International Journal of Research in Interdisciplinary Studies
Volume 3, Issue 6, June 2025
https://www.ijris.com | ISSN (Online): 2584-1017

Retaining Wall Designs for Soil Instability Control: A Case Study in Sapang Bato, Angeles City, Pampanga

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Abstract—This study focuses on the recurring issue of soil instability in Sapang Bato, Angeles City, Pampanga, a region that is known for its steep slopes and high susceptibility to monsoon rains and typhoons. As a preventative precaution against more soil erosion and infrastructure damage along a roadside embankment next to Rizal Street, the research focuses on developing an optimal reinforced concrete retaining wall. The study employs a mixed-methods approach that combines field surveys, qualitative interviews, and analysis using GIS, HEC-HMS, AutoCAD, and PLAXIS 2D. Different reinforced concrete retaining wall designs, particularly cantilever and counterfort designs, were assessed based on site compatibility, cost-effectiveness, and structural performance. Peak discharge and runoff were estimated using HEC-HMS, and slope stability under site-specific loading circumstances was ensured by acceptable lateral displacements validated by finite element modeling using PLAXIS 2D. These results confirm that the suggested construction is appropriate for reducing erosion and improving the impacted embankment's long-term safety and resilience. The cantilever wall design was suggested as the best option following comparative study, establishing a balance between structural soundness and practicality. This study serves as a model for comparable hazard-prone locations in semi-urban contexts and offers a workable, site-specific approach for slope stabilization and erosion management.

Index Terms—**Soil Instability, Erosion Control, Retaining Wall, Slope Stabilization, Hydrologic Modeling.**

1. Introduction

The Philippines is under the Pacific Typhoon Belt, experiencing high levels of natural disasters such as typhoons, storm surges, and rising sea levels. The effects of the month-long monsoon rains on soil stability ran very deep in

Pampanga, wherein the impact of rainfall patterns on the soil of the showed that the most vulnerable areas were earth-banked terraces, where the peak rate of erosion occurred during intense periods of rainfall. Soil erosion involves the gradual removal of surface layers or topsoil by natural forces like water and wind, which is considered one of the major environmental concerns in the Philippines. The threat of soil erosion also put critical infrastructural elements such as embankments used for transportation at risk. Thus, soil erosion control measures are needed to be integrated to counteract slope failures. Infrastructure built on slopes came with risks, and retaining walls were known to reduce and control these issues by stabilizing soil, preventing slope failure, and mitigating soil erosion.

A. Review of Related Literature

Floodwater impacts the stability of transportation embankments which causes weakness in slopes afterward by processes including fast water drawdown, sliding, erosion as well as reduced ground stability by increased saturation of water in the ground [8]. The most observed vulnerable area to soil erosion was identified by the experiment using RUSLE and GIS which showed that 88.2% of the basin is still at low risk of soil loss, while there is a more pronounced incidence of moderate to severe soil erosion that affects nearly 30.7% of its area, within the basin or areas with high altitude and steep slopes along with high rainfalls [13]. Various techniques which can be used to control soil erosion are building retaining structures, terracing, mechanical stabilization, and different temporary and permanent erosion controls. However, most studies about slope protections shows that the best solution is building retaining walls. Major considerations for designing retaining walls include purpose of the wall, site conditions, topography and soil type, choice of hardened materials, and attention to the required height of the wall and load-carrying requirements, proper drainage to avoid accumulation of water behind the wall, and conformance to local regulations [29].

B. Background of the Study

Sapang Bato, a barangay in Angeles City, is uniquely vulnerable to these hazards due to its proximity to the Abacan River and its steep slopes, which exacerbates soil instability and erosion risks. It has an elevation ranging from 151 to 300 meters; these elevation differences influence water runoff patterns and increase the susceptibility of higher areas to erosion and flooding. Typhoon Carina in July 2024 caused severe flooding that overwhelmed drainage systems and led to infrastructure damage, including erosion near roads [48].

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Currently, the community relies on sandbags as a countermeasure for soil erosion. As stated by the risk management office of the Barangay, the use of sandbags for soil instability in the affected area arose due to its simple design and availability.

Fig. 1. Actual documentation of soil erosion in Sapang Bato

C. *Study Area*

The study area is Purok 3 Rizal Street, Sapang Bato, Angeles City, Pampanga, which was known to have mountainous areas that were frequently ravaged by soil erosion due to the high elevation [53]. Sapang Bato, the largest barangay in terms of territory in Angeles, is located northwest of Angeles near the Clark Freeport Zone. It is identified as one of the highest elevated areas at 750 feet above sea level and was in close proximity to water systems, such as the Abacan River.

D. *Objectives of the Study*

The general objective of the study is to propose the most suitable retaining wall design as a countermeasure to the soil instability issues experienced in Barangay Sapang Bato, Angeles City. This is achieved by analyzing and comparing various reinforced concrete retaining wall designs for effectiveness and compatibility with the prevailing conditions of the study area to propose the most suitable design for protective measures.

Specific Objectives:

Specifically, the study aims to determine the following:

- Assess the existing soil instability issues in Sapang Bato, Angeles City using GIS software.
- Review different retaining walls that are compatible with the present conditions of the area's soil profile.
- Select, propose, and design the most suitable retaining wall in terms of cost-effectiveness and overall structural performance.

E. *Significance of the Study*

The study aims to propose the best countermeasure for soil instability in Sapang Bato that will benefit the following stakeholders:

Residents: The people residing in the nearby areas, specifically the residents of Sapang Bato, directly benefits from the findings of the study, as it mitigates the soil instability experienced in the community and promotes a better quality of life.

Local Government Unit of Sapang Bato, Angeles City: The LGU responsible for disaster preparedness and environmental management significantly benefits from this study, as it provides information on best practices for disaster prevention and cost-effective, durable retaining wall designs.

Disaster Risk Reduction Management Office: The office benefits from informative insights regarding an optimized retaining wall design that refines existing disaster risk reduction strategies, mitigates the impact of soil instability, and contributes to creating resilient community infrastructure.

Research Community: Current researchers in similar fields of engineering and environmental risk management utilizes the study's findings and data, particularly in analyzing various retaining wall designs and evaluating effective solutions for mitigating soil instability in similar geographic conditions.

Future Researchers: The findings and methodologies generated in this study provides valuable data for future researchers conducting studies on the comparison of retaining wall designs. Through thorough investigations, they arere able to maximize the resources provided to them.

F. *Scope and Limitation*

- The study proposes the most suitable reinforced concrete retaining wall design to address soil instability in a specific 20m x 13m eroded segment near the Barangay Hall of Sapang Bato, Angeles City.
- It analyzes and compares cantilever, and counterfort retaining wall types based on site conditions.
- Data sources include literature, government records (DPWH, LGU, ACDRRMC), interviews, and field surveys.
- Design follows NSCP 2015 and ACI codes.
- Flood control and project scheduling are excluded.
- Backflow analysis is not considered.
- The study uses a culvert approach due to time, resource, and reference constraints.
- Cost analysis is limited to concrete mix and steel bars and is done in simplified form.

G. *Scope and Limitation*

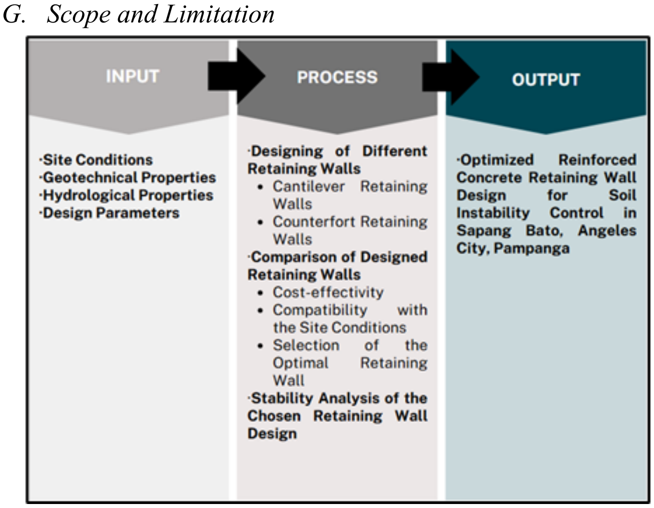


Fig. 2. Conceptual framework

Figure 2 indicates the conceptual framework, laid out using the Input-Process-Output (IPO) model to show the simplified process that the study undertook. In the Input stage, necessary data were collected from various government agencies and offices, field observations, and interviews regarding the site's present conditions. During the Process phase, review of different retaining wall designs narrows down the options to those most compatible with the site. The selected types then proceeded to the design process, such as cantilever and counterfort walls, each possessing unique structural features suited to various scenarios. These designs are then compared based on cost-effectiveness and compatibility with site conditions, ensuring that the final design met both budgetary and practical requirements. Finally, the Output is an optimized reinforced concrete retaining wall design specifically developed for controlling soil instability in the Sapang Bato region.

2. Methodology

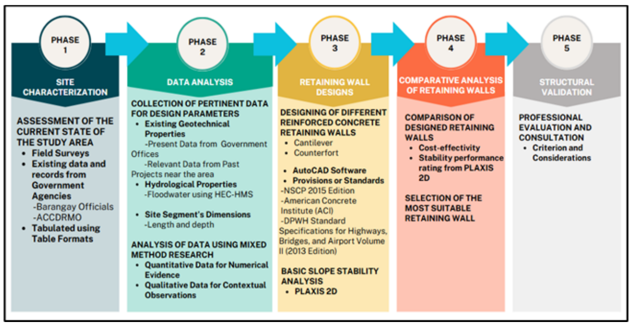


Fig. 3. Methodological framework

A. Research Design

Mixed-method research (MMR) combined qualitative and quantitative approaches to provide a comprehensive understanding of complex issues. MMR allowed for an extensive analysis, as quantitative data focused on measurable aspects such as the results from utilized software, while qualitative data captured insights from community members, particularly barangay officials, adding depth to the findings [55]. This combination of qualitative and quantitative approaches enhanced the study's validity by providing both numerical evidence and contextual observations from those affected by soil instability [56], such as in Sapang Bato, Angeles City.

B. Research Instrument

The researchers used relevant data from various government agencies and academic journals focused on slope protection and soil stability. The researchers prepared a request letter approved by the school authorities to gather pertinent data from the following government agencies such as ACDRRMO, DPWH, PAGASA, and LGU. Moreover, the researchers also conducted qualitative interviews with relevant stakeholders such as residents and barangay officials to investigate key issues concerned with rain-triggered soil erosion within the area. Additionally, the researchers also used different software like QGIS, HEC HMS, AutoCAD, and PLAXIS 2D for data analysis.

C. Data Collection Methods

Preliminary data were gathered through qualitative (conversational interviews and field observations) and quantitative methods (secondary data and software results).

Qualitative Methods: Field observations collected site-specific data like dimensions, slope gradients, and elevation changes; meanwhile, hydrological observations were carried out to gather information about the existing drainage system beneath the road including its drainage points, and nearby water bodies to determine how the movement of water affected the stability of the slope in the area. Qualitative interviews were conducted with barangay officials and residents living in the area to gather valuable insights regarding any historical flooding, soil movements, and other observed changes in the region.

Quantitative Methods: Among the secondary data gathered were the Hydrometeorological Map, Topographic Map, and Contour Map of Angeles City, copies of yearly rainfall observations from PAGASA, and maps from Google Earth and Google Maps.

Codes and Specifications: The research study utilized the guidelines from the National Structural Code of the Philippines (NSCP) 2015 Edition, the American Concrete Institute (ACI), and the Department of Public Works and Highways (DPWH) Standard Specifications for Highways, Bridges, and Airports Volume II (2013 Edition) as references for safety aspects.

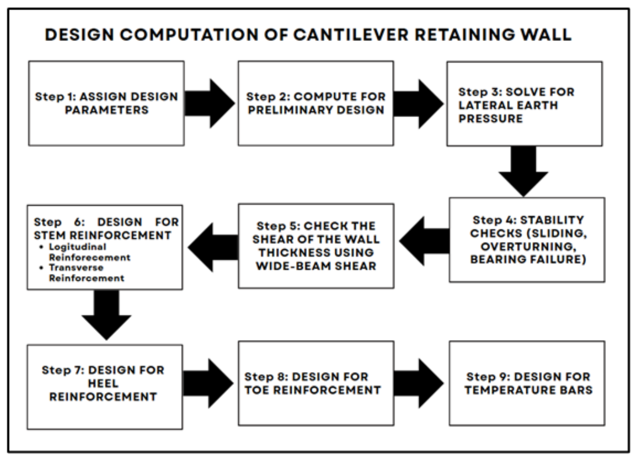


Fig. 4. Cantilever wall design computation

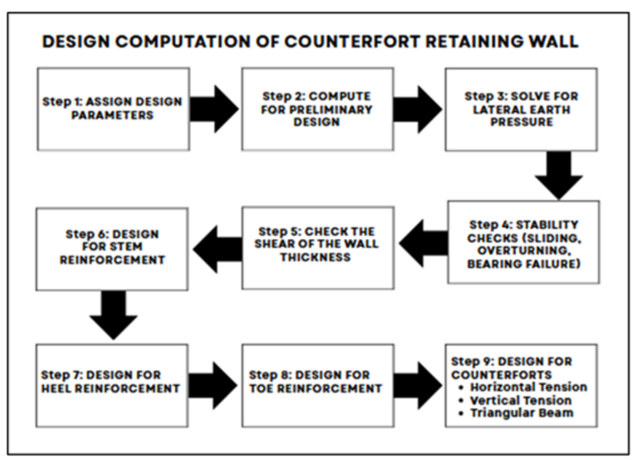


Fig. 5. Counterfort wall design computation

Selection Methods: The selection of the final optimized design of retaining wall for erosion countermeasure will be based on cost analysis and stability performance of the comparing walls from Plaxis 2D.

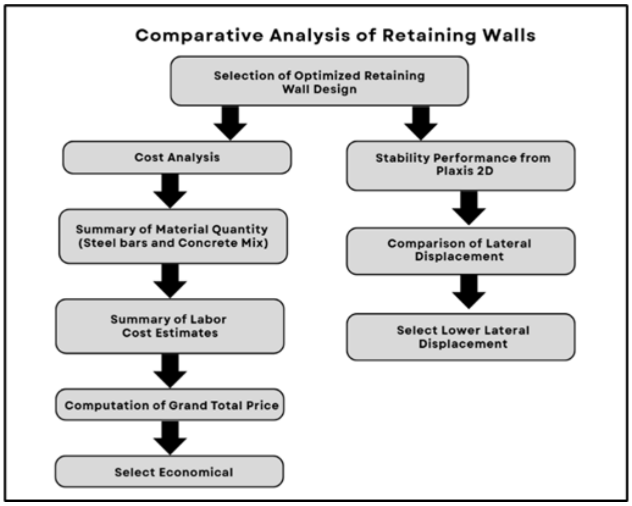


Fig. 6. Comparative analysis of wall designs

D. *Data Analysis*

The collected qualitative data from the interviews with barangay council and experts were examined using thematic analysis. Common themes such as historical flood patterns, observed soil shifts, and community concerns were coded and categorized to contextualize the quantitative findings. The quantitative data, including existing maps and hydrological data, are analyzed to determine any existing correlations and susceptibility in slope structure, as well as to define the hydrological parameter for the design of retaining wall. Moreover, the following software tools were used: QGIS to analyze the erosion risk, HEC-HMS to analyze rainfall data and define peak discharge, AutoCAD to visualize retaining wall dimensions and reinforcement, and Plaxis 2D for stability analysis.

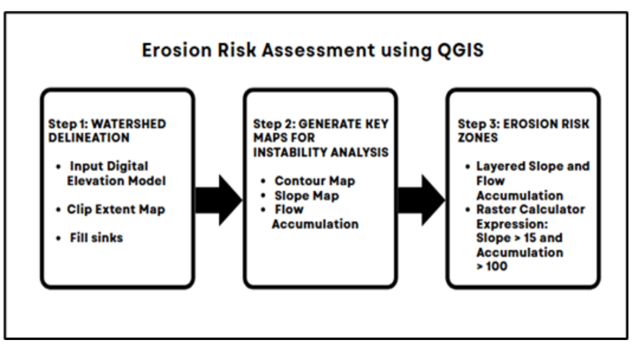


Fig. 7. Erosion risk assessment

For the initial step, the researchers confirmed the existence of soil erosion in Sapang Bato, mainly their study area, by using QGIS software. After that, hydrologic modeling was the subsequent process to determine the peak discharge of flow water that will be utilized in sizing the pipe culvert that would penetrate transversely in the wall design, together with the computation of both cantilever and counterfort. After such process, stability analysis was performed to ensure the safety of the design against lateral displacement.

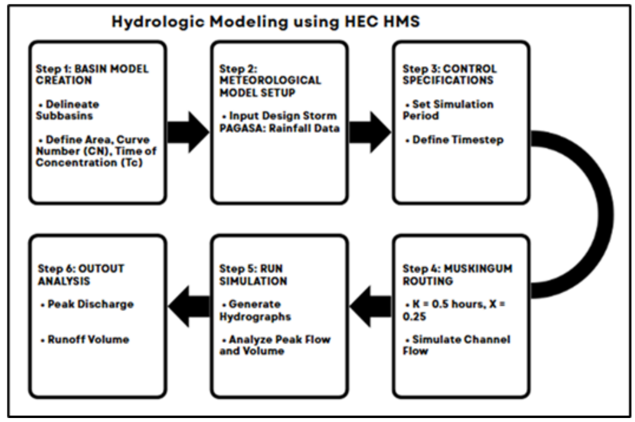


Fig. 8. Hydrologic modeling

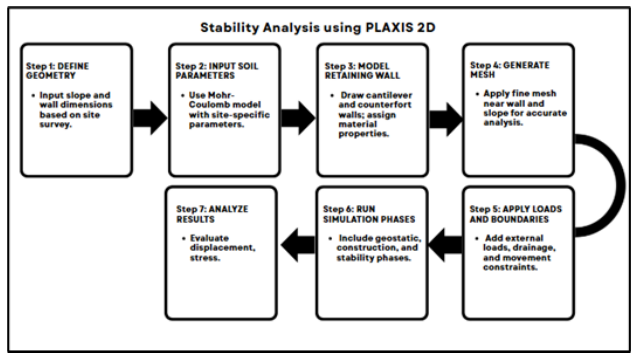


Fig. 9. Stability analysis

3. Results and Discussions

A. *Assessment of Soil Instability in Sapang Bato*

The erosion risk assessment of the area was examined by using both QGIS analysis for software results and qualitative interviews for contextual understanding.

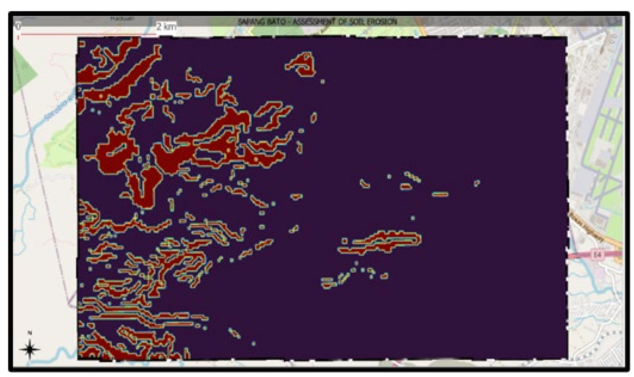


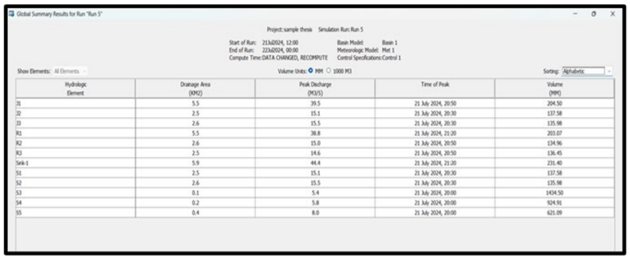
Fig. 10. Erosion risk map

This figure illustrates the area within Sapang Bato that are most susceptible to erosion and soil instability. To identify these critical zones, the researchers utilized the Raster Calculator in QGIS, combining two key hydrological and topographical parameters—flow accumulation and slope. By integrating these two datasets, the analysis effectively pinpointed locations with steep slopes and high accumulation which could lead to soil displacement or embankment failure.

Based on the figure, almost half of the area in Sapang Bato is prone to erosion.

On the other hand, the results from the thematic analysis of interviews concluded that: [1] Residents believe that heavy rainfall was the primary cause of the erosion in the area; [2] Barangay officials depended mostly on short term countermeasures such as sandbagging for the recurring issue of erosion; and [3] Respondents think that retaining wall can be beneficial or effective if designed properly. Therefore, both methods proven that there is soil erosion issue in Sapang Bato.

B. Hydrologic Modeling


Global Summary Results for Run "Run 5"

Project: sample thesis Simulation Run: Run 5

Start of Run: 21Jul2024, 12:00 Basin Model: Basin 1
End of Run: 22Jul2024, 00:00 Meteorologic Model: Met 1
Compute Time: DATA CHANGED, RECOMPUTE Control Specifications: Control 1

Show Elements: All Elements Volume Units: MM 1000 M3 Sorting: Alphabetic

Hydrologic Element	Drainage Area (KM2)	Peak Discharge (M3/S)	Time of Peak	Volume (MM)
J1	5.5	39.5	21 July 2024, 20:50	204.50
J2	2.5	15.1	21 July 2024, 20:30	137.58
J3	2.6	15.5	21 July 2024, 20:30	135.98
R1	5.5	38.8	21 July 2024, 21:20	203.07
R2	2.6	15.0	21 July 2024, 20:50	134.96
R3	2.5	14.6	21 July 2024, 20:50	136.45
Sink-1	5.9	44.4	21 July 2024, 21:20	231.40
S1	2.5	15.1	21 July 2024, 20:30	137.58
S2	2.6	15.5	21 July 2024, 20:30	135.98
S3	0.1	5.4	21 July 2024, 20:00	1434.50
S4	0.2	5.8	21 July 2024, 20:00	924.91
S5	0.4	8.0	21 July 2024, 20:00	621.09

Fig. 11. Peak discharge

Upon further execution the software was able to calculate the peak discharge for each subbasin and runoff volume. The data needed for the calculations is from subbasin 5 which is 8.0 m^3/s for peak discharge and 621.09 m^3 for runoff volume. These parameters are derived from channel length, slope, and approximate travel time, and are calibrated iteratively to produce realistic outcomes.

C. Review of Types of Retaining Walls

The researchers conducted an elimination process to determine the most suitable retaining wall design for their proposed study. This evaluation is based on several criteria, including wall height, length, soil classification, construction material, and cost. First to be eliminated are gravity and semi-gravity walls due to their limited height capacity. Second, anchored walls are also excluded, as they are more used for deep excavations in soft or weak soils. Likewise, sheet pile walls are eliminated as they are normally applied to temporary structures. Third, MSE walls, although cost-effective because of long-term durability problems and lower structural strength compared to reinforced concrete structures.

Therefore, the highlighted parts are the selected cantilever and counterfort retaining walls. Cantilever walls is adopted due to its compatibility with the soil composition of the site. Moreover, counterfort is incorporated and considered as it satisfied overall considerations.

TYPE OF RETAINING WALL	HEIGHT RANGE	LENGTH RANGE	SOIL TYPE	CONSTRUCTION MATERIALS	COST
Gravity Wall	Up to 3 m	5 to 30 m	Coarse-grained soil with good bearing capacity	Concrete, stone, masonry, sometimes crib or gabion	Low to moderate
Semi-Gravity Wall	Up to 4 m	10 to 40m	Similar to gravity wall but allows for less bearing strength	Concrete with some reinforcement	Moderate
Cantilever Wall	4 to 10 m	15 to 50 m	Stable soils like sandy gravel	Reinforced Concrete	Moderate to High
Counterfort Wall	Over 6 m (6 to 12m)	25 to 100 m	Firm, stable soils	Reinforced Concrete (Wall & Counterfort)	Higher due to complexity
Anchored Wall	5 to 25m	10 to 10 m	Soft or firm soils, unstable slopes	Concrete, steel with tiebacks/anchors	High
Sheet Pile	Up to 6 to 9 m (can go higher)	10 to 80 m	Soft to medium cohesive soils, near water	Steel, vinyl, timber, precast concrete	Moderate
Mechanically Stabilized Earth (MSE) Wall	3 to 20 m	20 to 100 m	Broad range, especially coarse or mixed soils	Modular concrete panels, geogrid/geotextile reinforcements	Moderate

Fig. 12. Elimination of types of retaining wall

Table 1
Cantilever top layer design computations

Description	Results
Provided Dimension of Retaining Wall	a. Total Height of the Retaining Wall = 6.6 m b. Height of the Cantilever Retaining Wall = 6.m c. Thickness of the Bottom Stem = 0.72m d. Thickness of the Top Stem = 0.4 m e. Thickness of the Footing = 0.6 m f. Base of the Footing = 4.2 m g. Length of toe = 1.4 m h. Concrete Cover for Stem = 75 mm i. Concrete Cover for Heel and Toe = 50 mm j. Depth of Backfill = 6 m
Stability Checks	a. Sliding: 2.65 >1.5 ∴ Safe against sliding b. Overturning: 3.20 >1.5 ∴ Safe against sliding c. Uplift: R = 0.7 > e = 0.21 ∴ There is no uplift

Table 2
Cantilever bottom layer design computations

Description	Results
Provided Dimension of Retaining Wall	a. Total Height of the Retaining Wall = 7.7 m b. Height of the Cantilever Retaining Wall = 7m c. Thickness of the Bottom Stem = 0.84m d. Thickness of the Top Stem = 0.55 m e. Thickness of the Footing = 0.7 m f. Base of the Footing = 4.9 m g. Length of toe = 1.63 m h. Concrete Cover for Stem = 75 mm i. Concrete Cover for Heel and Toe = 50 mm j. Depth of Backfill = 7 m
Stability Checks	a. Sliding: 2.08 >1.5 ∴ Safe against sliding b. Overturning: 2.35 >1.5 ∴ Safe against sliding c. Uplift: R = 0.82 > e = 0.25 ∴ There is no uplift

Table 3
Counterfort design computations

Description	Results
Provided Dimension of Retaining Wall	a. Total Height of the Retaining Wall = 15.8 m b. Height of the Counterfort Retaining Wall = 13 m c. Thickness of the Stem = 0.80 m d. Thickness of the Footing = 2.8 m e. Base of the Footing = 8 m f. Length of toe = 2.4 m g. Concrete Cover for Stem = 75 mm h. Concrete Cover for Heel and Toe = 50 mm j. Depth of Backfill = 13 m
Stability Checks	a. Sliding: 1.58 >1.5 ∴ Safe against sliding b. Overturning: 2.96 >1.5 ∴ Safe against sliding c. Uplift: R = 1.33 > e = 0.56 ∴ There is no uplift

Table 4
Culvert design computations

Description	Results
Pipe Classification	Class IV Precast Reinforced Concrete Pipe Inner diameter: 1600 mm Thickness of wall: 140 mm (Standard) Outer diameter: 1880 mm = 1900 mm Length of pipe: 0.60 m due to the stem thickness D-Load: 48 $\frac{kN}{m} - m$
Pipe Diameter	8m3/s Peak Discharge in Manning's Equation: 1.57m or 1.60m diameter RCP
Pipe Culvert Dimensions	Culvert Clearance for Reinforcement: 300mm for all sides ∴ Adopt 2.5m by 2.5m Culvert

D. Retaining Wall Designs

See table 1 to 3.

E. Pipe Culvert Design

See table 4.

F. AutoCAD Design Models

This section presents the proposed structural design of both the cantilever and counterfort retaining walls, detailing the corresponding reinforcement layout, dimensions, and structural elements.

1) Cantilever Retaining Wall Design

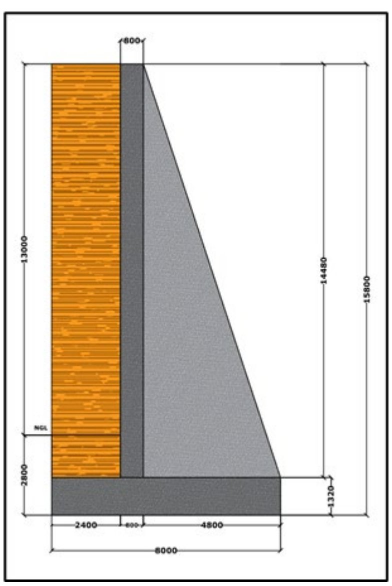


Fig. 15. 2D Model of counterfort design

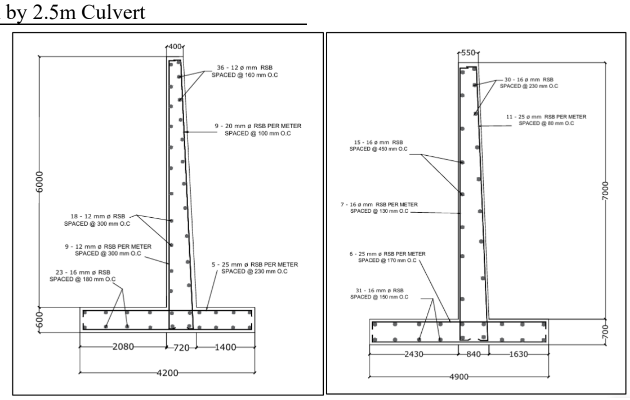


Fig. 14. Detailed cantilever reinforcement

2) Counterfort Retaining Wall Design

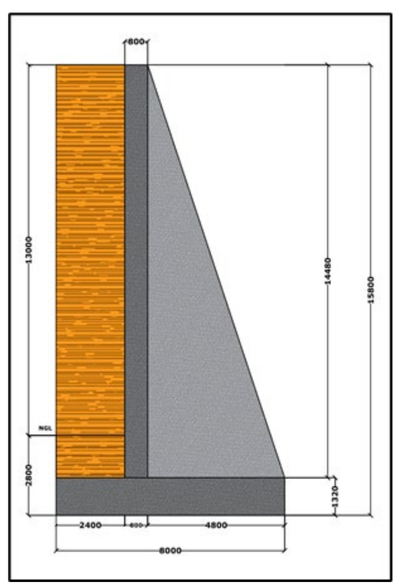


Fig. 15. 2D Model of counterfort design

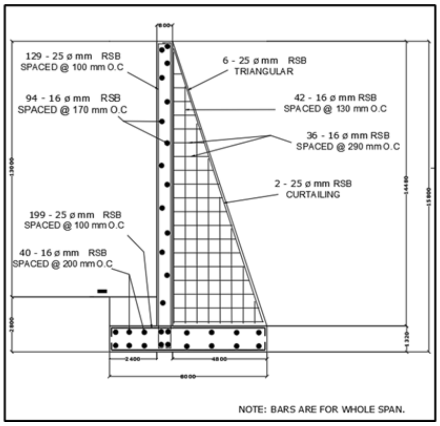


Fig. 16. Detailed counterfort reinforcement

3) *Pipe Culvert Design*

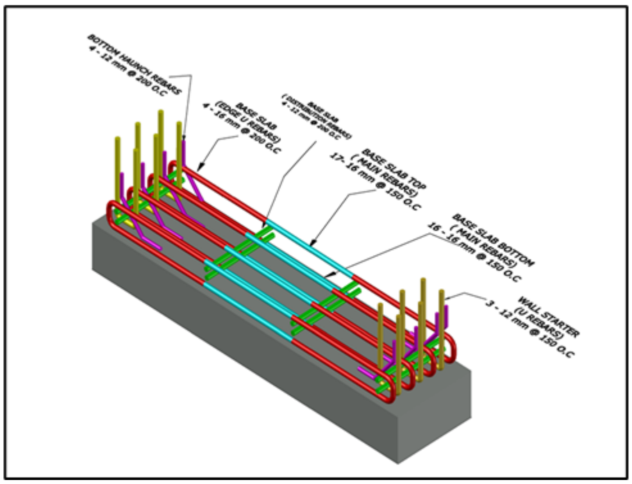


Fig. 17. Detailed culvert base reinforcement

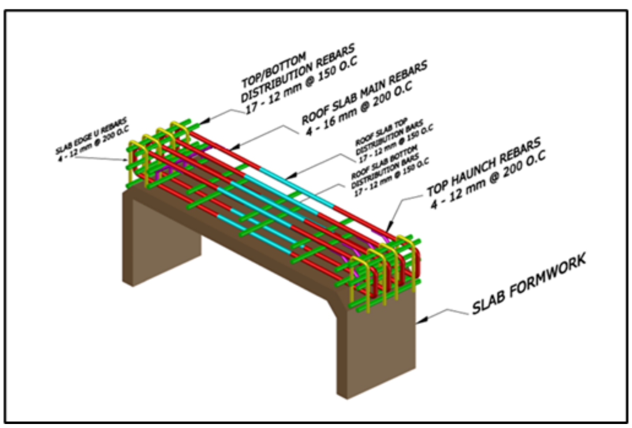


Fig. 18. Detailed culvert top reinforcement

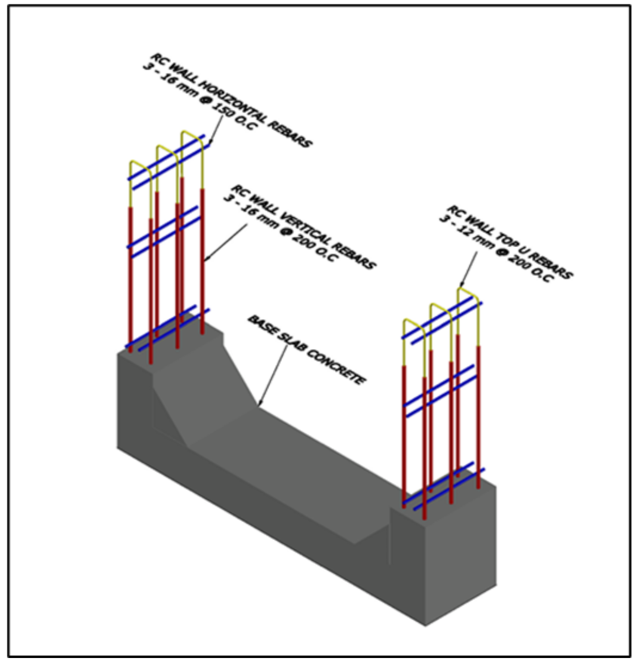


Fig. 19. Detailed side culvert reinforcement

For the span of 20m length, a section from 7.5m from the right corner of the eroded road embankment has an existing drainage pipe beneath the road which would penetrate the proposed retaining wall. This drainage system adopted the pipe culvert approach in the penetrated section of retaining wall, which is 2.2 meters below the road grade.

G. *Global Stability*

The results of the analysis for the stability performance of the retaining walls are shown as deformation patterns, stress distribution, changes in pore pressure, and development of shear strain.

The key findings of the analysis of the stability of the slope by total displacement contours under static loading of cantilever wall – the displacement was a maximum of 2.22m — graphically exaggerated for clarity—at the toe of the upper retaining wall, where stress concentration would be anticipated. However, it is observed in the figure that other than the area at the toe, remaining sections of the retaining wall are safe from lateral displacement. In general, deformation is moderate and localized, with no indication of deep failure.

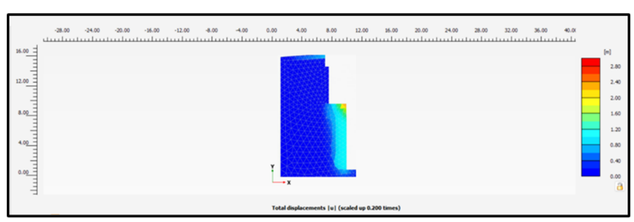


Fig. 20. Cantilever lateral displacement

Table 5
Total estimated costs

	Material Cost		Labor Cost	Total Cost
	Steel Reinforcement	**Concrete Mix**		
Cantilever Wall	₱1,713,360.00	₱1,530,900	₱ 307,950	₱3,552,210.00
Counterfort Wall	₱1,248,670.00	₱3,677,184	₱298,150	₱5,224,004.00

A numerical simulation is also conducted to evaluate the performance of the counterfort wall under static loading; the post-construction conditions indicate a maximum total displacement of 2.481m at the vicinity of the top of the wall. This displacement is in accordance with anticipated wall deformation patterns and is within acceptable serviceability limits. The displacement mechanism is gradual and smooth, showing no failure symptoms, which means that the wall is both structurally and geotechnically sound.

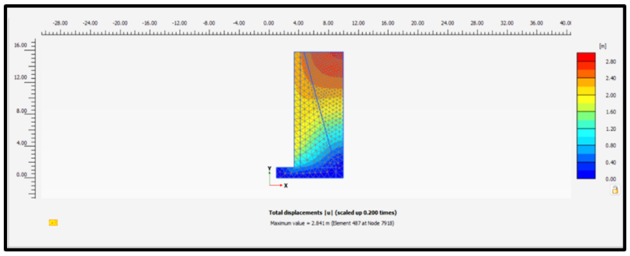


Fig. 21. Counterfort lateral displacement

H. Selection of Optimized Retaining Wall Design

1) Cost Effectiveness

The cost analysis of the materials shows a considerable disparity between the two retaining wall designs. From the calculated quantities and prevailing unit prices, the cantilever retaining wall design had a lower total material cost than the counterfort wall. Thus, cantilever retaining wall design was favored in terms of cost-effectiveness.

2) Stability Performance

Moreover, based on the stability performance from PLAXIS 2D, the two-tiered cantilever wall has better structural behavior, as seen through lower maximum lateral displacement under the same stability criteria. Staged height and stepped backfill of the cantilever wall seem to result in more effective distribution of earth pressure along with better overall stiffness. With a lateral movement difference of 0.631 meters, the cantilever wall is found to be more efficient in managing deformation and stability.

I. Final Proposed Optimized Retaining Wall Design

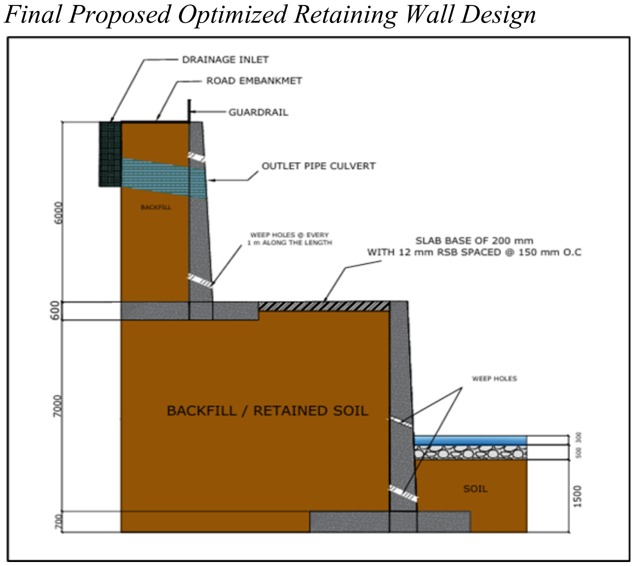


Fig. 22. Proposed two-tiered cantilever retaining wall

According to the results from cost analysis and structural performance assessment, the most optimal retaining wall design for the Sapang Bato location is the two-tiered cantilever retaining wall.

4. Conclusion and Recommendation

A. Conclusion

Based on the findings of the study, it is confirmed that there is an existing soil erosion issue in Sapang Bato which leads to a need for immediate countermeasure such as building retaining wall. After all the analysis, evaluation, and proper design, this study came up with the two-tiered cantilever retaining wall as the best solution for the issue. It has lower construction costs and better performance in stability that offers long-term stability, efficient material use, and strong erosion control for the Sapang Bato site. It is concluded that in-depth analysis of the design process and considerations to the site conditions were crucial in any project planning.

B. Recommendations

The recommendations aim at aiding stakeholders such as the local government administration, civil engineers, environmental groups, and residents in orderly implementation of controls in securing and sustainably managing matters of instability, further erosion of soil in Sapang Bato.

Local Government Units (LGUs): The LGUs should impose stronger controls on erosion and slope stability, especially where the areas are prone to being affected, for example, in Sapang Bato. Health education campaigns may also be rolled out to instruct residents on appropriate waste disposal because litter that plugs drainage systems immensely contributes to the exacerbation of erosion.

Civil Engineers: Civil engineers who will be working on the site itself are recommended to carry out a comprehensive comparative analysis of various retaining wall and erosion control techniques during the literature review process.

Future Researchers: It is highly suggested that the forthcoming researchers apply sophisticated technical software like HEC-HMS, HEC-RAS, PLAXIS 2D, and QGIS to more accurately study hydrological, hydraulic, and geotechnical information. High-resolution and high-fidelity datasets must be given priority in order to obtain reliable and accurate results.

Road Redesign: In future infrastructure development, consideration must be given to other reasons for soil instability, including the lack of a sufficient roadside drainage canal and inadequate road banking in curving road segments, as emphasized by Engr. Duya.

Geographic Information Systems (GIS): Local authorities are encouraged to integrate new geospatial tools like GIS in their disaster management and infrastructure planning policies. GIS applications allow for accurate risk mapping, hazard analysis, and strategic planning so that local authorities may develop interventions designed to minimize the impact of natural disasters like slope failures and flooding.

Exploration of Study Area: Subsequent research should look to broaden the scope of the study region in order to have a more complete knowledge of regional conditions affecting soil instability. An expanded scope will enable a more thorough and holistic examination of patterns of erosion, drainage characteristics, and topographic effects within adjacent zones, resulting in more informed and efficient engineering solutions.

References

[1] Holden J. et al. (2024). The effects of internal erosion on granular soils used in transport embankments. Soils and Foundations, Volume 64.

[2] Mejia, K. (2023). Delineation of Soil Erosion in the Pampanga River Basin Using the Revised Universal Soil Loss Equation (RUSLE). https://che.uplb.edu.ph/theses-data/delineation-of-soil-erosion-in-the-pampanga-river-basin-using-the-revised-universal-soil-loss-equation-rusle/?fbclid=IwY2xjawF2sQdleHR

[3] Guy, L., 2024. Ultimate guide to what factors need to be considered when designing a retaining wall. Retaining Wall Specialists Auckland. https://retainingwallspecialistsauckland.co.nz/what-factors-need-to-be-considered-when-designing-a-retaining-wall/

[4] Orejas, T. (2020). Flooding in Pampanga feared to worsen as river swells after Ulysses, Inquirer News. INQUIRER.net. https://newsinfo.inquirer.net/1360401/flooding-in-pampanga-feared-to-worsen-as-river-swells-after-ulysses

[5] Jaime et al. (2020). Geo-hazard mapping of the Province of Pampanga: A reference for Disaster Preparedness panorama.

[6] Dawadi et al., (2021). Mixed-Methods Research: A Discussion on its Types, Challenges, and Criticisms. Journal of Practical Studies in Education, 2(2) pp. 25–36.

[7] Creswell, J., et al. (2020). Research Design: Qualitative, Quantitative, and Mixed Methods Approaches (5th ed.). SAGE Publications. https://us.sagepub.com/en-us/nam/research-design/book255675