A Proposed Design of Slope Protection Using Biaxial Geogrids to Mitigate Soil Erosion at Sapang Balen Creek, Calulut, City of San Fernando, Pampanga

Jhobert P. Move[1], Maui B. Miranda[1], Ma. Alessandra M. Navar[1], Winkel John M. Navarro[1], Gerard Jules I. Ocampo[1], Mark Kevin M. Ocampo[1], Ma. Lois G. Dela Cruz[1], Ariel G. Pabalate[1]

[1]*Civil Engineering Department, Don Honorio Ventura State University, Bacolor, Pampanga, Philippines*

Corresponding Author: jhobertmove6@gmail.com

***Abstract*: This study addresses the ongoing issue of soil erosion and slope protection failure along Sapang Balen Creek in Barangay Calulut, City of San Fernando, Pampanga. It proposes a reinforced slope protection system using biaxial geogrids in combination with concrete structures. A multidisciplinary approach was employed, incorporating community surveys, hydrologic and hydraulic modeling (HEC-HMS and HEC-RAS), and geotechnical simulations (GEO5). Survey responses from 100 residents revealed high awareness of erosion-related problems, especially among long-term dwellers, but also highlighted limited community engagement and perceived inconsistency in government response. Hydrologic and hydraulic analysis modeled 50- and 100-year storm events, determining critical flood parameters such as discharge rates, channel capacity, and flow velocity. The proposed design met all safety criteria, including stability against sliding, overturning, and internal failure. GEO5 simulations confirmed the structure's strong performance and compliance with geotechnical standards. The findings support the use of geogrid-reinforced systems as a sustainable and effective solution to mitigate creekbank erosion and enhance long-term resilience in vulnerable areas.**

***Keywords*: Biaxial Geogrids, Geotechnical, Slope Protection, Soil Erosion, Stability.**

1. Introduction

Climate change greatly affects slope protection by intensifying rainfall and transforming hydrological processes, resulting in higher soil erosion, slope instability, and increased landslide hazards, particularly in susceptible areas such as Southeast Asia and the Philippines [1][2]. In regions like Pampanga's Sapang Balen Creek, Calulut, its impacts endanger both ecological and structural stability, especially in highly populated urban areas like San Fernando and Angeles City. The research centers on the design of biaxial geogrid slope protection to prevent erosion, with the use of geotechnical engineering and advanced simulation methods to build resilient solutions. The research intends to advance the land management practices, infrastructure safety, as well as environmental conservation by understanding natural and anthropogenic causes of slope failure.

Slope stability plays a crucial role in the design of slope protection. Factors brought by the climate change such as increased rainfall and extreme weather events which can be observed by collecting data that points to historical trends and rainfall patterns in the Philippines which result in soil erosion that significantly impacts slope stability.

Soil erosion consequently affects the slope stability in terms of higher risk of landslide because landslides frequently take place on an eroded area of the soil. As the sliding increases, soil cohesion is decreasing, and slopes are getting steeper as the water infiltration increases [3]. Furthermore, erosion forms conditions where slopes are getting unstable without any sign of warnings bringing risk to infrastructure, human life and property. Impending signs of slope failure which include subsidence and crack tension may be suddenly formed because there's an ongoing erosion process [4].

In the fields of geotechnical application and civil engineering, geogrids are a crucial innovation intended to strengthen structures and increase soil stability. Geogrids have been used in stabilization efforts all around the world for about thirty years. The function has been used for long time as ballast, base or subbase reinforcement, depending on the application, the most significant component governing this function is not strength, but rather a specific stiffening of granular materials by interlocking, as demonstrated by recent findings from both the field and laboratory [5].

Biaxial Geogrid is versatile as it brings strength along both longitudinal and transverse directions. It is used in many applications in the field of roadways and ground stabilization. Commonly consisting of durable polypropylene, the grid-like structures of geogrids permit the effective locking of soil beside the load distribution system. Biaxial geogrids have found widespread application across the geographical map of the world regarding mechanical ground stabilization [6].

A. Conceptual Framework

The conceptual framework presented in Figure 1 is a systematic approach of investigating the slope conditions of the area along Sapang Balen Creek. The process takes place in Phase I when the current conditions are reviewed through stream gaging field surveys, and some collected data from relevant government offices are gathered. Then in Phase II, hydrological as well as hydraulic modeling involving simulation of water flow or the catchment behavior was established using HEC-HMS and HEC-RAS. Phase III comprises the implementation of existing standards, such as DPWH 28 Specifications, the National Structural Code of the Philippines (2015 Edition), and ACI guidelines with drafting through AutoCAD. Phase IV utilizes Bishop Method for geotechnical analysis of the slope by using GEO5 to determine whether the designed slope is stable and of adequate strength to ensure an all-rounded robust solution.

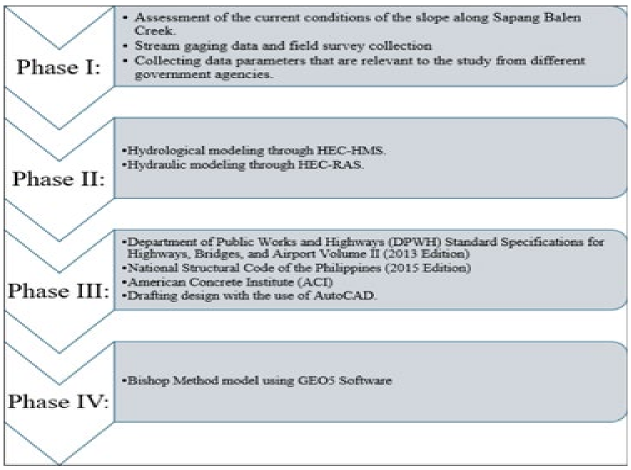


Fig. 1. Paradigm of the study

2. Methodology

The study's methodological approach is depicted in Figure 2. There were five stages in the proposed geogrids slope protection design: problem identification, identifying the goals of the research, review of related literature, interpretation of data, and data collection.

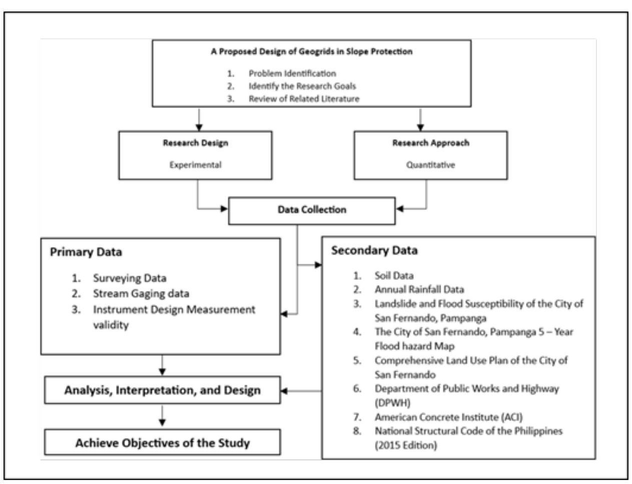


Fig. 2. Methodological method of the study

A. Research Instrument

The researchers used a modified structured questionnaire, originally developed by Barin et al. (2024) in their study on stone-pitched retaining walls for soil erosion control in San Agustin Creek, San Fernando, Pampanga. This questionnaire, designed to assess key feasibility concepts such as respondents' years of residency, awareness, experiences related to slope protection, and observations on soil erosion impacts, was adapted to suit the specific context of Sapang Balen Creek and the proposed use of Biaxial geogrids for slope protection. Its validity was reviewed by a psychometrician, a grammarian, and a statistician. Additionally, the study incorporated a review of related literature on slope protection and gathered data from various government agencies to support the evaluation.

B. Data Collection

Researchers formally requested letters of approval from the school authorities to collect relevant data, which was subsequently provided to the following governmental agencies: City Planning and Development Coordinator's Office (CPDCO), Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA), Department of Public Works and Highways (DPWH), Light Detection and Ranging Portal for Archiving and Distribution (LiPAD), and National Mapping and Resource Information Authority (NAMRIA).

C. Design Interpretation

The Researchers designed slope protection with the utilization of Biaxial Geogrids were interpreted with the use of provisions from NSCP 2015, ACI, and DPWH Standard Specifications for Highways, Bridges, and Airport Volume II (2013 Edition) were utilized for the analysis and interpretation of data collected for the design.

3. Results and Discussion

This chapter of the study presents the findings that were derived from collected data through research question surveys and upcoming software simulations. Structured analysis is executed to provide a comprehensive understanding of study's feasibility by integrating insights in qualitative and quantitative manner. On this phase of methodology, designed slope protection with the utilization of Biaxial Geogrids were interpreted with the use of provisions from NSCP 2015, ACI, and DPWH Standard Specifications for Highways, Bridges, and Airport Volume II (2013 Edition) were utilized for the analysis and interpretation of data collected for the design.

A. Research Questionnaire Responses

Most respondents (99%) are willing to support the proposed design of slope protection using Biaxial Geogrids to address soil erosion and slope protection failure as shown in the table above. A total of 60% of the respondents always notice slope protection failure and soil erosion as causes of soil degradation. Half of the respondents answered that the local government

Table 1
Table for survey questionnaire tallies

	Part 1: Background Information	Less than a year	1-3 years	4-6 years	7-9 years	10 years and above
1	How long have you been residing around Sapang Balen Creek in Calulut?	1	3	4	6	86
2	How long has it been since you first became aware of soil erosion issues and slope protection failure in your locality?	2	5	3	9	81
3	How long have you been experiencing soil erosion and slope protection failure in your area?	3	2	5	7	83

	Part 2: Awareness and Experience	YES	NO
1	Are you aware of the slope protection failure issue in Sapang Balen Creek in Calulut?	99	1
2	Have you personally witnessed or experienced issues related to slope protection failure in Sapang Balen Creek in Calulut?	94	6
3	Over the past years, have you seen any government effort or project implemented to address slope protection failure in your community?	91	9
4	Do you think redesigning a slope protection that utilizes Biaxial geogrids will help you address slope protection failure?	99	1
5	Given the benefits of a slope protection, are you willing to support the proposal design of a slope protection using Biaxial geogrids as a countermeasure for soil erosion and slope protection failure at Sapang Balen in Calulut?	99	1

	Part 3: Observations of the Impact of the Erosion in the Creek	Never	Rarely	Seldom	Often	Always
1	How often do you experience soil erosion and slope protection failure due to intensive rainfall in your area?	2	6	18	16	58
2	How often does soil erosion and slope protection failure cause damage to your residential property?	18	30	43	9	0
3	In your experience, how often do you observe soil erosion and slope protection failure contributing to soil degradation?	1	3	20	16	60
4	How often do local communities actively participate in initiatives to alleviate the impacts of soil erosion and slope protection failure?	2	9	56	7	26
5	How often does the local government proactively engage in efforts to mitigate the impacts of soil erosion and slope protection failure in Sapang Balen Creek?	3	21	53	10	13

"Seldom" engages in addressing the issue regarding soil erosion.

B. Hydrologic Engineering Center – Hydrologic Modeling System (HEC-HMS)

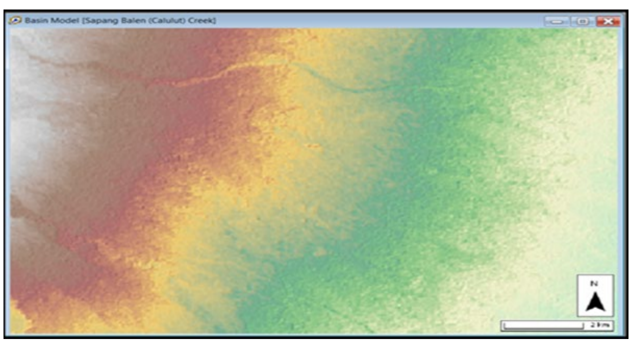


Fig. 3. Digital elevation map

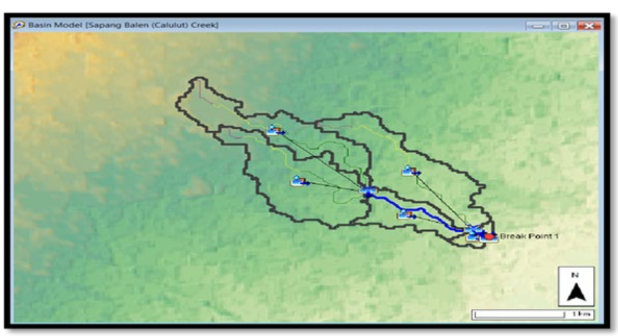


Fig. 4. Basin model [Sapang balen (Calulut) creek]

The Basin Model map of Sapang Balen (Calulut) Creek in HEC-HMS visually organizes the watershed into hydrologic units, starting with a thick black boundary defining its total contributing area. Within the envelope, thinner black lines delineate subbasins, which are smaller, moderately consistent units that generate runoff.

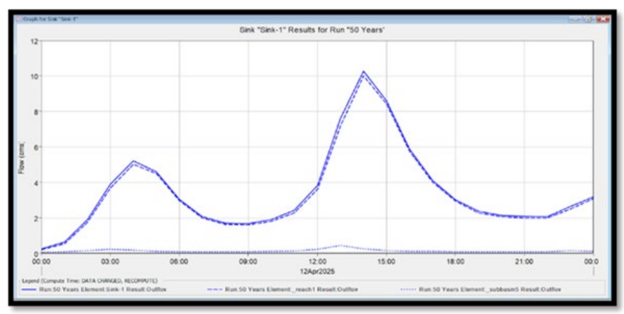


Fig. 5. Hydrograph for 50 – Year return period's sink

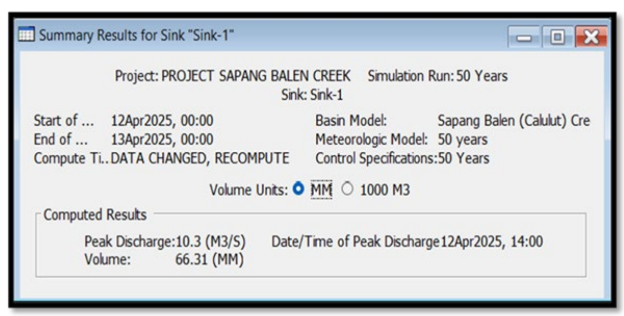


Fig. 6. Hydrologic simulation summary result for 50 – Year return period's sink

Figure 5. Hydrograph for 50 – Year Return Period's sink

The findings of the hydrologic simulation for the Sapang Balen Creek Basin in Calulut, Pampanga, utilizing the Hydrologic Modeling System (HEC-HMS) of the Hydrologic Engineering Center are shown in Figure 5 and 6. The purpose of the simulation was to simulate the watershed's flow behavior during a storm event with a 50-year return time.

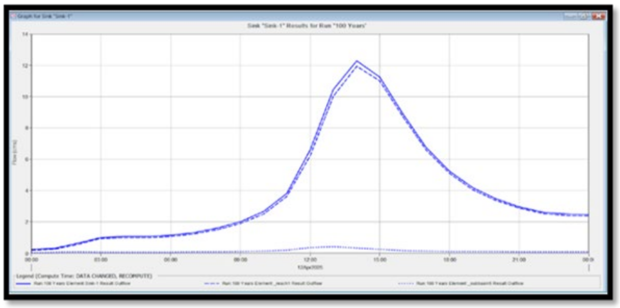


Fig. 7. Hydrograph for 100 – Year return period's sink

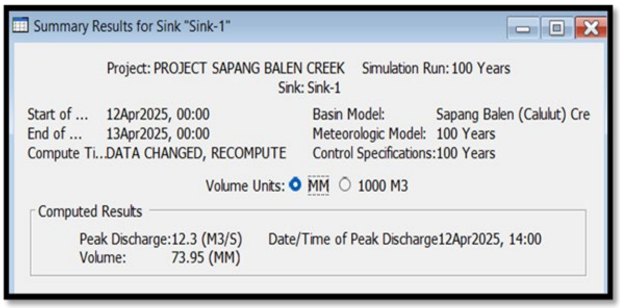


Fig. 8. Hydrologic simulation summary result for 100 – Year return period's sink

Figures 7 and 8 show the result for 100-Year Return Period using HEC-HMS model for the Sapang Balen Creek Basin. Accurate hydrologic analysis of extreme rainfall-runoff scenarios is offered, as seen in the output summary and hydrograph. This data highlights the possibility of increased flood hazards under scenarios of excessive rainfall, which is essential for infrastructure development, floodplain mapping, and disaster preparedness. These findings emphasize the importance of using extended return period models when managing urban watersheds to ensure adequate resilience against more severe climate events.

C. Hydrologic Engineering Center – River Analysis System (HEC-RAS)

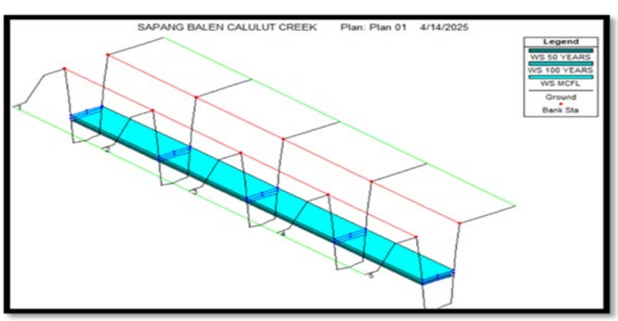
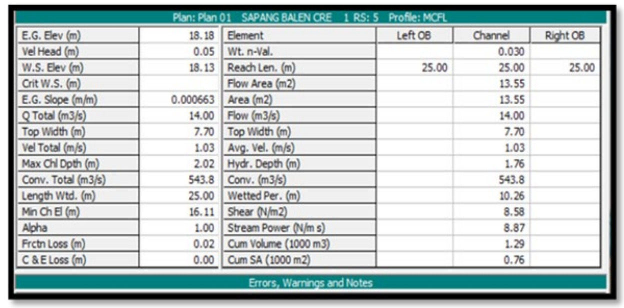


Fig. 9. Perspective plot

Figure 9 contains hydraulic and geometric parameters for a river cross-section specifically for Sapang Balen Creek in Brgy Calulut , City of San Fernando, Pampanga Station 5.

The hydraulic data provided offers critical insights into the channel's behavior under flow conditions and its capacity to handle potential flood events. All flow is currently confined within the main channel, suggesting that the existing channel is adequate for conveying base flows or smaller storm events without overtopping into adjacent overbank areas [7].



Plan: Plan 01   SAPANG BALEN CRE   1 RS: 5   Profile: MCFL

E.G. Elev (m)	18.18	Element	Left OB	Channel	Right OB
Vel Head (m)	0.05	Wt. n-Val.		0.030	
W.S. Elev (m)	18.13	Reach Len. (m)	25.00	25.00	25.00
Crit W.S. (m)		Flow Area (m2)		13.55	
E.G. Slope (m/m)	0.000663	Area (m2)		13.55	
Q Total (m3/s)	14.00	Flow (m3/s)		14.00	
Top Width (m)	7.70	Top Width (m)		7.70	
Vel Total (m/s)	1.03	Avg. Vel. (m/s)		1.03	
Max Chl Dpth (m)	2.02	Hydr. Depth (m)		1.76	
Conv. Total (m3/s)	543.8	Conv. (m3/s)		543.8	
Length Wtd. (m)	25.00	Wetted Per. (m)		10.26	
Min Ch El (m)	16.11	Shear (N/m2)		8.58	
Alpha	1.00	Stream Power (N/m s)		8.87	
Frctn Loss (m)	0.02	Cum Volume (1000 m3)		1.29	
C & E Loss (m)	0.00	Cum SA (1000 m2)		0.76	

Errors, Warnings and Notes

Fig. 10. Result at critical station

To sum up, the hydraulic assessment of Sapang Balen Creek at Station 5 indicates that the channel currently has sufficient capacity to convey base flows and smaller storm events without overtopping. With moderate shear stress and efficient flow characteristics, the channel performs well under existing conditions.

D. Design Calculation

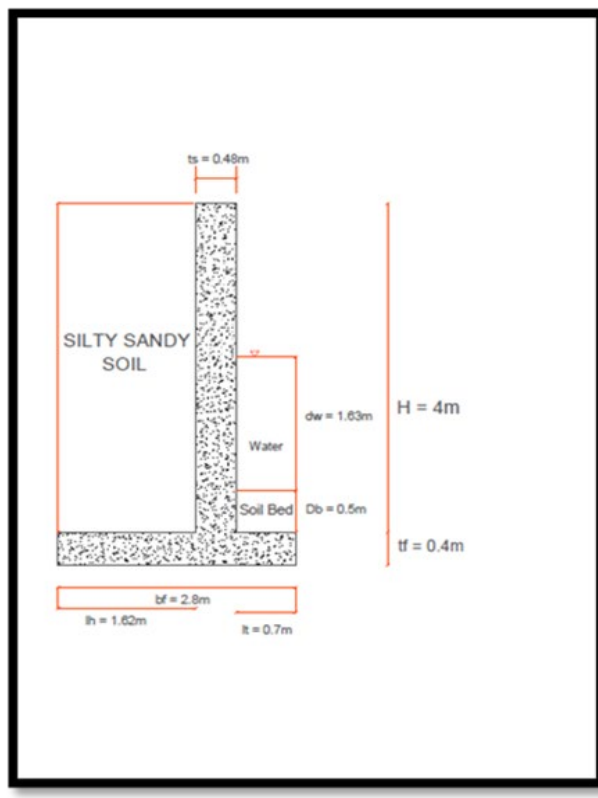


Fig. 11. Calculated dimensions of the cantilever type reinforced concrete slope protection

After a thorough analysis and calculations, researchers come up with the final design of Biaxial Geogrids Soil Reinforcement with a Cantilever type of reinforced concrete slope protection design in Auto-Cad. The reinforcement details on the Stem/Wall include 4 pieces 25mm\empty set with 180mm spacing o.c. Heel reinforcement includes 6 pieces 25mm\empty set spaced at 320mm o.c. On the other hand, the soil reinforcement details include 8 layers of CTM Geogrids: CTM GGB 20/20 with a minimum layering overlapping of 300mm and vertical spacing of 500mm o.c.

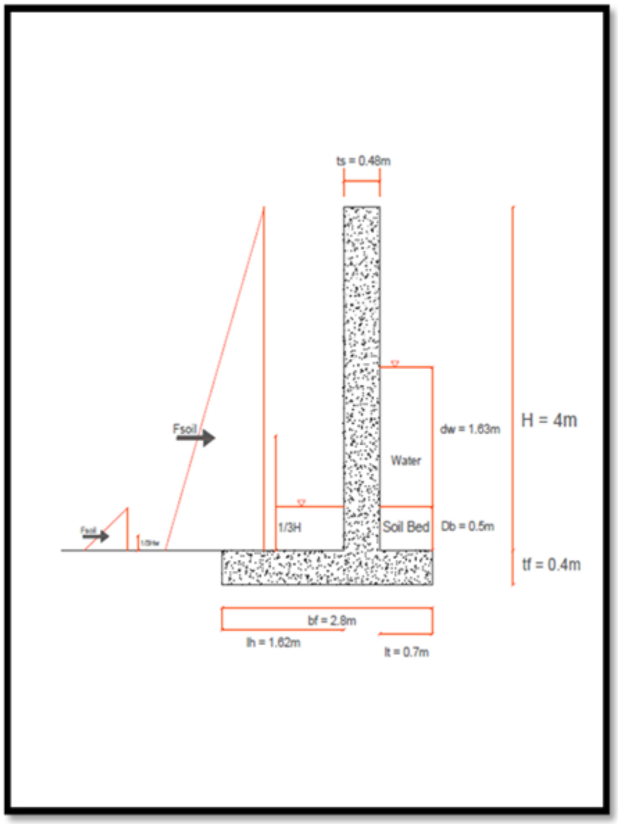


Fig. 12. Lateral earth pressure

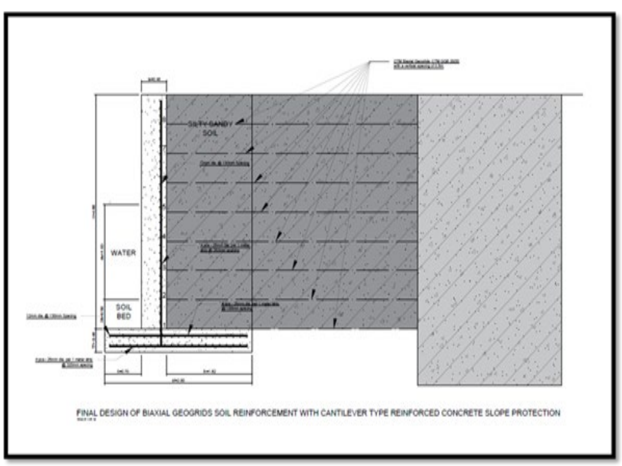


Fig. 13. Final design of biaxial geogrids soil reinforcement with cantilever type reinforced concrete slope protection

E. Geotechnical Analysis Using GEO5 Software

Fig. 14. Design verification result

The retaining wall structure passes both overturning and slip verifications based on applied forces and positions. These results demonstrate compliance with standard geotechnical stability requirements and suggest that the design is strong under the modeled load case. Both overturning and slip are greater than the factor safety of 1.5, where overturning is 1.65 and slip is 1.73 [8][9].

Fig. 15. Dimensioning analysis result

The retaining wall design meets minimum standards for overturning and slide stability. The overturning safety factor surpasses the minimal limit of 1.5 by 28.5%, demonstrating significant resistance from self-weight and reinforcement [10]. The slip check also satisfies the minimum required safety factor with a 3.5% margin, due to horizontal reinforcement and counteracting water pressure [11]. These results demonstrate the wall's structural adequacy and safety under the specified load conditions.

Fig. 16. Slip factor analysis result

The slip along the geotextile is satisfactory since it exceeds the minimum recommended factor of safety value of 1.5, indicating that it complies with standard safety requirements.

Due to the high vertical loads from the wall and reinforced soil, as well as the presence of facing friction, the structure effectively resists sliding [12]. These factors contribute to a high factor of safety against slip, which is much higher than the minimum recommended value. The system, therefore, ensures structural stability and reliable performance under the applied loads.

Fig. 17. Internal stability analysis result

In Figure 17, the tensile strength is over 42.4% wherein a result below 100% indicates that the reinforcement strength is adequate. The resistance to pullout, which is the capacity of reinforcement to stay anchored in the ground, is very low at 1.6%, showing a high factor of safety. These findings are consistent with federal and geotechnical design codes, which require factors of safety of more than 1.5 for both tensile strength and pullout resistance [12].

Fig. 18. Global stability result

The global stability of the structure is satisfactory with a large safety margin (FS = 2.58), exceeding the factor of safety of 1.5, according to the Bishop Method [12]. This guarantees the overall system will resist sliding failure and have long-term integrity under anticipated load conditions.

4. Conclusions and Recommendations

To address the pressing problem of soil erosion and slope protection failure along the banks of Sapang Balen creek in Calulut, City of San Fernando, Pampanga was the aim of the study through proposing a slope protection system that utilizes Biaxial Geogrids in conjunction with reinforced concrete structures. Researchers adopted a multi-disciplinary approach, combining hydrologic and hydraulic modeling, geotechnical evaluation, and a comprehensive community-based survey to ensure the reliability and contextual credibility of the proposed intervention. Results from a community survey highlighted a widespread and long-standing awareness of soil erosion and slope protection failure, but limited participation in erosion control initiatives and inconsistent perception of government actions underscore the need for more integrated and transparent strategies. With the use of HEC-HMS and HEC-RAS, researchers successfully modeled stormwater behavior for 50-year and 100-year return periods, identifying critical design parameters such as maximum channel flood levels and flow velocities. Based on the design calculations and supported by GEO5 Software, the proposed structure satisfies all stability requirements, and the use of Biaxial Geogrids reinforcement proved vital in enhancing structural integrity and erosion resistance.

The following recommendations are proposed to support the implementation and sustainability of slope protection measures in Sapang Balen creek in Calulut based on the findings and engineering analyses:

A. Community Involvement in Maintenance and Monitoring

It is important to promote active participation from residents in maintaining slope protection systems. Establishing local watch groups or maintenance teams initiated by the Calulut barangay officials to help in early identification of structural damage or erosion indicators, allowing for prompt corrective actions.

B. Capacity Building and Technical Training

Because stakeholders behind slope protection systems are professionals' engineers, researchers suggest that it is crucial to implement regular technical discussions and training that focus on topics like sustainable erosion control, use of geosynthetic materials, and structural monitoring knowledge sharing between experienced professionals and local personnel will strengthen the long-term success of protective interventions.

C. Optimization of Geogrids Placement and Spacing

To maximize the structural benefits of and cost-efficiency of the slope protection system, future projects should explore the effect of varying geogrids layer spacing, overlap length, and embedment depth under different soil types and load conditions. Site-specific optimization can reduce material use while maintaining or even improving overall stability.

D. Monitoring the Long-Term Performance of Geogrid-Reinforced Structures

Establishing a long-term monitoring program to observe the performance of geogrid-reinforced section after implementation along small creek applications. Data such as ground movement, structural deflection, and signs of geogrid exposure or degradation should be documented regularly to assess the durability of the system under real environmental conditions.

E. Incorporating Seismic Analysis Considering Local Soil Conditions

Given that the soil in San Fernando City is classified as soft, it is essential to integrate seismic analysis into the slope protection design. During seismic occurrences, soft soil can intensify ground shaking, raising the possibility of slope failure. Thus, site-specific seismic hazard assessments, dynamic slope stability analyses, and the application of seismically resilient materials and strengthening techniques should all be incorporated into engineering designs. This will guarantee that even in the event of an earthquake, the slope protection measures continue to be solid and functional.

F. Integrating Hydrodynamic Analysis for flow Impact Assessment

To ensure the durability and performance of slope protection structures during peak flow events, a comprehensive hydrodynamic analysis should be integrated into the design process. Assessing Sapang Balen Creek's water velocity, flow patterns, flood frequency, and scour potential is part of this. Hydrodynamic modeling will help minimize erosion and structural deterioration during periods of high rainfall and storm surge by directing the design of energy-dissipating structures, suitable lining materials, and sufficient drainage systems.

G. Construction Techniques and Methods

The researchers suggest conducting a more thorough investigation into the proper installation of biaxial geogrid reinforcement in proximity to residential zones, as this process entails greater complexity and potential risks. Given the proximity of homes, any errors could lead to damage or safety concerns. Gaining a comprehensive understanding of these factors is essential to ensure that the installation is carried out safely, efficiently, and with minimal disturbance to residents.

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