
Using software tools for structural analysis, engineers can model the culvert's behavior under different L/H ratios and soil conditions. The software calculates the stresses, deflections, and internal forces, allowing for an optimized design that meets safety and serviceability requirements. This approach ensures that the culvert is designed efficiently to withstand the anticipated loads and environmental conditions, providing durability and long-term performance.

LITERATURE REVIEW

Anwer H. Dawood et al (2024) Using a digital elevation model and the Water Modeling System (WMS) software, you assessed the catchment area and factors contributing to flooding. Hydrological, climatic, and soil data were gathered and analyzed using the Harmonized World Soil Database (HWSD), while hydraulic calculations using the Hydrological Engineering Center-Hydrological Modeling System (HEC-HMS) determined the maximum flood discharge for 50, 100, and 200-year return periods.

To resolve the flooding issue, you designed a new culvert using Bentley Culvert Master software. The analysis showed that the current culvert is inadequate, prompting the design of a new cross-section area of 52.5 m^2, which can accommodate a flow capacity of 201 m^3/s for a 100-year return period. This new culvert design is a more economical and efficient solution, surpassing the existing culvert's capacity and ensuring floodwaters will no longer rise to street level, mitigating future flooding risks on the Erbil-Kirkuk roadway.

Imran Bhutto et al (2023) was explain box culverts are vital structures facilitating drainage, water passage, and serving as traffic routes beneath roads. They are designed in various shapes and sizes to meet specific waterway and traffic demands. This review paper offers an in-depth analysis of the advancements and studies related to box culverts. Through a comprehensive literature review and analysis of past research, the study identifies key findings that shape the research objectives. Specifically, this work focuses on analyzing the performance of box culverts under different skew angles and span-to-height (S/H) ratios for two-cell configurations. The paper aims to provide technical insights and recommendations for future research on the structural behavior of box culverts.

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METHODOLOGY

Designing a reinforced cement concrete (RCC) culvert involves analyzing and addressing several structural factors and load cases to ensure the culvert's safety and durability. Here's a step-by-step overview of the structural design process considering live loads, effective width, and earth pressure coefficients.

When designing RCC culverts, the following load cases are typically considered:

Dead Load (DL): Weight of the culvert structure (self-weight of slabs, walls, footings, etc.).

Live Load (LL): This includes vehicular loads as per relevant codes (e.g., IRC, AASHTO). These are based on the type of vehicles expected, such as IRC Class A or Class 70R.

Impact Load (IL): Additional load from vehicular movement, typically considered as a percentage of the live load.

Earth Pressure (EP): Lateral pressure exerted by soil, which varies depending on soil type, depth, and backfill.

Water Pressure (WP): If the culvert is expected to carry water, hydrostatic pressure must be included.

Surcharge Load (SL): Loads from any overburden or traffic on the embankment above the culvert.

Buoyancy: For culverts with a potential for being submerged, upward water pressure should be considered.

Temperature Stresses: Variations in temperature can cause expansion or contraction of materials.
Modeling and analyzing a culvert using STAAD Pro involves several steps to ensure accurate representation of the structure and its response under various load conditions. Below is a general guide on how to approach the process. By following these steps, you can effectively model and analyze a culvert structure in STAAD Pro, ensuring safety, structural efficiency, and code compliance. Properly apply lateral earth and water pressure loads as they are critical for culvert design. Consider spring supports or foundation models to simulate the soil-culvert interaction more accurately.

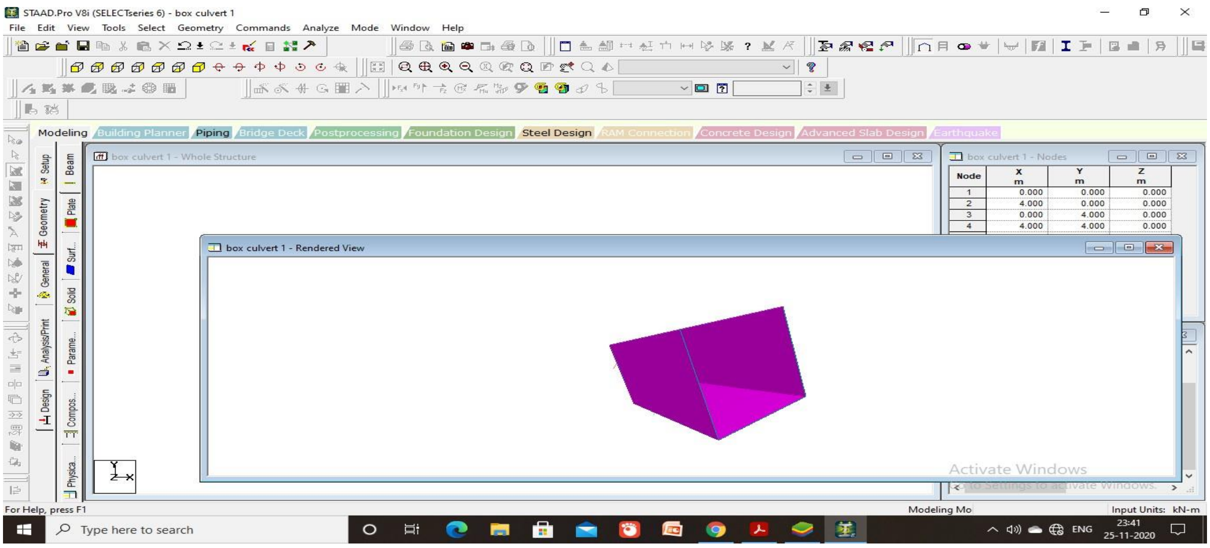

Figure 1 Basic model of box

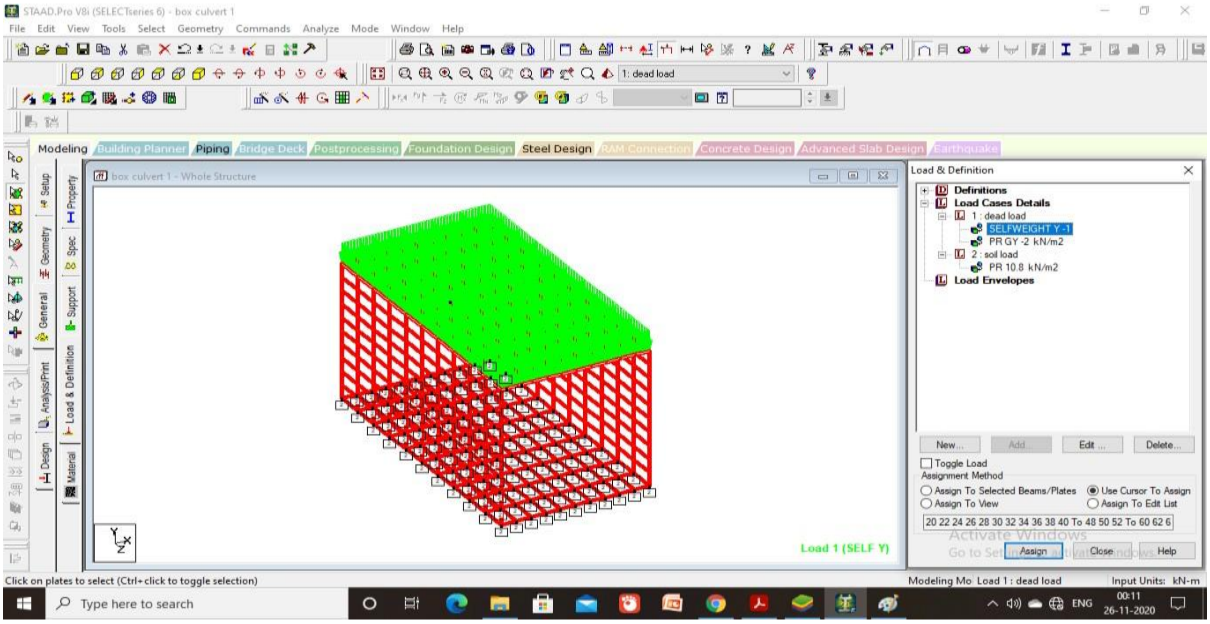

Figure 2 Load on box culvert

RESULT AND DISCUSSION

Preparing a detailed results and interpretations chapter for a report. Briefly describe the purpose of this chapter, emphasizing that it presents the results of the structural analysis conducted using STAAD Pro. Provide a concise summary of the analysis performed, including the type of structure, loading conditions, and key parameters considered. Present tables showing shear force values at various locations or sections of the structure. Include details such as section locations, shear force values, and any significant observations

Ultimate Bearing Capacity

The **ultimate bearing capacity (q_u)** refers to the **maximum vertical pressure** that can be exerted on the ground surface without causing shear failure in the supporting soil. Essentially, it represents the highest load a soil can support per unit area before it fails due to shearing. This concept is critical in the design of foundations, ensuring that the soil beneath a structure can safely bear the loads transferred from the building or structure above without undergoing excessive deformation or collapse. Table 4.1 shown the different angle of internal friction and L/H ratio.

Table 1 Ultimate bearing capacity (q_u) KN/m^2

S. No	Internal Friction Angle Φ	L/H Ratio		
		1	1.5	2
1	16	103.81	146.92	204.39
2	18	160.34	261.57	337.73
3	25	248.87	351.13	458.92
4	28	371.23	584.46	698.12
5	30	452.68	638.73	895.47

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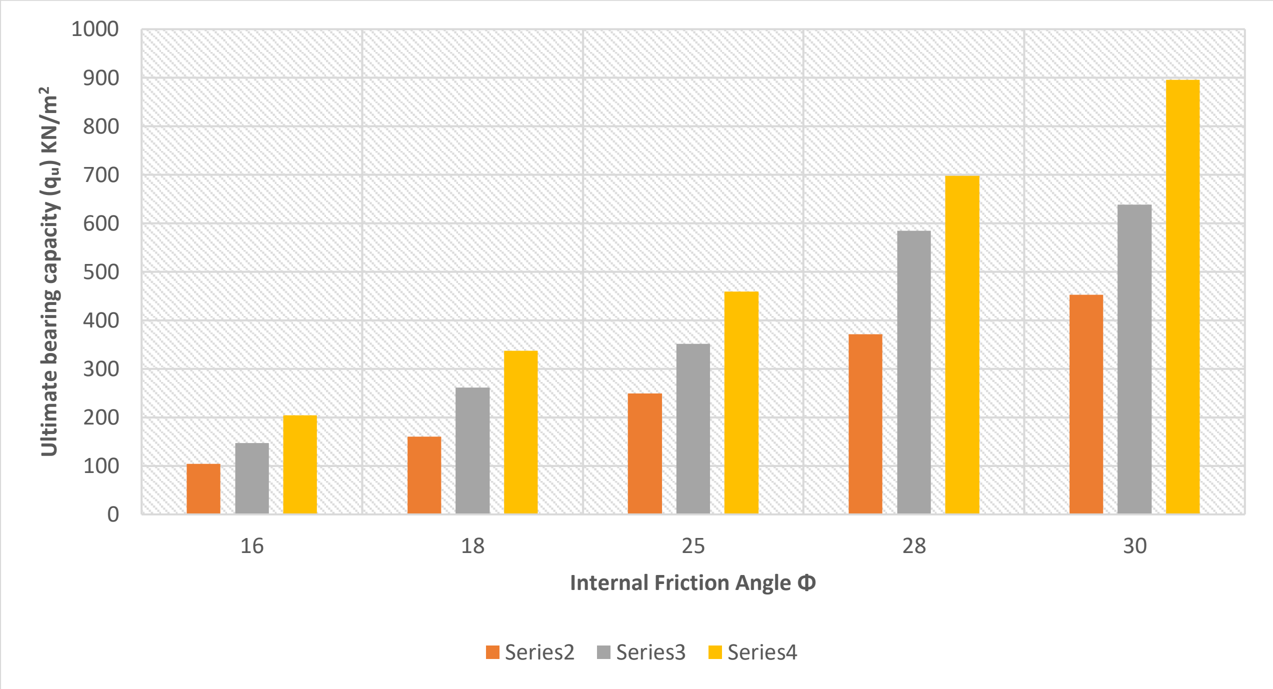

Figure 3 Ultimate bearing capacity

Table 2 Shear force on deck slab in KN

S. No	Internal Friction Angle Φ	L/H Ratio		
		1	1.5	2
1	16	270.32	281.15	298.65
2	18	267.87	279.32	280.31
3	25	265.32	274.31	275.56
4	28	265.12	271.30	272.30
5	30	261.23	265.32	267.81

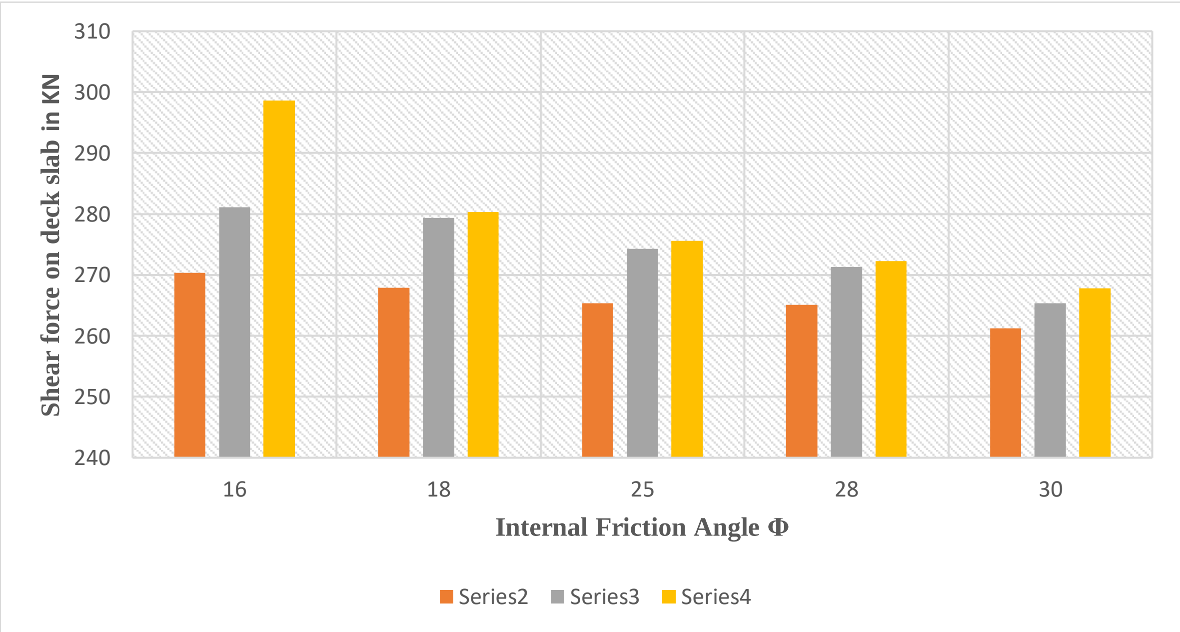

Figure 4 Shear force on deck slab

CONCLUSION

Findings regarding the behavior of a box culvert under varying angles of internal friction and L/H (length-to-height) ratios offer key insights into its structural responses.

Net Ultimate Bearing Capacity (Qnu)

- **Increase of 25%** as both the **angle of internal friction** and **L/H ratio** increase.
- This suggests that improved soil friction and the culvert's geometry contribute significantly to the bearing capacity.

Deck Slab Shear Forces (Vd)

- Shear forces in the deck slab are **constant** across all models, regardless of changes in the angle of internal friction or the L/H ratio.

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