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# INTEGRATED GEOTECHNICS AND HYDRAULICS STRATEGIES IN PIPES: CASE STUDY OF PLAZA MAGDALENA

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## INTRODUCTION

In the urban area of Cobán, Guatemala, the Plaza Magdalena Shopping Center is located, which drives local economic development, but is exposed to the risk of flooding. In order to protect it, a project has been developed to channel and protect the Cahabón River. This project integrates hydraulic and geotechnical aspects, focusing on the stability and sustainable behavior of gabion structures. The impact of stone particle size and the application of polymer coatings was analyzed, using digital tools for hydraulic analysis and design.

The methodology used highlights the crucial importance of considering safety factors in the planning of hydraulic works with a long-term sustainability perspective. The vital importance of accurately specifying materials and addressing multiple aspects to ensure the resilience and durability of pipeline infrastructures, in harmony with the surrounding geotechnical and environmental setting, is emphasized.

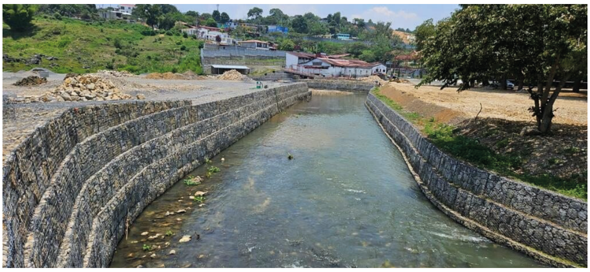


Figure 1: Circulation of the Cahabón River in the structure.

Source: visualization of the channeling (own photography, 2024)

## PIPELINE WORKS AND THE IMPORTANCE OF MATERIAL SPECIFICATION

Gabions are flexible and permeable containment structures that are widely used in civil engineering for erosion control, flood protection, slope stabilization and sedimentation control in rivers and canals (Giler-Ormaza et al., 2020; López, 2005). Their design and applications have evolved significantly over time, from their origin in the 19th century as wooden baskets filled with stone to modern double-twisted metal mesh structures with hexagonal openings.

Gabion design is based on principles of slope stability, open flow hydraulics and soil mechanics (Arévalo Algarra et al., 2021). Factors such as the type and size of the stone used, the strength and durability of the wire mesh, and the geometry of the structure are considered to ensure its effectiveness and longevity.

Gabion applications are diverse, including channel linings, retaining walls, bank protection and soil stabilization.

## IMPORTANCE OF STONE PARTICLE SIZE IN THE STABILITY AND HYDRAULIC BEHAVIOR OF GABION STRUCTURES

The particle size of the stone used in gabions plays a fundamental role in their stability and hydraulic behaviour. ASTM D6711-01 (2008) provides analysis methods to determine the particle size distribution of materials used in gabion construction (ASTM International, 2008) which allows the selection of stones of appropriate size to optimise the strength of the structure and its drainage capacity.

The influence of particle size on gabion stability lies in its ability to resist water erosion and maintain the cohesion of the fill. Stones that are too small can cause obstruction of the spaces between the meshes, reducing drainage capacity and increasing the risk of failure due to internal flow. On the other hand, stones that are too large can compromise the structural integrity and permeability of the gabion (Cole et al., 1996; Kilgore, 2005).

## POLYMER COATING AND ITS EFFECT ON ABRASION PROTECTION IN GABIONS

Polymer coating applied to the wire mesh of gabions plays a crucial role in protecting against abrasion and corrosion, extending the life of the structure in aggressive environments. These coatings provide a protective barrier that reduces direct contact between the steel core and the environment, thus minimizing wear and degradation (Mohamed, 2009; Salmasi et al., 2021; Stefano & Ferro, 1998).

It is important to select suitable coatings that are compatible with the wire mesh material and able to withstand the specific environmental conditions (ASTM International, 2021).

## METHODOLOGY

To carry out this study, a quantitative research approach was adopted, in line with the guidelines established by (Hernández Sampieri & Mendoza Torres, 2018) that allowed to objectively and measurably analyze the influence of stone particle size, wire mesh thickness, and polymer coating on the stability and hydraulic behavior of gabion structures. This quantitative approach was complemented with a qualitative analysis of the technical and operational aspects related to the channeling and containment of the Cahabón River, specifically for the Shopping Center located in the urban area of the municipality of Cobán, department of Alta Verapaz.

The selection of parameters to be analyzed was carried out considering the relevance of each one in the performance of gabion structures. Priority was given to stone particle size, taking into account the studies of (Zaharia, 2017) who highlight the importance of granulometry in the strength and stability of gabions. In addition, the thickness of the wire mesh was evaluated based on the recommendations of (Uray, 2022), who have investigated the relationship between the thickness of the wire and the retention capacity of the stones within the gabion.

Polymer coating was also considered as an important parameter, influenced by the research of (Cajka et al., 2023), who have demonstrated the benefits of polymer coating in abrasion and corrosion protection in gabion structures.

In addition, the *FHWA Hydraulic Toolbox* Program (FHWA, 2024) digital tool was used to perform hydraulic and design analyses. This tool provides a variety of calculations and functions that allow for detailed hydrology and hydraulic design analyses, facilitating the evaluation of different scenarios and the generation of accurate and reliable results (Azimi, 2021). The use of this program not only improves the accuracy of calculations, but also optimizes response time and allows for the consideration of multiple variables and conditions that affect the hydraulic behavior of the designed structures.

In the case study, the Cahabón River, which runs along the periphery of the project, was channeled in order to properly manage its flow and prevent possible risks associated with flooding. The channeling works extend over 1,200 meters, with a width of 8 meters and a height of 5 meters. This infrastructure was installed with the aim of safely channeling the waters, mitigating the risk of flooding and protecting the surrounding areas. The correct execution of this channeling is crucial to guarantee the safety and sustainability of the project, minimizing environmental and social impacts.

The selection of the geotechnical parameters and the methodology used for this work were based on the need to guarantee the effectiveness and durability of the gabion structures, especially in critical hydraulic conditions. These structures are designed to withstand high flow velocities and erosive forces, providing stability and protection to the river banks. In situations where the flow velocity can reach considerable levels, it is vital to ensure that the construction materials and techniques are suitable to withstand such conditions without compromising the integrity of the work (Hajialigol et al., 2024).

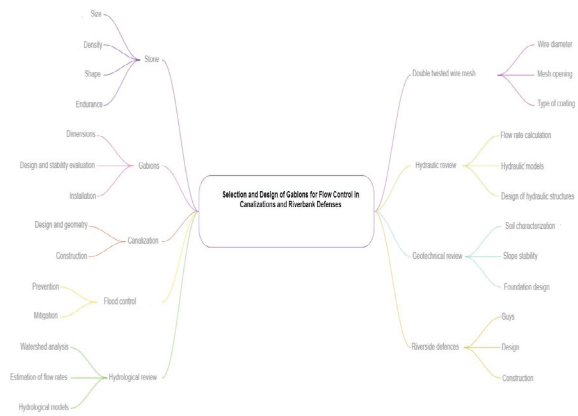



Figure 2: Design methodology for gabion channels.

Source: self made.

## RESULTS

The collected data, including D50 particle size of 400 mm, stone specific gravity of 25 kN/m³ and porosity of 30%, together with 2.4 mm thick wire mesh coated with a polymer to protect the zinc and steel core, were used as input into the *FHWA Hydraulic Toolbox* Program (FHWA, 2024). This software allows for detailed and accurate hydraulic and design analyses, taking into account the curved geometry of the pipeline and other relevant parameters such as R/T ratio > 10 and a radius curvature factor of 1 m.

$$\tau = 0.0091\,(\gamma - \gamma_s)(MT + MTC) \quad [1]$$

$\tau$ = gabion allowable shear stress.

$\gamma$= specific weight of gabion (kN/m³).

$\gamma_{s=}$ specific weight of water (kN/m³).

MT= height of the gabion box (m).

MTC= thickness constant, 1.24 meters (m).

The interpretation of the results obtained focuses on the hydraulic behavior, stability and strength of the gabion structures. The computational tool (FHWA, 2024) was applied to evaluate the effectiveness of the channeling. Considering the 1% slope to maintain the flow velocity within the desired limits, it is essential to analyze the interaction between the retained soil and the gabion structure to control the turbulence along the channeling.

Experimental studies have shown that in sinuous channels with beds susceptible to erosion, flow velocity can increase significantly at bends, reaching up to 8.5 m/s at the entrance to the bend. This highlights the importance of properly managing the slope and flow control to ensure channel stability and efficiency (Ghani et al., 2023).

The analyses carried out included the study of *bend shear*, a crucial aspect for the stability of gabion structures, which was examined in detail using the aforementioned software. Variations in flow depth, flow area, velocity and critical depth were observed along the channel, providing a comprehensive understanding of the structure's hydraulic behaviour.

Table 1 shows a number of key parameters relating to the size of stone used in a channel, as well as the corresponding shear stresses, safety factors and heights. The average stone diameter (D50) is set at 400 mm. The shear stress on the channel is 0.39 kPa, while the associated safety factor is 1.5. In addition, the channel height is specified at 5 metres.

| Stone size | Range | Shear stress on the channel | Security factor | h |
|---|---|---|---|---|
| | [mm] | [kPa] | | [m] |
| D50 | 400 mm | 0.39 | 1.5 | 5 m |

Table 1: Results of pipeline analysis.

Source: the own authors

Reference is made to investigations of flow behaviour in open channels. For example, (Afzalimehr et al., 2010; Kim & Paik, 2018; Lee & Julien, 2006) have investigated the influence of channel geometry on the hydraulic behaviour of structures, while (Chinnarasri et al., 2008; Huber & Biesiadecki, 2021) have analysed the importance of polymer coating in abrasion protection under fluvial conditions, being crucial for the preservation of structures.

Roughness, which is calculated using the equations provided by the FHWA for open channel analysis, is characterized by a Manning coefficient (n) of 0.0538. This coefficient, which is crucial in determining the flow, varies according to the interaction inherent to the soil particle size. This variability facilitates the accurate calculation of the corresponding flow rate, allowing an efficient assessment of the hydraulic conditions in the channel.

The graphs resulting from this analysis provide a clear visual representation of the relationship between flow depth and other key hydraulic parameters, allowing for accurate assessment of pipeline performance and informed decision making for future similar projects.

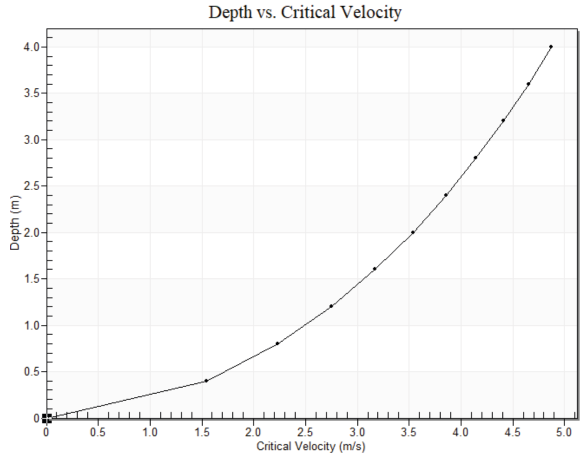



Figure 3: Relationship between depth and flow velocity

Source: the own authors

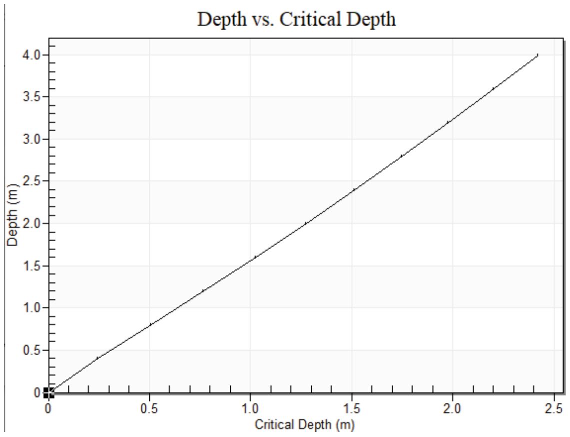



Figure 4: Channel depth and critical depth relationship

Source: the own authors

## CONCLUSIONS

- The findings of this study underline the crucial importance of stone particle size and polymer coating in the stability and hydraulic behaviour of gabion structures. Careful selection of these materials not only impacts erosion resistance, but also abrasion protection, essential aspects to ensure the longevity and effectiveness of channelling works.

- The application of digital tools such as the FHWA Hydraulic Toolbox Program has simplified the meticulous and accurate analysis of hydraulic designs, enabling the evaluation of various situations and the generation of reliable results.

- The methodology used in this study highlights the importance of considering both hydraulic and geotechnical aspects in the design of channeling works. The evaluation by global, external and internal stability factors provides a comprehensive understanding of the behaviour of gabion structures, which is essential to ensure their long-term effectiveness and safety. This integration of multiple aspects in the design and construction of hydraulic works contributes significantly to their sustainability and durability over time.

Figure 5: Perspective of the containment work

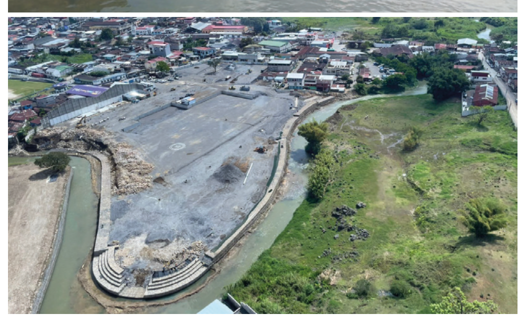
Source: visualization of the channeling (own photography, 2024).

## DISCUSSION

- The results obtained in this research support the need for accurate specification of materials used in the construction of channel works, particularly with regard to stone particle size and polymer coating. These factors not only influence the structural stability of gabions, but also their ability to resist the erosive and abrasive processes inherent in water flow.

- The use of computational tools for processing hydraulic data has provided an effective platform for hydraulic analysis and design of gabion structures. The ability to simulate different flow conditions and assess the hydraulic response of the channel has allowed for optimizing the design and anticipating potential problems prior to construction.

- It is crucial to carry out detailed geotechnical studies and hydraulic and hydrogeological analyses before selecting stone sizes for gabion structures. This practice ensures that design decisions are based on accurate data and that the resulting structures are durable and efficient.



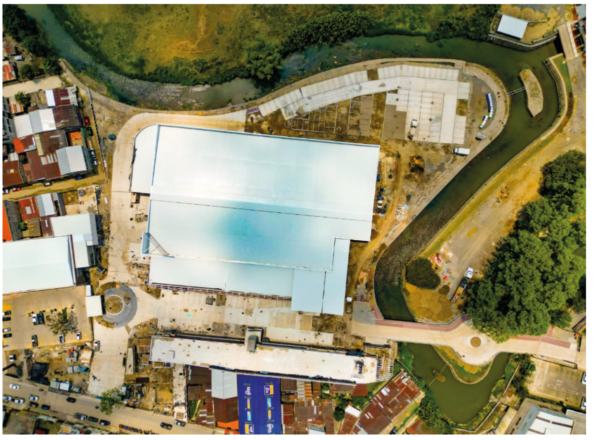


Figure 6: Aerial view of the project and its stages during its execution.

Source: stages during the construction phase (own photograph, 2024).

## THANKS

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