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Original Article

Analysis and Design of RCC Box Culvert

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Abstract - *Culvert design is an important part of infrastructure construction because it affects public safety and resilience in the face of dynamic hydraulic occurrences. Engineers may design culverts that efficiently manage water flow, improve infrastructure resilience, and contribute to the overall safety and functionality of traffic networks by considering numerous flow scenarios and conducting extensive assessments. By providing a designated passage for water, box culverts help manage flood risks. They ensure balanced water levels on both sides of the road embankment, reducing the risk of flooding on one side and minimizing the overall impact of floods. This paper dives into the design considerations for box culverts, specifically focusing on Live Load Distribution, Earth Pressure and Cushion Layer. Live Load Distribution refers to how traffic weight is spread across the culvert's top slab. The paper explores factors like the "angle of dispersion" or "effective width" that influence how this load is distributed. The weight of the surrounding soil exerts pressure on the culvert walls. This paper examines how the "coefficient of earth pressure" affects the design of these walls. Some box culverts have a layer of material placed on top of the slab to distribute loads and protect it from damage. This paper investigates the impact of the "depth of cushion" on the overall structure. By analyzing these design parameters, engineers can create more efficient and durable box culverts that effectively manage water flow and contribute to flood control efforts. This study has investigated culvert performance under diverse flow circumstances, encompassing both steady and fluctuating flows. This comprehensive approach has led to a deeper understanding of how culverts react to different water flow patterns and their ultimate performance limitations. This research emphasizes the need for complete design assessments and the use of technologies such as HEC-RAS in guaranteeing culvert safety and operation under various flow circumstances.*

Keywords - *Angle of dispersion, Box culvert, Coefficient of earth pressure, Cushion, Lateral earth pressure.*

1. Introduction

A culvert is a crucial component of the infrastructure that functions as a tunnel or closed conduit to allow water to flow freely from one place to another. Its main purpose is to transport surface water so that it can pass through a road embankment or be diverted off the highway Right-of-Way (ROW) and into a canal along the ROW. In order to effectively manage the flow of water while supporting the weight of construction and highway traffic loads, culvert design takes into account both structural and hydraulic factors. To accommodate varied needs, culverts are available in a variety of designs, including circular, elliptical, and box-shaped. The intended hydraulic performance, constraints on the upstream water surface elevation, highway profile, assessments of potential flood damage, building and maintenance costs, and expected service life all have an impact on the choice of culvert shape. When choosing the best culvert form for a certain project, these elements work together to influence the decision-making process. Culverts are considered modest constructions, yet their importance cannot be overstated. They are essential for maintaining the overall integrity of the traffic infrastructure and ensuring optimum drainage. It is essential to manage water effectively through culverts to avoid floods, preserve traffic safety, and shield nearby structures from possible water damage.

Culverts are frequently built utilizing structural elements that surround the full circumference and are covered with embankments. Some culverts, on the other hand, are supported by spread footings, with a concrete riprap channel or the streambed acting as the culvert's foundation. The goals of this design strategy are hydraulic efficiency and cost-effectiveness. Engineers make every effort to create culverts that function with submerged inlets during flood flows. Culverts can boost their hydraulic capacity and reduce the dangers of traffic interruption, property damage, and failure during floods by keeping the inlet submerged. This is an illustration of strong engineering techniques and taking into account economic issues. Culverts and bridges must be distinguished from one another. Bridges, unlike culverts, are not surrounded by embankments and are not built to use submergence to increase hydraulic capacity. However, certain bridges could be purposefully built to be submerged under flood circumstances. Any culvert that has a clear aperture greater than 20 feet, measured along the middle of the road between inside end walls, is regarded by the Federal Highway Administration (FHWA) as a bridge-class culvert. Due to their bigger size, such culverts are considered bridges and are subject to certain design and construction specifications. Although the price of a single culvert may be relatively low, the entire cost of culvert building accounts for a sizeable amount of the money allotted for highway projects.

Additionally, a sizeable portion of the costs related to maintaining the hydraulic aspects of roadways can be attributed to the upkeep of culverts. In order to improve traffic service and cut expenses, design requirements must be carefully chosen, and each culvert's hydraulic design must be thoroughly considered. Culverts that are affordable and well-designed increase traffic flow and long-term sustainability.

1.1. Necessity of the Project

It is essential to complete the project on culvert hydraulic behavior, design exploration, and culvert flow modeling and analysis using the HEC-RAS program for a number of reasons.

Ensuring Adequate Drainage: By enabling surface water to move beneath roads, culverts play a crucial part in keeping adequate drainage.

Environmental Impact Mitigation: Poorly constructed or operating culverts can have a negative impact on the surroundings. Erosion, habitat loss, and water pollution can result from inadequate drainage. Engineers can reduce the environmental effects of culverts because of the project's ability to comprehend the hydraulic behavior of culverts and make use of cutting-edge modeling techniques like HEC-RAS.

Increasing Infrastructure Resilience: The difficulties facing transportation infrastructure are getting worse due to climate change and harsh weather conditions. It is essential to build culverts that can endure these difficulties and continue to function under diverse flow conditions in order to increase resilience.

Cost-Effective Decision Making: The project gives engineers the opportunity to simulate various culvert designs and analyze their hydraulic performance using cutting-edge modeling tools like HEC-RAS.

1.2. Objectives

The following are the main objectives of the Project

1) To understand the hydraulic behavior of the culvert.
2) To understand the design of various culverts.
3) To module culvert flow using HEC-RAS.
4) To compare and analysis of HEC-RAS results.
5) To analysis in HEC-RAS with different discharge and different slopes.

2. Literature Review

A comprehensive variety of studies, research papers, and publications pertaining to numerous culvert-related topics would be included in a culvert-related literature review. A culvert literature review may address the following main topics:

Hydraulic Behavior and Performance Flow Capacity and Flow Patterns: Research on culvert flow capacity focuses on figuring out the highest flow rate that a culvert can handle without raising water levels too high upstream or too low downstream. Additionally, studies of flow patterns seek to comprehend how water flows through culverts, including the formation of velocity profiles, zones of flow separation, and the possibility for turbulence or vortices (Cabonce et al. 2019).

Velocity Distribution: Evaluating a culvert's hydraulic performance requires a thorough understanding of the distribution of velocities inside the structure. Researchers have looked at the velocity profiles at the entry, throat, and exit areas of culverts as well as other culvert sections. This data aids in assessing the efficacy of flow control mechanisms, such as baffles or sills, to reduce erosion and encourage effective water flow (Clark et al. 2014).

Energy Losses: Research has concentrated on calculating the amount of energy lost in culverts as a result of friction, turbulence, and abrupt changes in flow conditions. These studies seek to comprehend the variables, such as culvert form, roughness, entry circumstances, and flow velocities that contribute to energy losses. Engineers can create culverts with maximum hydraulic efficiency by reducing energy losses (Roushangar et al. 2019).

Inlet and Outlet Control parameters: Researchers have looked at how inlet and outlet control parameters affect the efficiency of culverts. This involves researching the impacts of buried and exposed inlets as well as various outlet arrangements. In order to achieve smooth flow transitions and avoid problems like inlet or outlet control submergence, which can reduce flow capacity and have backwater effects, the design must be optimized (Jaeger et al. 2019).

Sediment movement and Scour: For culverts to be kept in good condition for the long term, it is important to comprehend sediment movement and scour. Studies have looked into the patterns of scour, erosion, and sediment deposition close to culvert constructions. In order to reduce sedimentation and avoid scour-caused failures, this knowledge aids in the construction of suitable solutions, such as sediment traps, aprons, or erosion-resistant materials (Taha et al., 2020).

2.1. Hydraulic Behavior and Performance

Numerous studies have been done to improve the performance and durability of culvert design and construction, which are essential components of culvert development. The following essential elements are covered in the literature on culvert design and construction:

Design Criteria and Guidelines: Researchers have created design criteria and guidelines for culverts, taking into consideration numerous aspects such as road profiles, needed hydraulic capacity, and flood flows. These recommendations give engineers the necessary design criteria to guarantee appropriate water conveyance while taking into account the unique project requirements, such as culvert form, size, and alignment (Rowley and Hotchkiss 2014).

The Impact of Culvert Shape, Size, and Alignment: Researchers examine how culvert shape, size, and alignment affect hydraulic performance. In order to evaluate the benefits and drawbacks of various culvert designs, including circular, pipe-arch, and box culverts, in terms of flow capacity and resistance to sedimentation, studies compare the hydraulic properties of these various culvert shapes. Investigations also look at how culvert alignment and size affect flow patterns, energy losses, and scour risk in an effort to optimize these variables for efficient water transport (Iqbal et al., 2023).

2.1.1. Environmental Considerations

Culverts may have a big influence on aquatic habitats, thus, it is crucial to take the environment into account while designing and building them. The following significant elements are found in the literature that are pertinent to environmental issues in culvert design:

Ecological Impacts on Fish Passage and Aquatic Organisms: Studies have been carried out to evaluate the ecological effects of culverts on fish in particular. These studies look at the potential obstacles that culverts pose to fish passage, including flow rate, water depth, turbulence, and internal physical barriers. Researchers seek to discover possible limits and provide design solutions that reduce detrimental effects on fish populations by analyzing the behavior, migration patterns, and survival rates of various fish species in and around culverts (Anderson et al. 2012).

Designing Culverts for Ecological Connectivity and Natural Stream Processes: Research on the development and usage of culverts that support ecological connectivity and preserve natural stream processes is a primary area of interest. In order to ensure that aquatic creatures may travel freely through culverts, this requires taking into account the longitudinal and lateral connection of streams. Studies examine the design elements, such as the incorporation of fish passage structures like baffles, weirs, or fish ladders, that enhance fish movement. The impact of culvert design on preserving natural stream processes, including sediment transport, channel stability, and nutrient cycling is being investigated by researchers (O'Shaughnessy et al. 2016).

Mitigation strategies' Effectiveness: Research has been done to determine how well mitigation strategies work in reducing the ecological effects of culverts. These steps include the creation and use of fish-friendly culverts, which integrate elements like resting ponds, low-flow channels, and natural substrate to improve the circumstances for fish passage. In order to increase ecological connectedness and stream health generally, research also focuses on streambed restoration methods, such as the construction of riffles, pools, or other habitat modifications. Researchers can advise on the best methods for conserving or restoring aquatic ecosystems in culvert-affected regions by observing the effectiveness of these mitigation measures (Markle et al. 2017).

3. Methodology

3.1 Software Tools

HEC-RAS (Hydrologic Engineering Centers-River Analysis System) is employed in the current study. The U.S. Army Corps of Engineers created it as a frequently used piece of software. The hydraulic modeling of rivers, canals, and other water conveyance systems is its intended use. For performing one-dimensional steady and unsteady flow analysis, HEC-RAS offers a complete range of capabilities, including floodplain delineation, water surface profile calculation, sediment transport analysis, and bridge and culvert hydraulics. Hydraulic engineers all across the world use HEC-RAS, which is widely recognized in the industry. Engineers may use a variety of features in the program to evaluate and simulate how rivers and channels behave under various flow conditions. The capacity to do one-dimensional steady and unsteady flow analysis is one of HEC-RAS's core strengths. By taking into account variables like flow rates, channel geometry, and roughness, it is able to determine water surface profiles and flow characteristics along a river or channel. This knowledge is essential for determining flood risks, developing flood prevention strategies, and comprehending how existing buildings behave hydraulically.

Another crucial component of HEC-RAS is the identification of the floodplain. By calculating the depth and breadth of flooding during various flood events, the program helps identify at-risk locations and supports efficient floodplain management measures. Planning for land use, disaster preparedness, and infrastructure design all depend on this knowledge. Engineers may assess how sediments travel inside a river or channel by using the sediment transport analysis capabilities of HEC-RAS. This is crucial for determining the likelihood of erosion, deposition, and sedimentation since these processes might affect the stability and upkeep needs of hydraulic structures.

Additionally, HEC-RAS provides specialized hydraulic equipment for bridge and culvert construction. In order to evaluate the capacity, scour potential, and performance of bridges and culverts under various flow circumstances, engineers can simulate and analyze the flow through these structures. This aids in creating and sustaining a transportation system that is both safe and effective.

Users may enter geometric information, boundary conditions, and hydraulic parameters for their research reach using the software's graphical user interface. It simulates flow behavior calculates water surface profiles, and other hydraulic variables using the open channel hydraulics principles. The governing equations, including the Saint-Venant equations, are solved by HEC-RAS using a variety of numerical techniques and algorithms. Water surface profiles, velocity distributions, shear stresses, and flood inundation maps are only a few of the powerful visualization tools provided by HEC-RAS for the display and analysis of the findings. It allows engineers and hydrologists to estimate flood risks, evaluate the effectiveness of current hydraulic structures, build new structures, and evaluate the effects of various scenarios or interventions on river hydraulics. The fields of hydraulic engineering, floodplain management, river restoration, bridge and culvert design, and flood risk assessment all make extensive use of the program. It offers a solid framework for modeling and assessing the hydraulic behavior of rivers and channels, assisting in the process of planning and making decisions pertaining to the management of water resources and the prevention of flooding.

3.2. Required Data

The following information is often necessary when using HEC-RAS for culvert design:

3.2.1. Geometry Data

This section contains information on the size and shape of the culvert, as well as its width, height, diameter, slope, length, and alignment. In addition, the cross-sectional form, size, and slope of the channel above and downstream of the culvert may be required.

3.2.2. Manning's Roughness Coefficient

The roughness or friction of the channel and culvert walls is represented by Manning's n value. Calculating the flow resistance is necessary. For diverse materials, including concrete, metal, and plants, typical n values are given.

3.2.3. Inflows

The hydrograph, or flow rate entering the culvert, is included in the inflow data. Data on rainfall, hydrological models, or flow measurements may all be used to determine this. It is crucial to take into account both steady-state and irregular flow circumstances.

3.2.4. Boundary Conditions

To properly model the flow behavior, information regarding the downstream boundary conditions, such as water levels, tailwater heights, or outflow control structures, is required.

Data on the operation of the culvert, such as information on any gates, weirs, or control devices that are connected to the culvert and affect the flow conditions. The functioning and behavior of these characteristics must be modeled using this data.

Sediment Data

Data on sediment parameters, such as particle size distribution, sediment concentration, and settling velocity, may be required if sediment transport analysis is needed.

Design Requirements

It is important to indicate any particular design requirements or limitations for the culvert, such as the maximum permissible water levels, speed restrictions, or scour depths.

It is crucial to remember that the precise data needs might change based on the complexity of the culvert design, the required level of accuracy, and the analysis's goals.

3.3. Design and Modeling

To guarantee effective and secure water flow through culverts, design and modeling are essential components of culvert engineering. The following is a broad overview of culvert design and modeling considerations:

3.3.1. Design Considerations

Various factors must be taken into account while designing culverts to guarantee their optimum performance, structural integrity, and lowest environmental effects. The following are the primary culvert design considerations:

Hydraulic Performance

- To maintain effective water flow and avoid floods, appropriate hydraulic performance is essential. The following factors should be taken into account.
- Anticipated Flow Rates: The design should account for the anticipated flow rates, including peak flows during storm or flood events.
- Sizing and form: The culvert's size and form must be chosen carefully in order to accommodate the projected flow and avoid flow constraints.
- Control of the Inlet and Outlet: The design should provide a smooth transition and reduce energy losses at the Inlet and Outlet of the Culvert.
- Sediment movement: To ensure hydraulic efficiency, sediment movement and sedimentation inside the culvert should be taken into account.

Structural Integrity

Culverts need to be structurally sound in order to sustain a range of weights and forces. Take into account:

- Soil Loads: The design must take into consideration the soil's weight above the culvert, including active traffic loads and anticipated surcharge loads.
- Hydrostatic Forces: Culverts should be built to withstand the hydrostatic pressure that water may apply, especially in times of strong flow.
- Construction Materials: The durability and structural needs should be taken into consideration while choosing the right construction materials, such as concrete, steel, or corrugated metal.

Site Conditions

Designing culverts that are appropriate for the environment requires a thorough understanding of the site's circumstances. Take into account:

- Soil Type: The design and building methods for culverts are influenced by the strength, permeability, and compaction of the soil.
- Groundwater Levels: The foundation design of the culvert and the likelihood of seepage depend on the depth and volatility of the groundwater.
- Topography: The culvert's alignment, flow characteristics, and risk for erosion are impacted by the slope and orientation of the terrain.

Environmental Impact

- The design of culverts should reduce their negative effects on the environment. The following factors should be taken into account: - Streambed Stability: The culvert should be built to prevent major variations in water velocity and scour potential, and to reduce erosion and preserve the stability of the streambed.
- Fish Passage: When designing culverts, it is important to take into account the requirements of fish and other aquatic animals. To this aim, elements like fish-friendly baffles, step pools, or bypass channels should be included.
- Ecological Connectivity: In order to permit animal mobility and preserve natural ecosystems, the design should work to maintain ecological connectivity between upstream and downstream habitats.

Longevity and Maintenance

Designing for long-term strength and simplicity of upkeep is crucial. The following factors should be taken into account:

- Material Durability: The lifespan of the culvert may be increased by choosing materials that are very durable and resistant to corrosion, abrasion, and chemical deterioration.
- Designing access points, such as manholes or inspection chambers, makes it easier to conduct routine inspections and maintenance procedures.
- The service life of the culvert is increased by including facilities for future maintenance or rehabilitation, such as access points and reinforcing alternatives.

Engineers may create culverts that efficiently regulate water flow, offer structural stability, reduce environmental consequences, and require less maintenance during their lifespan by taking these design considerations into account.

3.3.2. Modeling

When designing culverts, modeling is essential because it gives engineers the ability to simulate and examine different hydraulic scenarios.

Numerical modeling enables a thorough knowledge of flow patterns, water levels, and velocity distributions inside and around culverts, especially when used with software tools like HEC-RAS. Data inputs, analysis, sensitivity analysis, and optimization are some of the phases that make up the modeling process.

Numerical modeling: Using software tools, numerical modeling entails simulating hydraulic phenomena and building virtual models of the culvert system. Comprehensive capabilities for one-dimensional steady and unsteady flow analysis are provided by the widely used software program HEC-RAS.

Inputs: Several inputs are necessary for an accurate culvert model, including:

Culvert Geometry: The model requires information on the size, shape, and alignment of the culvert. The culvert's length, breadth, and invert height are all included.

The input hydrographs, such as rainfall-runoff events or known flow rates, indicate the inflow circumstances to the culvert.

Manning's Cruelty Coefficients: Taking into consideration elements like the texture of the culvert material and vegetation, these coefficients describe the flow resistance within the culvert and its surrounds.

Boundary Conditions: For accurate modeling, upstream and downstream boundary conditions, such as water levels or flow rates, are essential.

Analysis: After receiving the required inputs, the model runs calculations to mimic the culvert's hydraulic behavior. The analysis consists of:

Water Surface Profiles: To determine the water levels at various points along the culvert, the model computes the water surface profiles along the culvert.

Flow Rates: The model calculates the culvert's flow rates under various circumstances, enabling engineers to evaluate the culvert's capacity.

Flow characteristics and probable scour zones are revealed by computing velocity distributions inside the culvert and its surroundings.

Sensitivity Analysis: Engineers can use modeling tools to do sensitivity assessments to determine the effects of changing design parameters. Engineers can assess the sensitivity of the culvert's performance by changing inputs like culvert size, roughness coefficients, or boundary conditions. Making wise selections and improving the design are made easier with the use of this knowledge.

By investigating various layouts, forms, and sizes, modeling helps to optimize culvert design. Engineers are able to simulate various scenarios and assess how well they perform in comparison to predetermined goals. Engineers can find the best culvert design that satisfies the project's criteria by repeatedly changing the design parameters and evaluating their impact.

Engineers may make better design choices by using numerical modeling to acquire useful insights into the hydraulic behavior of culverts. It helps with performance evaluation, problem identification, and design optimization to achieve desired outcomes, including effective water flow, low danger of flooding, and reduced propensity for scour. Additionally, without the need for actual prototypes, modeling offers a cost-effective method for evaluating numerous design possibilities, saving time and money during the design process.

3.4. Culvert Design Process Manually

Step 1: Identify the headwater height and flow rate.

The headwater height and flow rate must be determined first. The headwater elevation is the height of the water surface upstream of the culvert, and the flow rate is the volume of water that will be passing through the culvert. The local hydrology can be examined to determine these values.

Step 2: Decide on the size and kind of culvert.

The next stage is to choose the culvert type and size once the flow rate and headwater elevation have been determined. Culverts come in a wide variety of materials, including concrete, steel, and corrugated metal. The soil characteristics, headwater height, and flow rate will influence the choice of culvert.

Step 3: Make a hydraulic radius calculation.

The cross-sectional area of the culvert in relation to its wetted perimeter is measured by the hydraulic radius. The following formula can be used to determine the hydraulic radius:

$$R = A/P \tag{1}$$

Where:
R = hydraulic radius
A = cross-sectional area of the culvert
P = wetted perimeter of the culvert
where: A = cross-sectional area of the culvert.

Step 4: Calculate the velocity.

The velocity is the speed at which the water will be flowing through the culvert. The velocity can be calculated using the following formula:

$$V = Q/A \tag{2}$$

Where:
V = velocity
Q = flow rate
A = cross-sectional area of the culvert

Step 5: Discharge calculation.

The amount of water that will be discharged via the culvert per unit of time is known as the discharge. The following formula may be used to determine the discharge:

$$Q = VA \tag{3}$$

Where:
Q = discharge; V = velocity; A = cross-sectional area of the culvert
Formulas commonly used in culvert design:
Manning's Equation:

$$Q = (1/n) * A * R^{(2/3)} * S^{(1/2)} \tag{4}$$

Q: Flow rate (discharge)
n: Manning's roughness coefficient
A: Cross-sectional area of flow
R: Hydraulic radius
S: Energy gradient or slope of the flow
Hazen-Williams Equation:

$$Q = 1.318 * C * A * R^{(0.63)} * S^{(0.54)} \tag{5}$$

Q: Flow rate (discharge)
C: Hazen-Williams coefficient
A: Cross-sectional area of flow
R: Hydraulic radius
S: Energy gradient or slope of the flow
Rational Method:

$$Q = Ci * A \tag{6}$$

Q: Peak flow rate
Ci: Runoff coefficient for the catchment area
A: Catchment area

4. Results of HAC-RAS Model

The HEC-RAS model results for the culvert design yield important information about the system's hydraulic performance and behavior. Among the main conclusions are: The HEC-RAS model offers thorough details on flow rates and velocities at various points inside the culvert. The model determines the size and direction of flow at each site by simulating water flow through the culvert under various flow conditions. This information is essential for determining if the culvert can manage the anticipated flow rates. The amount of water flowing through the culvert per unit of time is represented by the flow rate, which is often given in cubic meters per second (m3/s) or cubic feet per second (cfs). Engineers can verify whether the culvert is properly designed to handle the predicted flow by examining the flow rates. In the event that the culvert's capacity is exceeded, flooding, backwater effects, or even structural failure may result.

Water flow through the culvert is measured in terms of velocity. The entry, throat, and exit sections of the culvert are among the locations where the HEC-RAS model determines velocities. High speeds can cause erosion and scour, which might jeopardize the integrity of the culvert and other buildings. Engineers can implement the necessary procedures to limit the consequences by identifying places with high velocities, such as changing the design of the culvert or adding flow control devices. For constructing and assessing the hydraulic performance of the culvert, the flow rates and velocities obtained from the HEC-RAS model offer useful information. Engineers may determine if the culvert is properly designed to manage the anticipated flow without having harmful effects by comparing the projected flow rates with design requirements and standards. Analyzing the velocities also aids in identifying possible issue locations where structural changes or flow control measures may be required to stop erosion and preserve the integrity of the culvert.

The HEC-RAS model estimates for various discharge circumstances in a culvert design are shown in Figures (5.1 to 5.6). These diagrams give important information about the culvert's hydraulic performance in various flow conditions. The depth and velocity data generated from the HEC-RAS model for various discharge rates are shown in Figures 5.1 to 5.6. The velocity measurements depict the rate of water flow, whilst the depth data show the water level inside the culvert. Many tendencies may be seen after evaluating the figure. Both the depth and velocity numbers generally increase as the discharge rises. This is to be expected since a larger discharge rate causes more water to flow through the culvert, increasing the water's depth and speed. It is essential to keep in mind that the depth and velocity measurements may change depending on where you are in the culvert. These statistics give a thorough summary of these variances and enable engineers and designers to evaluate the culvert's hydraulic performance across its entire length.

The information shown in these figures can be used to assess the culvert's ability to manage various flow rates. In order to make sure that the culvert can successfully carry water without producing flooding, excessive velocities, or scour, designers can compare the predicted depths and velocities with the intended design criteria. These data might also help in pinpointing any possible problem spots in the culvert. The necessity for velocity-reducing measures like flow control devices or energy dissipaters, for instance, may be indicated if the velocity values are very high for specific discharges. The depth measurements can also be used to estimate the likelihood of sedimentation or debris buildup inside the culvert. If the depth values are regularly high, it could be necessary to do maintenance or include new design elements to address these problems. It is crucial to remember that the quality and precision of the input data, such as cross-sectional geometry, boundary conditions, and Manning's roughness coefficients, is what determines how accurate the HEC-RAS model computations are. As a result, proper data collection and calibration are crucial for producing findings from the model that can be trusted. The cross-section of the culvert using the HAC-RAS model is shown in Figure 5.7.

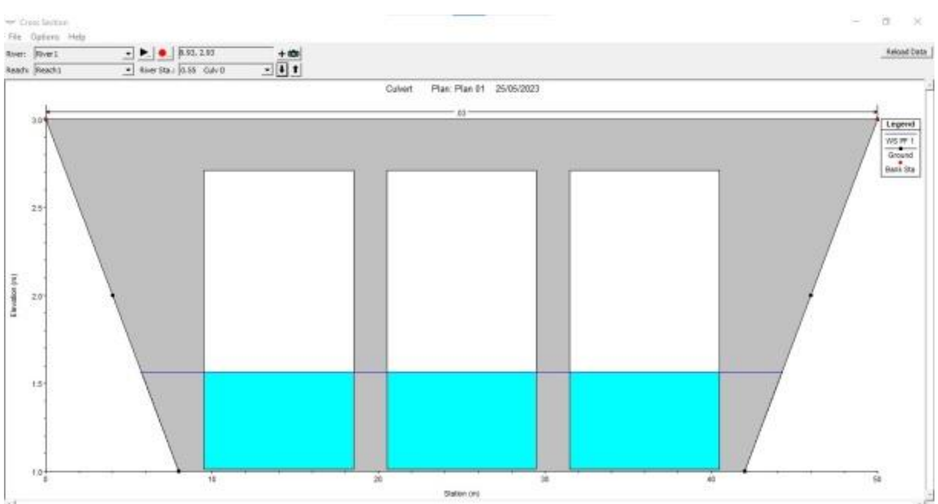

Fig. 1 HAC-RAS model calculation for discharge 20 m3/s for slope 0.30

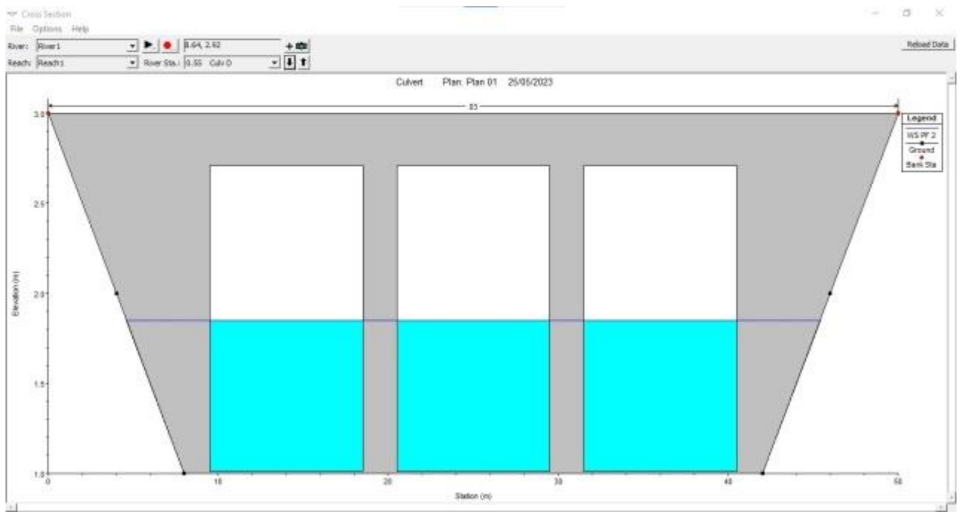

Fig. 2 HAC-RAS model calculation for discharge 40 m3/s for slope 0.30

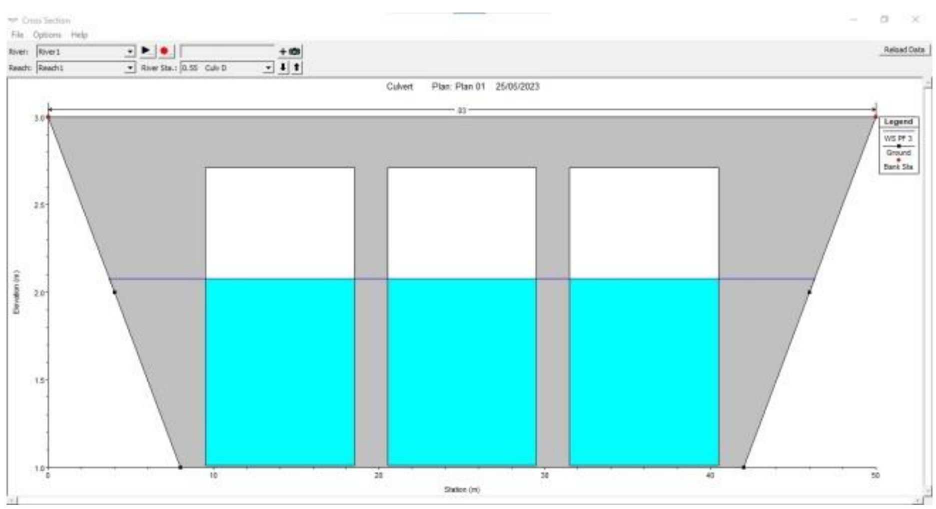

Fig. 3 HAC-RAS model calculation for discharge 60 m3/s for slope 0.30

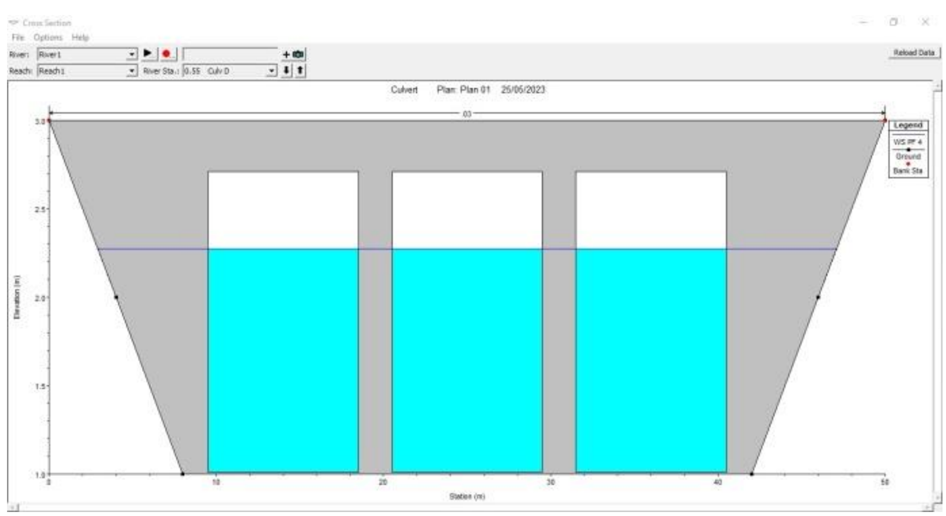

Fig. 4 HAC-RAS model calculation for discharge 80 m3/s for slope 0.30

Fig. 5 HAC-RAS model calculation for discharge 100 m3/s for slope 0.30

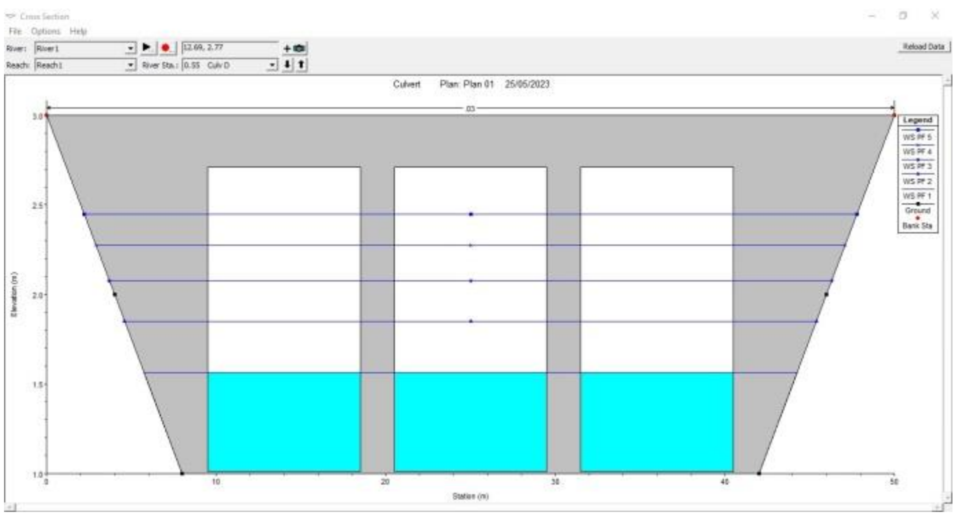

Fig. 6 HAC-RAS model legend level for all the discharges for slope 0.30

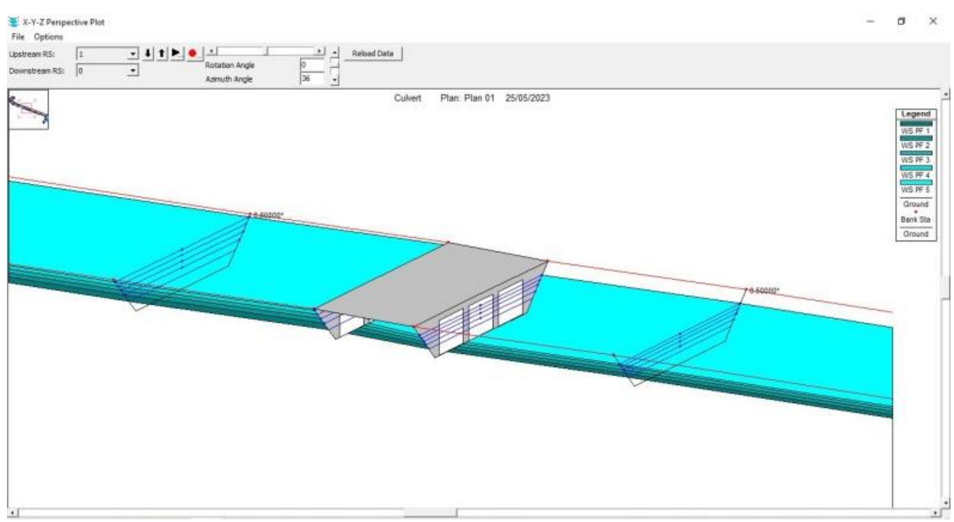

Fig. 7 Cross section of the culvert using the HAC-RAS model

5. Results of Manual Calculation

Based on the design steps the manual calculation has been performed.

Formula:

a) Manning's formula is widely used in open-channel hydraulics to estimate the flow velocity in a channel based on the channel slope, roughness coefficient, and hydraulic radius. The formula is expressed as:

V = (1 / n) * R^(2/3) * S^(1/2)

Where:

V = Flow velocity (m/s or ft/s)

n = Manning's roughness coefficient (dimensionless)

R = Hydraulic radius (m or ft)

S = Channel slope (m/m or ft/ft)

b) Q = A * V = (1 / n) * A * R^(2/3) * S^(1/2)

Where:

Q = Discharge (m³/s or ft³/s)

Parameters:

Discharge: 20 m3/s; 40 m3/s; 60 m3/s; 80 m3/s, 100 m3/s

Table 1 shows the detailed calculation of the culvert using the manual method.

Table 1. Calculation of the culvert using the manual method

Details	Flow Discharge Q	Gravitational Acceleration g	Wetted Perimeter P	Flow Area A	Hydraulic Radius R	Hydraulic Depth D	Output		
							Normal Flow depth y_n	Normal Flow Velocity V_n	Normal Froude Number F_n
Manual calculation for discharge 20 m3/s	6.67m^3/s	9.806 ms^2	10.77 m	3.85m^2	0.367m	0.385m	0.385m	1.733ms^{-1}	0.892
Manual calculation for discharge 40 m3/s	13.33m^3/s	9.806ms^{-2}	11.184m	5.92m^2	0.529m	0.592m	0.592m	2.251ms^{-1}	0.934
Manual calculation for discharge 60 m3/s	20m^3/s	9.806ms^{-2}	11.529m	7.65m^2	0.663m	0.765m	0.765m	2.616ms^{-1}	0.955
Manual calculation for discharge 80 m3/s	26.67m^3/s	9.806ms^2	11.336m	9.18m^2	0.776m	0.918m	0.918m	2.904ms^{-1}	0.968
Manual calculation for discharge 100 m3	33.33m^3/s	9.806ms^2	12.119m	10.6m^2	0.874m	1.06m	1.06m	3.145ms-1	0.976

6. Conclusion

In conclusion, the full research of culvert performance under diverse flow circumstances, including steady and unstable flow scenarios, has offered useful insights into the behavior and limits of culverts. This study provides several major takeaways. Firstly, as in the case of the slope of 0.30, the design discharge remains within the capacity of the culvert, and the culvert exhibits efficient flow regulation. This is particularly important for infrastructure and public safety since testing confirms the culvert's capacity to manage normal or continuous flow conditions.

Second, for culvert design features such as depth and velocity, a comparison of HEC-RAS with the Manual

Method demonstrates that HEC-RAS consistently generates more accurate and complete findings. When compared to the Manual Method, HEC-RAS's complex hydraulic model delivers more exact depth and velocity information. As a result, HEC-RAS is the primary instrument for culvert design and analysis.

The steady flow analysis indicated that the culvert efficiently regulated flow at lower discharge rates, showing suitability for moderate flow conditions when applied to scenarios with slopes of 0.50 and 10. However, when the rate of discharge grew, difficulties occurred. At 80 m^3/s, the culvert surpassed its capacity and failed to hold the flow at 100 m^3/s. This emphasizes the significance of completing complete design assessments that account for severe flow occurrences, which may necessitate design changes or advanced flood control systems. The unsteady flow study, which is useful for dynamic events like floods and dam releases, revealed a similar trend.

The culvert well-regulated lower discharge rates, but greater discharge rates presented complicated hydraulic behavior. At 60 m^3/s, a distinct flow pattern appeared, illustrating the dynamic character of hydraulic processes. At 80 m^3/s and 100 m^3/s, the flow surpassed the culvert's capacity, underlining the necessity for design revisions and sophisticated flood control techniques in such circumstances.

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