International Journal of Scientific Research and Engineering Development-– Volume 6 Issue 4, July- Aug 2023

Available at **www.ijsred.com**

RESEARCH ARTICLE OPEN ACCESS

Proposed Riverbank Protection Using Gabion Retaining Wall as an Alternative to the Collapsed Sheet Pile at Brgy. Bambang, Candaba, Pampanga

Erica Lhen M. Salonga*, Eric D. Paraiso**, Jerico T. Aga***, Justine Kyle B. Calo****, Vincent Carlo S. David*****, John Patrick L. Nuqui******, Angelika Jaime C. Perez*******, Mike Diether B. Galvez********, Juanita Carmelita R. Zoleta*********

*(Civil Engineering, Don Honorio Ventura State University, Pampanga Philippines
Email: 2019991711dhvsu.edu.ph)

**(Civil Engineering, Don Honorio Ventura State University, Pampanga Philippines
Email :2019996736@dhvsu.edu.ph)

***(Civil Engineering, Don Honorio Ventura State University, Pampanga Philippines
Email : 2019998441@dhvsu.edu.ph)

****(Civil Engineering, Don Honorio Ventura State University, Pampanga Philippines
Email : 2019994740@dhvsu.edu.ph)

*****(Civil Engineering, Don Honorio Ventura State University, Pampanga Philippines
Email : 2019990353@dhvsu.edu.ph)

******(Civil Engineering, Don Honorio Ventura State University, Pampanga Philippines
Email : 2019988574@dhvsu.edu.ph)

*******(Civil Engineering, Don Honorio Ventura State University, Pampanga Philippines
Email : 2019990359@dhvsu.edu.ph)

********(Civil Engineering, Don Honorio Ventura State University, Pampanga Philippines
Email : mbgalvez@dhvsu.edu.ph)

*********(Civil Engineering, Don Honorio Ventura State University, Pampanga Philippines
Email : jcrzoleta@dhvsu.edu.ph)

--************************----------------------------------

Abstract:

Gabion is a long-lasting, low-cost, and environmentally benign material that is an excellent choice for minimizing soil erosion and mitigating the effects of water discharge, which can create scouring. The issue with using sheet piling, on the other hand, is that it is easily corroded and is not an appropriate choice for water, and is entirely absorbing the effect generated by the large discharge of water in a nearby river area. To protect the community in Barangay Candaba, Bambang, Pampanga, the researchers designed a suitable retaining wall. The research study required data from previous retaining walls to be used as a reference in designing the gabion retaining wall. Based on the journal ENVIROMESH, which served as the basis for the design, the researcher concluded that the designed height of 9 meters met all of the safety and stability factors. Furthermore, according to additional research backed by related literature, 9 meters of height is safe in seismic activity of magnitude 9 or less. The trial-and-error method was used to calculate the probable design for the gabion retaining wall to achieve an effective result for the design criteria specified by the American Society of Civil Engineers (ASCE) code.

Keywords **—Stability, Sliding Pressure, Overturning Pressure, Bearing Capacity Pressure**

--************************----------------------------------

I. INTRODUCTION

When the natural flow of water in a river exceeds its capacity, a natural process known as "riverbank erosion" takes place, which results in the removal of soil and silt from the riverbank. In geography, a "riverbank" is the ground along the river's edge where water meets the shore. Heavy precipitation, snowmelt, or human activities that change the river's natural flow can all contribute to this. The path of the river may vary over time because of riverbank erosion, and neighbouring buildings and properties may also sustain damage.

Along riverbanks, retaining walls are the best way to stop erosion and shield neighbouring buildings from the force of the water. In these circumstances, retaining walls are frequently referred to as riprap or riverbank protection walls. By acting as a physical barrier that keeps the water back, retaining walls on riverbanks help to stabilize the soil and stop erosion. They are frequently constructed from big, heavy materials like stone, concrete, or riprap because they can withstand the force of the water and keep the soil from being washed away.

Retaining wall design and construction have seen numerous advancements throughout the years as new materials and methods are created to increase their efficiency and sustainability. Geosynthetics, Green walls, Fabricated walls, Soil Nailing's, and Gabion walls are just a few of the advancements in retaining wall design and construction that have contributed to improving the efficiency, sustainability, and overall performance of such retaining walls, making them an important solution for a variety of engineering and environmental problems.

Gabions are frequently used in riverbanks because they may enable water to flow through the wall while giving protection against erosion. They have found use with the advancements in material fabrication and coating technologies. Because water may pass through the gaps between the rocks in the gabion baskets, this helps keep water pressure from building up behind the wall. Additionally, gabion barriers may be built rapidly and affordably, and they are relatively simple to erect. Typically, local suppliers provide the materials for gabion walls, which can lower the cost of shipping and lessen its negative effects on the environment.

Gabion walls can be traced back to ancient civilizations such as the Egyptians, who utilized them to bolster the Nile River's banks. The term "gabion" is derived from the Italian word "gabbione," which means "large cage." Gabions were utilized as a type of military fortification in the 16th century, providing security for troops and soldiers during fights. Gabion walls were widely employed for military objectives during World War I, including as protective barriers and for building bunkers and trenches. Following the war, gabion walls saw a rise in popularity in civil engineering projects such as retaining walls, coastal defense, and erosion control.

In the 19th century, gabion walls were common, especially in Europe where they were utilized for slope stabilization, retaining walls, and riverbank protection. Gabion walls were discovered to be an efficient and cost-effective option at this time when new techniques for retaining walls and embankments were needed for the construction of railways and roadways.

Due to the introduction of new building methods and materials in the middle of the 20th century, gabion walls' popularity started to wane in favor of others, such as concrete. However, gabion walls have recently attracted new interest, notably because of their environmental advantages, such as their ability to blend in with the surrounding terrain and the use of locally available materials.

Gabion walls today are commonly utilized for riverbank protection, retaining walls, and erosion control, and they are acknowledged as a cost-effective and environmentally beneficial solution to a wide range of engineering and environmental concerns.

II. REVIEW OF RELATED LITERATURE

Gabions serve multiple purposes, including mitigating the speed of concentrated runoff and providing stability to slopes characterized by seepage or non-cohesive soils. They are particularly suitable for deployment at interfaces between soil and water, where factors such as soil properties, water turbulence, velocity, and anticipated vegetation cover indicate a risk of erosion under specified flow conditions. Gabions can be applied on steeper slopes compared to riprap, and in certain situations, they represent the most feasible solution for stabilizing an area when limited space is available to implement a more environmentally friendly, vegetation-based alternative.

According to Rohit Bhadhari (2019), a gabion mattress can be used for 30-50 years with good maintenance. He also stated that while there are several ways for protecting riverbanks from erosion, gabion constructions are frequently chosen due to their inexpensive cost of production, adaptability, durability, stability, and sustainability.

According to Thompson, Puklin& Marshall (2016), gabions employ local resources, are sturdy and flexible, and can be utilized on steeper slopes with less thickness for bank protection than riprap. Initially projected to have a design life of 25 years, constructions featuring gabions have demonstrated remarkable durability, lasting between 75 to 100 years. However, the susceptibility of gabion wire to abrasion caused by debris or bedload has led to wire breakage and subsequent failures. Notably, in Virginia, submerged gabion wire had a lifespan of only 10 years, despite claims by some researchers that gabions can remain structurally intact indefinitely. Regrettably, there is a dearth of information regarding the decay of gabions over time and the impact of woody vegetation growth within gabion baskets on the overall effectiveness, resilience, and long-term morphological changes of the structure.

The versatility, permeability, cost-effectiveness, eco-friendliness, and aesthetic appeal of gabion components have positioned them as a viable alternative to gravity retaining walls. Their utilization is particularly significant in modern technology, thanks to the development of flexible wires that enable gabion structures to maintain their integrity for extended periods ranging from 30 to 100 years without deformation. These findings were highlighted in a study conducted by Toprak, Sevim, and Kalkalan in 2016.

As stated by Najeeb Utamani et al. in 2019, gabions have demonstrated their effectiveness in mitigating riverbank erosion in various water bodies, including both major rivers and smaller streams susceptible to flooding. When designing a river erosion system, it is crucial to consider the anticipated peak volumes during river floods, as these periods pose the greatest threat to riverbanks and the efficacy of erosion prevention measures.

According to Obinna's findings in 2020, it is essential to compare the maximum pressure exerted by the gabion wall on the soil with the safe bearing capacity of the soil during the design process. This comparison is crucial to ensure appropriate design considerations. This issue is also affected by the type of gabion foundation, which in this situation is deemed a non-stiff footing. Obinna further remarked that the gabion retaining wall's overturning stability ensures that the soil kept behind the gabion wall does not cause the lateral collapse of the wall. For its analysis, the gabion wall is assumed to be rigid, with no sliding or partial breakdown between levels. The weight of the gabion wall acts as a stabilizing force, while the lateral pressure from the retained material or surcharge acts as a destabilizing factor.

Peerdawood and Mawlood's study in 2010 revealed that the height of a gabion wall, denoted as H, has a negligible impact on the factor of safety concerning sliding and overturning. However, it has a substantial influence on the factor of safety related to bearing capacity. The findings indicate that as the H-value increases, the factor of safety against bearing capacity decreases. Consequently, scientists conclude that the maximum safety of a gabion wall is constrained by the permissible bearing capacity of the underlying soil beneath the gabion structure.

Meanwhile, in their 2020 study, Freeman and Fischenich noted that if the soil in the study region has a lower permeability than the underlying bank material, water may be unable to travel easily through the gabions, resulting in hydrostatic pressure behind the gabions. Gabions may fail due to sliding or rotating failure as a result of this. If the soil placed atop the gabions is permeable enough to allow water to easily pass through, it may not retain enough water to maintain the appropriate plant.

In terms of earthquake stability, Nakazawa, et al. conducted a shake table test employing a full-scale gabion retaining wall in 2019 to evaluate earthquake resilience. The trials revealed that while gabion retaining walls have a fluid structure and bend easily owing to backfill soil pressure, they are durable structures that resist collapse.

III. METHODOLOGY

The research methodology is discussed in this chapter, including the research design, data gathering procedure, soil properties, and gabion design criteria. This study aims to design riverbank protection using gabions as a retaining wall at Brgy. Bambang, Candaba, Pampanga which can offer a long-term solution to addressing the problem.

A. Research Design

This study employs quantitative research to produce a suitable gabion design as a retaining wall to protect the riverbank in Brgy. Bambang, Candaba, Pampanga. In the collection of data, all the needed data was collected mainly in the Department of Public Works and Highways. The design criteria for designing the gabion mattress are based on ASCE, ASTM, and ISO.

B. Soil and gabion Properties

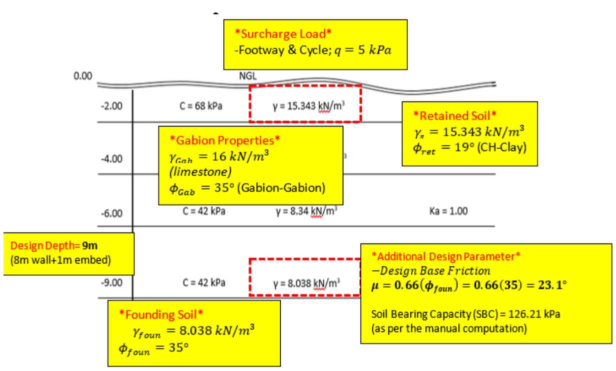


Figure 4. Soil Properties

As per the existing soil parameter in Figure 4 (also attached in Appendix C), the unit weight of retained soil and founding soil was present. Based on the design reference ENVIROMESH Design Guide Series, the researchers used the surcharge load (q) of 5kPa since the considered category of traffic area is only footways and cycle tracks. And for the unit weight of gabion is 16kN/m3, considering that the gabion fill material was limestone which was the commonly used fill material for gabions in the Philippines. For the frictional value (ϕgab) of gabion-to-gabion, 35 degrees of the interface is taken. For the design base friction (μ), ENVIROMESH Design Guide Series provided a formula for getting its value, and it is 0.66 multiplied by the frictional value of the foundation. By substituting all the given values, μ was equal to 23.1°. The angle of retained soil is not given, so the researchers used a reference from Geotech Data which (CH-Clay) friction angle is equal to 19°.

C. Design Criteria

The design begins with selecting traildimensions for a typical vertical cross-section through the wall. Four main steps must then be followed:

1. Determine the forces acting on the wall.

2. Check that the resisting moment exceeds the overturning moment by a suitable safety factor.

3. Check that sliding resistance exceeds the active horizontal force by a suitable safety factor.

4. Check that the resultant force falls within the middle third of the wall's base and that the maximum bearing pressure is within the allowable limit. These steps are iteratively repeated until a suitable design that meets all criteria is achieved. The wall stability must be checked at the base and each course.

D. Stability Check

In the design of the gabion retaining wall, it is required to evaluate the structure for lateral soil pressure stability problems and to execute a check safety factor of sliding, overturning, bearing capacity, and slope stability according to proper safety factor limitations. The coulomb theory active horizontal soil pressure coefficients that are effective in the design should also be computed.

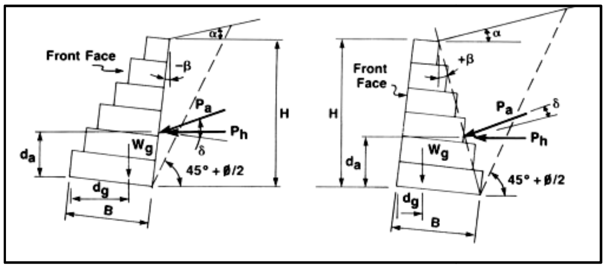


Figure 5. Pressures active on Gabions

E. Filling Materials of Gabion Basket

The permeability of gabion retaining walls allows for the use of various soil types as fill material. When selecting the appropriate filler soil, factors such as the proximity of quarries to the construction site, groundwater conditions, and the excavation area need to be considered. The gabion basket is filled with these specially selected soils and compacted to ensure optimal performance. Fill materials within the gabion structure allow efficient water drainage toward the ground behind the wall.

The rocks utilized in gabions and mattresses should possess durability and strength, enabling them to withstand submersion in water and adverse weather conditions without deterioration. These rocks must be carefully selected, ensuring they are consistently graded and ranging in size from 100 mm to 200 mm. Additionally, filled gabions should have a minimum density of 1,400 kg/m3, and the distribution of voids within the structure should be uniform and well-balanced.

No rock may be larger than 2/3 the depth of the mattress, and at least 85% of the stone's weight must have a size bigger than 80 mm. There must be no way for a stone to get through the mesh.

Cobblestones, rubbles, shattered stones, concrete lumps, or other filling materials specified by the Engineer shall be used as filling materials for polyester net gabions. The filling materials must meet the specifications given in Table 1.

Property	Type	Weight					
		1 ton	2 ton	3 ton	4 ton	6 ton	8 ton
Diameter	A	50 - 190	50 - 190	50 - 190	50 - 190	-	-
(mm)	B	100 - 190	100 - 190	100 - 190	100 - 190	100 - 190	100 - 190

Table 1. Filling Material Requirements

F. Wiremesh Properties

Steel wire mesh is the primary material used for constructing gabions, which can vary in length and height. These gabions are versatile and permeable structures commonly employed for erosion control, such as retaining walls, sea walls, channel linings, revetments, and weirs. The gabion units are constructed using a double-twisted wire mesh container, which is divided into internal cells of consistent size. These units are interconnected with similar structures and then filled with stones, creating flexible and monolithic gabion structures.

The following are the minimum size of galvanized and PVC-coated wire to be utilized in the manufacture of wire mesh gabions and mattresses:

Gabions and Mattresses Wires	Gabions		Mattresses	
	Metallic Coated	PVC Coated	Metallic Coated	PVC Coated
Body Wires	3.05	2.70	2.20	2.20
Selvedge or Perimeter Wire	3.80	3.40	2.20	2.70
Tying and Connecting Wire	2.20	2.20	2.20	2.20

Table 2. Wire Diameters

G. Geo-Textile/Filter Fabric

Geotextile Property	ASTM Test Method	Geotextile Property Requirements			
		Separation		Soil Stabilization	
AOS	D4751	No. 30 Max.		No. 40 Max.	
Water Permittivity	D4491	0.02 sec^{-1}		0.10 sec^{-1}	
Grab Tensile Strength in machine and x-machine direction	D4632	115 kg. Min.	75 kg. Min.	145 kg. Min.	92 kg. Min.
Grab Failure Strain, in machine and x-machine direction	D4632	< 50%	≥ 50%	< 50%	≥ 50%
Seam Breaking Strength	D4632	100 kg. Min.	65 kg. Min.	125 kg. Min.	80 kg. Min.
Puncture Resistance	D6241	225 kg. Min.	140 kg. Min.	280 kg. Min.	195 kg. Min.
Tear Strength, in machine and x-machine direction	D4533	35 kg. Min.	23 kg. Min.	50 kg. Min.	35 kg. Min.
Ultraviolet (UV) Radiation Stability	D4355	50% strength retained Min., after 500 hours in xenon arc device.			

IV. RESULT AND DISCUSSION

This chapter presents the findings of the study, which were based on the process described in the preceding chapter. The researchers collected all the necessary data and consulted with professionals to ensure that it is effective and satisfies the requirements of the planned project.

The design activities were closely watched and assessed, revealing the following significant discoveries.

A. Wall Geometry

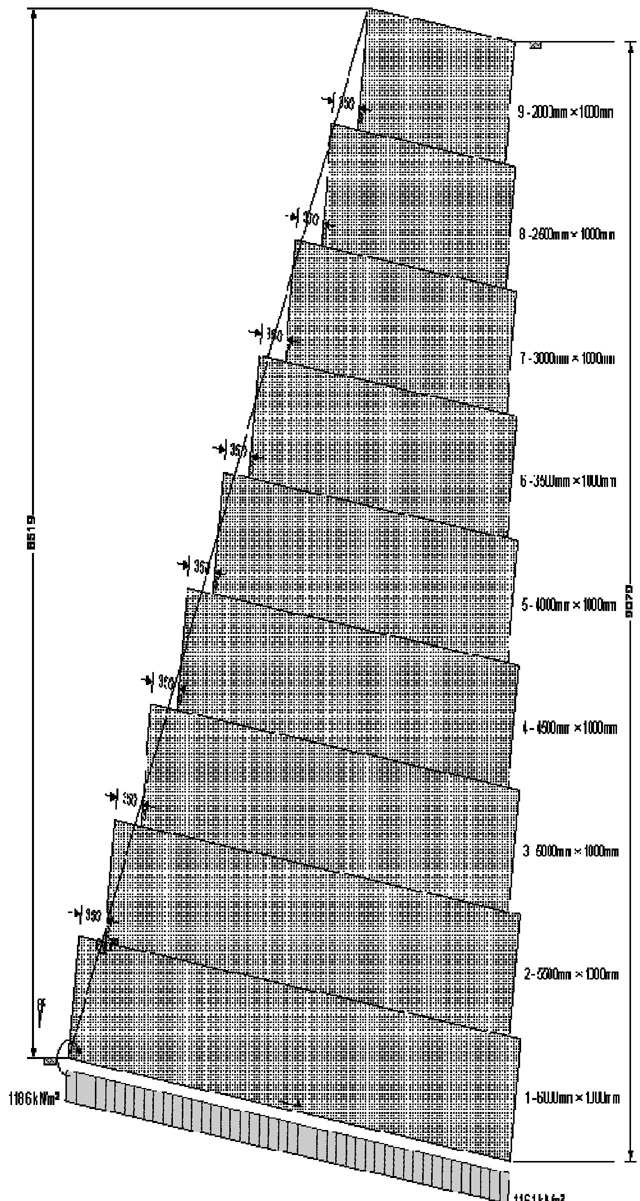
The researchers conduct trials to achieve the dimensions of each gabion. Considering the limitation mentioned in the previous chapter, the researchers were able to get the minimum height for each gabion. Given the designed height of 9 21 meters, they divide it into 10 to get the minimum height of 0.90 meters for each gabion. For the first trial, they considered the minimum height of 0.9 meters for each gabion and checked if the safety factor had been met. Throughout the calculations and checking, it passed the safety factor for overturning pressure and bearing capacity pressure. But for sliding pressure, it failed to pass the Upon checking, 0.90m failed to meet the safety factor for sliding. Table 5 shows the design summary using 0.90 meters. The computation for this design is attached in Appendix E.

Action	Resistance	Force	FoS	Allowable FoS	Status
Overturning, sliding and bearing at base level					
Overturning (kNm/m)	2267.85	613	3.696	2.000	PASS
Sliding (kN/m)	297.81	199.61	1.491	1.500	FAILED
Bearing (kN/m^2)	126.2	107.73	1.179	1.000	PASS
Eccentricity (mm)	Reaction acts within the middle third of base				PASS

Design Summary using 0.90-meter height

a.) Assumed dimension of the wall.

Gabion 1 width;	w_1 = 6000 mm
Gabion 1 height;	h_1 = 1000 mm
Gabion 2 width;	w_2 = 5500 mm
Gabion 2 heigth;	h_2 = 1000 mm
Step to front face between courses 1 and 2;	s_2 = 350 mm
Gabion 3 width;	w_3 = 5000 mm
Gabion 3 height;	h_3 = 1000 mm
Step to front face between courses 2 and 3;	s_3 = 350 mm
Gabion 4 width;	w_4 = 4500 mm
Gabion 4 height;	h_4 = 1000 mm
Step to front face between courses 3 and 4;	s_4 = 350 mm
Gabion 5 width;	w_5 = 4000 mm
Gabion 5 height;	h_5 = 1000 mm
Step to front face between courses 4 and 5;	s_5 = 350 mm
Gabion 6 width;	w_6 = 3500 mm
Gabion 6 height;	h_6 = 1000 mm
Step to front face between courses 5 and 6;	s_6 = 350 mm
Gabion 7 width;	w_7 = 3000 mm
Gabion 7 height;	h_7 = 1000 mm
Step to front face between courses 6 and 7;	s_7 = 350 mm
Gabion 8 width;	w_8 = 2500 mm
Gabion 8 height;	h_8 = 1000 mm
Step to front face between courses 7 and 8;	s_8 = 350 mm
Gabion 9 width;	w_9 = 2000 mm
Gabion 9 height;	h_9 = 1000 mm
Step to front face between courses 8 and 9;	s_9 = 350 mm



2D Presentation of Gabion Retaining Wall

b.) Given the unit weight of fill which is equal to:

Unit weight of fill; **γd = 16.0 kN/m3**

c.) Calculate the total weight of the entire gabion.

Weight of gabion 1; $W_{g1} = \gamma_d \; x \; w_1 \; x \; h_1$

$$W_{g1} = 16.0 \; {}^{kN}/_{m} \times 6.0 \; m \times 1.0 \; m = 96.0 \; {}^{\mathbf{kN}}/_{\mathbf{m}}$$

Weight of gabion 2; $W_{g2} = \gamma_d \; x \; w_2 \; x \; h_2$

$$W_{g2} = 16.0 \; {}^{kN}/_{m} \times 5.5 \; m \times 1.0 \; m = \mathbf{88.0} \; {}^{\mathbf{kN}}/_{\mathbf{m}}$$

Weight of gabion 3; $W_{g3} = \gamma_d \; x \; w_3 \; x \; h_3$

$$W_{g3} = 16.0 \; {}^{kN}/_{m} \times 5.0 \; m \times 1.0 \; m = \mathbf{80.0} \; {}^{\mathbf{kN}}/_{\mathbf{m}}$$

Weight of gabion 4; $W_{g4} = \gamma_d \; x \; w_4 \; x \; h_4$

$$W_{g4} = 16.0 \; {}^{kN}/_{m} \times 4.5 \; m \times 1.0 \; m = \mathbf{72.0} \; {}^{\mathbf{kN}}/_{\mathbf{m}}$$

Weight of gabion 5; $W_{g5} = \gamma_d \; x \; w_5 \; x \; h_5$

$$W_{g5} = 16.0 \; {}^{kN}/_{m} \times 4.0 \; m \times 1.0 \; m = \mathbf{64.0} \; {}^{\mathbf{kN}}/_{\mathbf{m}}$$

Weight of gabion 6; $W_{g6} = \gamma_d \; x \; w_6 \; x \; h_6$

$$W_{g6} = 16.0 \; {}^{kN}/_{m} \times 3.5 \; m \times 1.0 \; m = \mathbf{56.0} \; {}^{\mathbf{kN}}/_{\mathbf{m}}$$

Weight of gabion 7; $W_{g7} = \gamma_d \; x \; w_7 \; x \; h_7$

$$W_{g7} = 16.0 \; {}^{kN}/_{m} \times 3.0 \; m \times 1.0 \; m = \mathbf{48.0} \; {}^{\mathbf{kN}}/_{\mathbf{m}}$$

Weight of gabion 8; $W_{g8} = \gamma_d \; x \; w_8 \; x \; h_8$

$$W_{g8} = 16.0 \; {}^{kN}/_{m} \times 2.5 \; m \times 1.0 \; m = \mathbf{40.0} \; {}^{\mathbf{kN}}/_{\mathbf{m}}$$

Weight of gabion 9; $W_{g9} = \gamma_d \; x \; w_9 \; x \; h_9$

$$W_{g9} = 16.0 \; {}^{kN}/_{m} \times 2.0 \; m \times 0.90 \; m = \mathbf{32.0} \; {}^{\mathbf{kN}}/_{\mathbf{m}}$$

Weight of entire gabion; $W_g = W_1 + +W_2 + W_3 + W_4 + W_5 + W_6 + W_7 + W_8 + W_9$

$$W_g = 86.4 \; {}^{kN}/_{m} + 79.2 \; {}^{kN}/_{m} + 72 \; {}^{kN}/_{m} + 64.8 \; {}^{kN}/_{m} + 57.6 \; {}^{kN}/_{m} + 54.0 \; {}^{kN}/_{m} + 43.2 \; {}^{kN}/_{m} + 36.0 \; {}^{kN}/_{m} + 28.8 \; {}^{kN}/_{m} = \mathbf{576} \; {}^{\mathbf{kN}}/_{\mathbf{m}}$$

d.) Calculate the Vertical and Horizontal center of gravity of the gabion.

Horizontal distance to center of gravity gabion 1;

$$\boldsymbol{x_{g1}} = \frac{\boldsymbol{w_1}}{\mathbf{2}}$$

$$x_{g1} = \frac{6000 \; mm}{2} = \mathbf{3000} \; \boldsymbol{mm}$$

Vertical distance to center of gravity gabion 1;

$$\boldsymbol{y_{g1}} = \frac{\boldsymbol{h_1}}{\mathbf{2}}$$

$$y_{g1} = \frac{1000 \; mm}{2} = \mathbf{500} \; \boldsymbol{mm}$$

Horizontal distance to center of gravity gabion 2;

$$\boldsymbol{x_{g2}} = \frac{\boldsymbol{w_2}}{\mathbf{2}} + \boldsymbol{s_2}$$

$$x_{g2} = \frac{5500 \; mm}{2} + 350 \; mm = \mathbf{3100} \; \boldsymbol{mm}$$

Vertical distance to center of gravity gabion 2;

$$\boldsymbol{y_{g2}} = \frac{\boldsymbol{h_2}}{\mathbf{2}} + \boldsymbol{h_1}$$

$$y_{g2} = \frac{1000 \; mm}{2} + 1000 \; mm = \mathbf{1500} \; \boldsymbol{mm}$$

Horizontal distance to center of gravity gabion 3;

$$\boldsymbol{x_{g3}} = \frac{\boldsymbol{w_3}}{\mathbf{2}} + \boldsymbol{s_2} + \boldsymbol{s_3}$$

$$x_{g3} = \frac{5000 \; mm}{2} + 350 \; mm + 350 \; mm = \mathbf{3200} \; \boldsymbol{mm}$$

Vertical distance to center of gravity gabion 3;

$$\boldsymbol{y_{g3}} = \frac{\boldsymbol{h_3}}{\mathbf{2}} + \boldsymbol{h_1} + \boldsymbol{h_2}$$

$$y_{g3} = \frac{1000 \; mm}{2} + 1000 \; mm + 1000 \; mm = \mathbf{2500} \; \boldsymbol{mm}$$

Horizontal distance to center of gravity gabion 4;

$$\boldsymbol{x_{g4}} = \frac{\boldsymbol{w_4}}{\mathbf{2}} + \boldsymbol{s_2} + \boldsymbol{s_3} + \boldsymbol{s_4}$$

$$x_{g4} = \frac{4500 \; mm}{2} + 350 \; mm + 350 \; mm + 350 \; mm = \mathbf{3300} \; \boldsymbol{mm}$$

Vertical distance to center of gravity gabion 4;

$$y_{g4} = \frac{h_4}{2} + h_1 + h_2 + h_3$$

$$y_{g4} = \frac{1000\ mm}{2} + 1000\ mm + 1000\ mm + 1000\ mm = \mathbf{3500\ mm}$$

Horizontal distance to center of gravity gabion 5;

$$x_{g5} = \frac{w_5}{2} + s_2 + s_3 + s_4 + s_5$$

$$x_{g5} = \frac{4000\ mm}{2} + 350\ mm + 350\ mm + 350\ mm + 350\ mm = \mathbf{3400\ mm}$$

Vertical distance to center of gravity gabion 5;

$$y_{g5} = \frac{h_5}{2} + h_1 + h_2 + h_3 + h_4 + h_5$$

$$y_{g5} = \frac{1000\ mm}{2} + 1000\ mm + 1000\ mm + 1000\ mm + 1000\ mm + 1000\ mm = \mathbf{4500\ mm}$$

Horizontal distance to center of gravity gabion 6;

$$x_{g6} = \frac{w_6}{2} + s_2 + s_3 + s_4 + s_5 + s_6$$

$$x_{g6} = \frac{3500\ mm}{2} + 350\ mm + 350\ mm + 350\ mm + 350\ mm + 350\ mm = \mathbf{3500\ mm}$$

Vertical distance to center of gravity gabion 6;

$$y_{g6} = \frac{h_6}{2} + h_1 + h_2 + h_3 + h_4 + h_5 + h_6$$

$$y_{g6} = \frac{1000\ mm}{2} + 1000\ mm + 1000\ mm + 1000\ mm + 1000\ mm + 1000\ mm + 1000\ mm = \mathbf{5500\ mm}$$

Horizontal distance to center of gravity gabion 7;

$$x_{g7} = \frac{w_7}{2} + s_2 + s_3 + s_4 + s_5 + s_6 + s_7$$

$$x_{g7} = \frac{3000\ mm}{2} + 350\ mm + 350\ mm + 350\ mm + 350\ mm + 350\ mm + 350\ mm = \mathbf{3600\ mm}$$

Vertical distance to center of gravity gabion 7;

$$y_{g7} = \frac{h_7}{2} + h_1 + h_2 + h_3 + h_4 + h_5 + h_6 + h_7$$

$$y_{g7} = \frac{1000\ mm}{2} + 1000\ mm + 1000\ mm + 1000\ mm + 1000\ mm + 1000\ mm + 1000\ mm + 1000\ mm = \mathbf{6500\ mm}$$

Horizontal distance to center of gravity gabion 8;

$$x_{g8} = \frac{w_8}{2} + s_2 + s_3 + s_4 + s_5 + s_6 + s_7 + s_8$$

$$d_{h_{soil}} = \frac{H}{3} - w_1 x \sin(\varepsilon)$$

$$d_{h_{soil}} = \frac{9079\ mm}{3} - 6000\ mm \times \sin(8°) = \mathbf{2191\ mm}$$

Surcharge;

$$F_{surch_h} = p_{o_Q} K_a H \cos(90 - \alpha + \delta)$$

$$F_{surch\_h} = 5.0 \times 0.440 \times 9.079\ m \times \cos(90 - 90.4° + 19°) = \mathbf{19.0}\ kN/m$$

Height of surcharge thrust resolved vertically;

$$d_{h_{surch}} = \frac{H}{2} - W_1 \sin(\varepsilon)$$

$$d_{h_{surch}} = \frac{9079\ mm}{2} - 6000\ mm \times \sin(8°) = \mathbf{3705 mm}$$

b. Vertical forces

Gabion weight;

$$F_{gabion\_v} = W_g = \mathbf{576.0}\ kN/m$$

Retained soil;

$$F_{soil_v} = P_{a_{soil}} \sin(90 - \alpha + \delta)$$

$$F_{soil\_v} = 278.5\ kN/m \times \sin(90 - 90.4° + 19°) = \mathbf{88.8}\ kN/m$$

$$X_g = [(w_{g1})(x_{g1}) + (w_{g2})(x_{g2}) + (w_{g3})(x_{g3}) + (w_{g4})(x_{g4}) + (w_{g5})(x_{g5}) + (w_{g6})(x_{g6}) + (w_{g7})(x_{g7}) + (w_{g8})(x_{g8}) + (w_{g9})(x_{g9})]$$

$$X_g = [(96.0\ kN/m)(3000\ mm) + (88.0\ kN/m)(3100\ mm) + (80.0\ kN/m)(3200\ mm) + (72.0\ kN/m)(3300\ mm) + (64.0\ kN/m)(3400\ mm) + (56.0\ kN/m)(3500\ mm) + (48.0\ kN/m)(36000\ mm) + (40.0\ kN/m)(3700\ mm) + (32.0\ kN/m)(3800\ mm) = \mathbf{3317\ mm}$$

Vertical distance to center of gravity (entire gabion);

$$Y_g = [(w_{g1})(y_{g1}) + (w_{g2})(y_{g2}) + (w_{g3})(y_{g3}) + (w_{g4})(y_{g4}) + (w_{g5})(y_{g5}) + (w_{g6})(y_{g6}) + (w_{g7})(y_{g7}) + (w_{g8})(y_{g8}) + (w_{g9})(y_{g9})] / W_g$$

Ka = 1.033 (D/B)

Ka = 1+0.33 $\left(\frac{29.5275\ ft}{225.3937\ ft}\right)$

Ka = 1.0432

$Q_a = \frac{N/4}{K}$

$Q_a = \frac{11/4}{1.0432}$

Q_a = 2.636 kips/ft² or 126.2 kN/m²

a.) Pressure at base

Force normal to base;

$$N_s = N\cos(\varepsilon) + T\sin(\varepsilon)$$

$$N_s = 671.2\ kN/m \times \cos(8°) + 282.9\ kN/m \sin(8°) = \mathbf{704.0}\ kN/m$$

Eccentricity;

$$e = \frac{w_1}{2} - \frac{(M_R - M_O)}{N_s}$$

$$e = \frac{6000\ mm}{2} - \frac{(2753.4\ kN/m - 648.7\ kN/m)}{704.0\ kN/m} = \mathbf{11\ mm}$$

Reaction acts within middle third of base

b.) Pressure at toe;

$$\sigma_{toe} = \frac{N_s}{w_1}\left[1 + \left(6\left(\frac{e}{w_1}\right)\right)\right]$$

$$\sigma_{toe} = \frac{704.0\ kN/m}{6.0\ m}\left[1 + \left(6\left(\frac{0.011\ m}{6.0\ m}\right)\right)\right] = \mathbf{118.6}\ kN/m^2$$

c.) Pressure at heel;

$$\sigma_{heel} = \frac{N_s}{w_1}\left[1 - \left(6\left(\frac{e}{w_1}\right)\right)\right]$$

$$\sigma_{heel} = \frac{704.0\ kN/m}{6.0\ m}\left[1 - \left(6\left(\frac{0.011\ m}{6.0\ m}\right)\right)\right] = \mathbf{116.1}\ kN/m^2$$

$$F_oS_s = \frac{300.3\ kN/m}{186.8\ kN/m} = \mathbf{1.608}$$

Allowable factor of safety;

$$F_oS_{s_{allow}} = \mathbf{1.500}$$

PASS – $F_oS_s > F_oS_{s_{allow}}$

d.) Factor of safety;

$$F_oS_Q = \frac{q}{max(\sigma_{toe}, \sigma_{heel})} = 1.064$$

$$F_oS_Q = \frac{126.2\ kN/m^2}{118.6\ kN/m^2} = 1.064$$

Allowable factor of safety;

$$F_oS_{Q_{allow}} = 1.000$$

$$PASS - \quad F_oS_Q > F_oS_{Q_{allow}}$$

Design Summary

Design Summary of Gabion Retaining Wall

Action	Resistance	Force	FoS	Allowable FoS	Status
Overturning, sliding and bearing at base level					
Overturning (kNm/m)	2753.4	648.7	4.244	2.000	PASS
Sliding (kN/m)	300.3	186.8	1.608	1.500	PASS
Bearing (kN/m^2)	126.2	118.6	1.064	1.000	PASS
Eccentricity (mm)	Reaction acts within the middle third of base				PASS

V CONCLUSSION

Considering the problem of the riverbank in Candaba, Pampanga, specifically in Bambang, using alternative riverbank protection may solve the existing and an all-time issue of riverbank protection in the said area.

The researchers think of a long-term solution, explore more about the advanced engineering solution, and propose using gabion. Characteristics like flexibility, sustainability, adds aesthetic appeal, and the capability of gabion to lessen the water velocity force of the river, which is the main cause of the existing retaining wall in Bambang, Candaba to be damaged, is the reason why the researchers came up proposing the use of gabion as a replacement.

Based on the study, a 9-meter-high gabion retaining wall with 9 gabion steps having dimensionsof 6000mmx1000mm, 5500mmx1000mm, 5000mmx1000mm, 4500mmx 1000mm, 4000mmx1000mm, 3500mmx1000mm, 3000mmx1000mm, 2500mmx1000mm, and 2000mmx1000mm, respectively passed the factor of safety for stability, overturning stability, sliding stability, and bearing capacity. Therefore, the researchers concluded that this proposed design of gabions could be used as a future reference and is acceptable if it was ever installed as an alternative to sheet piles.

ACKNOWLEDGMENT

First and foremost, heartfelt thanks and gratitude to God, the Almighty, for His guidance during their research work, which enabled the researchers to carry out their work successfully. The researchers would like to offer their heartfelt gratitude to their research advisor, Engr. Mike Diether B. Galvez, for his outstanding support throughout this study. His vigor and ideas have a profound impact on them. They are very grateful for what he has provided for them. They would also like to display their deepest gratitude and earnest appreciation to the following persons for their knowledge and expertise in assisting and supporting their group to finish this study: To Engr. Mariane P. Nunag and Engr. Juanita Carmelita R. Zoleta for being their Civil Engineering Project instructors and for their encouragement to finish the research study, sharing their knowledge and assisting them throughout the year. To Engr. Jayvee R. Bonifacio for being their consultant and for guiding them in making their research to be performed and executed and for helping them to make their imagination become reality. To their parents who gave their unending support physically, mentally, and financially, for their love and care which served as their inspiration to pursue this painstaking journey. And to thosewho are not mentioned, the researchers would liketo express their gratitude insupporting

them in one way or another in achieving this success.

REFERENCES

[1] **ASCE** - Technical engineering and design guides as adopted from the US ArmyCorps ofEngineers No4 (1994)
[2] Enviromesh Design Guide Series Volume 1 | January 2017. A Design guide for buildingGabion Retaining Walls
[3] Freeman, G. E., and Fischenich, J.C. (2000). "Gabions for streambank erosioncontrol,"
[4] **Gabion Wall Design.** Modular Gabion Systems A Division of C. E. ShepherdCompany 2221 Canada Dry Street Houston TX 77023.
[5] **Marg, Kama Koti (2018).**Guidelines for Design and Installation of GabionStructures.
[6] Nakazawa H., Usukura, K., Hara, T., Suetsugu, D., Kuribayashi, K., Nishi, T.,
[7] **Kimura, S., & Shimomura S. (2019).** Problems in Earthquake Resistance Evaluation of GabionRetaining Wall Based on Shake Table Test with Full-Scale Model. Journal ofDisaster Research Vol. 14 No.19.
[8] Peerdawood, C. T., &Mawlood, Y. I. (2010), Analytical Study for Stability ofGabionWalls. Journal of Pure and Applied Sciences. Salahaddin University – Hawler. Vol. 22 No. 5
[9] **Price, B. S.c (2018)**. Gabion Earth Retaining Wall Example Calculations. IntecConsulting C10487. Rev B.
[10] Shah, S. Y., Islam, Z. U., & Rather, S. A. (2018). Engineering Feasibility of GabionStructures over Reinforced Concrete Structures. Int. Res. J. of Eng. And Tech, 5(10).
[11] Thompson, D., Puklin, L., Marshall E., (2016). The long-term impact of channelstabilization using gabion structures on Zealand River, New Hampshire,Ecological Engineering, Volume 95, Pages 779-792, ISSN 0925-8574
[12] Toprak, B., Sevim, O., &Kalkan, I. (2016). Gabion walls and theiruse. InternationalJournal of Advances in Mechanical and Civil Engineering, 3(4), 56-58.
[13] **Uray, E. (2022)**. Gabion structures and retaining walls design criteria. AdvancedEnginering Science, 2, 127-134
[14] **Veld, A.C., (2015).** Potential Measures to reduce Fluvial and Tidal Floods in thePampanga Delta. National University of Singapore.
[15] **Villar, M. A., (2018)**. Amendment to DPWH Standard Specification for Item 1714Gabions and Mattresses. Department Order No. 42 Series of 2018.
[16] **Yang, G., Liu, Z., & Huang X. (2009)**. Protection Technology and Applications of
Gabion. Proc. of Int. Symp. On Geoenvironmental Eng. ISGE2009

