RESEARCH ARTICLE OPEN ACCESS

A Proposal Design of Stone-Pitched Retaining Wall as a Countermeasure for Soil Erosion in San Agustin Creek, San Agustin, San Fernando, Pampanga

Marycon Cyril P. Caisip[1], John Mitzgerald M. Barin[2], Xandra Patricia A. Barrera[3], Jilian Meg D. Bonus[4], Jerrie Alex R. Cadena[5], Jose Jesus M. Vergara Jr[6], Miriam B. Villanueva[7], John Vincent G. Tongol[8]

[1](Civil Engineering Department, Don Honorio Ventura State University, Bacolor, Pampanga, Philippines email: maryconcyrilcaisip01@gmail.com)

[2] (Civil Engineering Department, Don Honorio Ventura State University, Bacolor, Pampanga, Philippines email: barin2420@gmail.com)

[3] (Civil Engineering Department, Don Honorio Ventura State University, Bacolor, Pampanga, Philippines email: xxandrpatricia@gmail.com)

[4] (Civil Engineering Department, Don Honorio Ventura State University, Bacolor, Pampanga, Philippines email: bonusjilianmegd@gmail.com)

[5] (Civil Engineering Department, Don Honorio Ventura State University, Bacolor, Pampanga, Philippines email:jerriecadena@icloud.com)

[6] (Civil Engineering Department, Don Honorio Ventura State University, Bacolor, Pampanga, Philippines email: Vergarajj17@gmail.com)

[7] (Civil Engineering Department, Don Honorio Ventura State University, Bacolor, Pampanga, Philippines email:mbvillanueva@dhvsu.edu.ph)

[8] (Civil Engineering Department, Don Honorio Ventura State University, Bacolor, Pampanga, Philippines email:jvgtongol@dhvsu.edu.ph)

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Abstract:

Tropical storms and typhoons frequently hit San Fernando, the capital of Pampanga in the Philippines, due to its varied topography. This study centers on San Agustin Creek in San Fernando, an area that is highly vulnerable to erosion and slope instability. To stabilize slopes and blend in with the surrounding environment, a stone-pitched retaining wall is the proposed solution. The wall's flexibility allows for soil movement and lowers the possibility of structural damage to neighboring properties. The interlocking stones increase the wall's resilience against heavy rainfall. Survey showed that there is an ongoing erosion problems and property damage experienced by the residents. Hydrological (HEC-HMS) and hydraulic (HEC-RAS) modeling were utilized in this study to comprehend the behavior of the creek and direct the design of the retaining wall. Despite having a lower Nash-Sutcliffe Efficiency (NSE) score, the results of the hydrologic modeling showed a "Very Good" Percent Bias (PBIAS) — indicating reliable data input for hydraulic analysis. The hydraulic modeling showed how retaining walls can lessen areas that are vulnerable to flooding, which in turn lowers the risk of property damage. The structure was drawn and examined using AutoCAD and GeoStudio. To guarantee adherence to safety standards, the study followed the National Structural Code of the Philippines (NSCP) 2015 and the guidelines set forth by the American Concrete Institute (ACI). The study's comprehensive approach to addressing erosion challenges in San Agustin Creek was strengthened by the stability analysis, in which factors like sliding resistance, overturning, and breakwater were considered.

Keywords **—Slope Protection, Stability, Erosion, Stability Analysis, Geotechnical**

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I. INTRODUCTION

Geotechnical engineering plays a key role in protecting the environment against threats caused by natural forces and environmental dynamics. In this field, creating and implementing effective slope protection systems is important, especially in areas with different topography and temperatures [1].Pampanga, which is located in Central Luzon, Philippines, has a distinctive topography and is prone to tropical storms. Pampanga's capital, San Fernando, is a vital core for the region's economy and society. The San Fernando-based San Agustin Creek represents a focal point in the ponder because of its susceptibility to erosion and unstable slopes [2].

II. REVIEW OF RELATED LITERATURES

Slope stability, slope protection, erosion control, and creek stability are all crucial components of civil engineering and environmental supervision, particularly in areas with various terrains, and calamity prone areas. This study thoroughly examined these interconnected concerns to initiate long-term and sustainable findings for San Agustin Creek in San Fernando, Pampanga.

A.Erosion Issues on Creeks in the Philippines

The Philippines has about 419 major rivers, 127 of which are protected by government supervision. In the year 2010, around 90% of the identified watersheds were assessed as hydrologically critical, destroyed, and posing hazards to downstream infrastructure. Soil erosion exacerbates this problem because it not only affects soil fertility and productivity but also has a severe influence on downstream towns' household water supply [3]. Moreover, sedimentation in rivers reduces their water-carrying capacity, increasing the risk of local flooding due to heavy rains. About 16 million cubic meters of soil in the country have been depleted from the country's 4.7 million hectares of watershed due to its steep topography, deforested highlands, and heavy rainfall [4].

B. Slope Stability

Slope stability refers to the ability of a slope or embankment to withstand various forces without undergoing significant deformation or failure. Landslides, water, and soil erosion resulting from natural rainfall are responsible for a significant proportion of slope instability, potentially reaching 90% [5]. In regions like the Philippines, where typhoons and seismic events are common, slope stability is paramount to safeguard lives, infrastructure, and the environment [6]. To lessen the creek's instability and the risk of erosion, it is necessary to implement measures to protect the slope and the structural strength [7].

C. Slope Protection

Slope protection mitigates the adverse effects of rainfall, road runoff velocity, and soil erosion. In contrast, slope protection engineering frequently serves to satisfy the stability requirements of slopes, which may lead to a possible decrease in ecological consequences [8].The current approaches used for slope protection in the country often include the utilization of concrete riprap, stone masonry, or sodding techniques [9]. The commonly available solutions are the retaining walls, gabion baskets, riprap, slope terracing, vegetative cover, and other geotechnical engineering techniques [10]. The choice of slope protection technology is determined by criteria such as slope angle, soil type, local climate, and available resources. A detailed understanding of these measures and their relevance is required for developing successful slope protection systems that are adapted to the specific conditions of a given region.

D. Stone-Pitched Retaining Wall

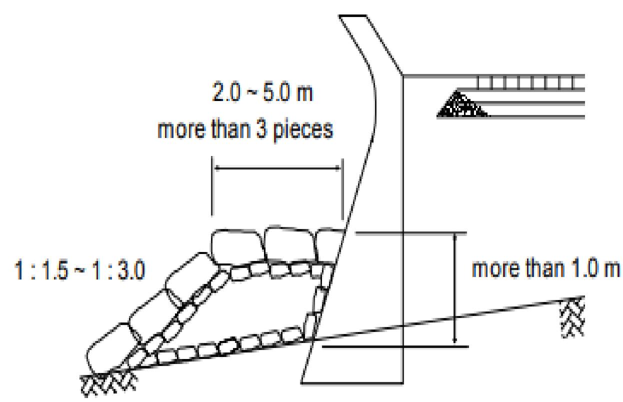

Fig. 1 Using Stone-Pitch with Filling Material [11]

As illustrated in Figure 1, stone pitching is a technique used to prevent soil collapse due to water overflow. The process involves constructing a series of small barriers or terraces along the slope of the soil. In the Philippines, rubble or stone pitching is a prevalent way of mitigating soil erosion and landslides. This method is frequently used in embankments and culverts to slow stormwater flow. Pitching works are used to avoid surface weathering, scouring, stripping, and erosion, as well as, in rare situations, small-scale soil slope collapse. In order to distribute the flow throughout the hard surface of the wall and around the protruding rock, medium-sized boulders are placed in mortar and left exposed [12].

Simple designs, such as dry-stone masonry, can be quickly demolished, however it can be mitigated using grouted riprap, stone or rubble pitching, concrete block revetments, reinforced concrete, or stone masonry [11]. From bottom to top, the spaces in between must be filled with hand-placed mortar, and the surface must be cleaned to show the distinct faces of the stones—every mortared joint needs to be scraped 5 mm below the rock pitching's surrounding surface [11].

E. Annual Rainfall in Pampanga

TABLEI
SUMMARY OF ANNUAL RAINFALL IN PAMPANGA[13]

Period (Year)	Annual Rainfall (centimeter)
2013	220.63
2014	169.08
2015	218.04
2016	189.07
2017	173.08
2018	275.69
2019	193.95
2020	183.77
2021	181.41
2022	194.23
January to October 2023	206.78

Table 1 shows the annual rainfall recorded in Pampanga. The Philippine Atmospheric, Geophysical, and Astronomical Services Administration (PAGASA) Clark Weather Station provided the data utilized in procuring this table. The table contains the ten-year annual rainfall period necessary for the mathematical modeling of extreme hydrological events, such as droughts or floods, and for understanding the water cycle and precipitation's impact on the environment. The table also includes vital information about the amount of rainfall over a specified period. The years were listed chronologically from 2013 to 2023.

F. Landslide and Flood Susceptibility Map of the City of San Fernando

Landslides may occur because of heavy rainfall, leading to ground saturation, erosion of the base slope, and changes to a material's strength through weathering [14]. Flooding may occur when water overflows due to heavy rainfall or saturates typically dry lands. Floods usually take hours or days to develop, giving locals time to be ready and evacuate. Floods can occasionally form suddenly and with little or no notice. While numerous ways may cause a flood, the most typical one is when rivers, streams, or creeks overrun their banks. This kind of flooding is referred to as a riverine flood [15].

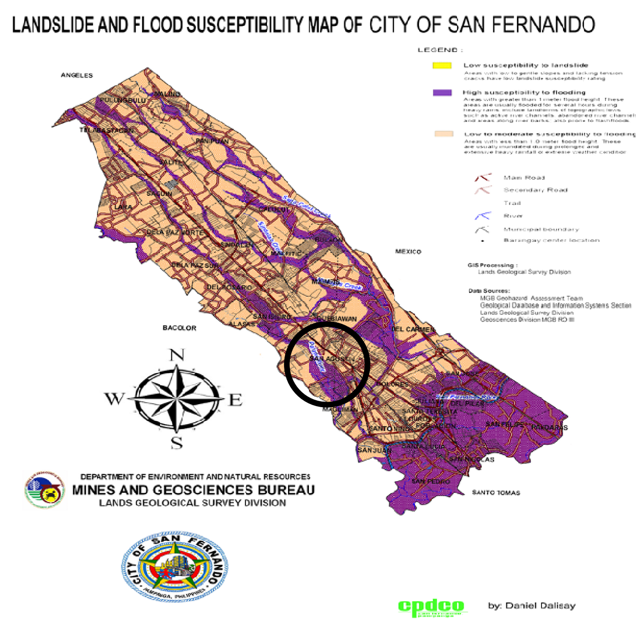

Fig. 2 Landslide and Flood Susceptibility Map of the City of San Fernando [16]

Figure 2 illustrates the susceptibility to landslides and floods in San Fernando, Pampanga.

Yellow areas indicate low landslide susceptibility due to gentle slopes and the absence of tension cracks. Purple areas signify high flood susceptibility, experiencing floods over 1 meter in height, particularly in topographic lows like active and abandoned river channels. These locations are prone to extended flooding during heavy rains and are susceptible to flash floods. Cream- or nude-colored areas exhibit low to moderate flood susceptibility, with inundation below 1 meter during prolonged heavy rainfall or extreme weather. San Agustin Creek falls within the purple-colored areas on the map, indicating high susceptibility to flooding.

G. Brief Discussion of the Proposal Study

Fig. 3 Slope Rehabilitation Project in Selected Areas of the San Agustin Creek, City of San Fernando, Pampanga

A selected portion of the slope of San Agustin Creek which is shown in Figure 3 was stabilized by a retaining wall. Specifically, the retaining wall was constructed within Saint Augustine Village, Barangay San Agustin, City of San Fernando, Pampanga.

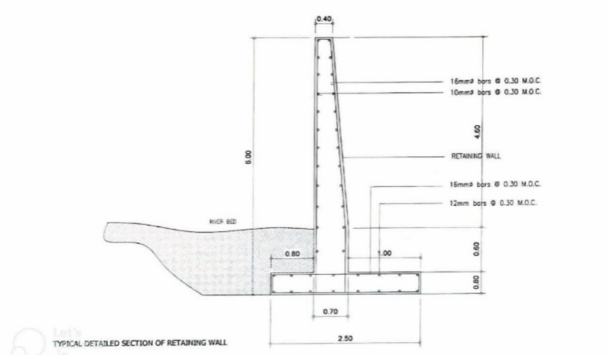

Fig. 4 Typical Detailed Section of the Retaining Wall [17]

A selected portion of the slope of San Agustin Creek which is shown in Figure 3 was stabilized by a retaining wall shown in Figure 4. Specifically, the retaining wall was constructed within Saint Augustine Village, Barangay San Agustin, City of San Fernando, Pampanga. The retaining wall spans approximately 70 meters and is part of a project supervised by the Engineering Department of the City of San Fernando, Pampanga.

Fig. 5 San Agustin Creek in Ramar Village, Barangay San Agustin, City of San Fernando, Pampanga

Figure 5 shows the slope condition of the creek. Slope stability is the capacity of a slope or embankment to sustain varied stresses without severe deformation or failure [5]. Erosion and landslides, two common natural disasters, may accelerate soil degradation and loss. Rainfall frequently causes such dangers because it affects the physical stability and soil composition [18]. Soil bearing capacity is the capacity of the soil mass to withstand the gravitational forces acting upon it and any extra loads including the possible dynamic stresses like those caused by an earthquake. It is an essential requirement for a slope to be stabilized to protect people, property, and the environment from possible massive soil erosions caused by typhoons, heavy rains, and even earthquakes [5].

The bare slope along San Agustin Creek in Ramar Village, Barangay San Agustin, City of San Fernando, Pampanga, is undergoing bank deterioration which is a result of natural erosion processes intensified by heavy rainfall and its connection to the contiguous waterway linked to the Pampanga River Basin. Hence, implementing slope protection is imperative to maintain the ecological integrity of the creek [19].

In the Philippines, a range of slope protection techniques is employed to mitigate potential risks. Specifications regarding Rubble Masonry Walls can be sourced in standards set by the Department of Public Works and Highways in the Philippines in the "Standard Specifications for Highways, Bridges, and Airports" released in 2015 [20]. Furthermore, the construction of retaining walls proves crucial in preventing soil movement on steep slopes [21].

H. Study Area

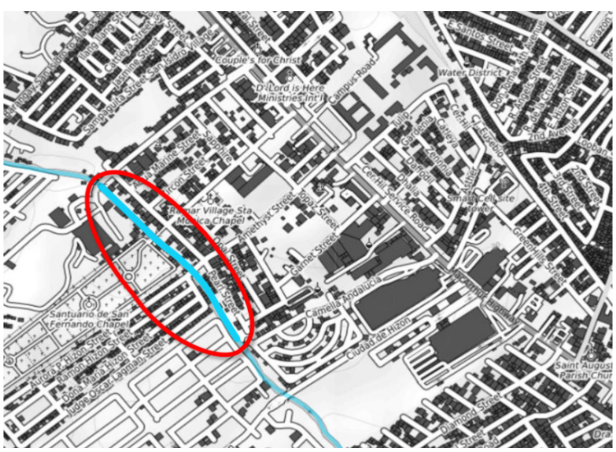

Fig 6. Topography Map of San Agustin Creek in Ramar Village, Barangay San Agustin, City of San Fernando, Pampanga, Philippines[22]

Figure 6 shows the topography map of San Agustin Creek in Ramar Village, Barangay San Agustin, City of San Fernando, Pampanga, Philippines. Even though San Fernando mostly has a flat ground surface, there are also some raised or steep portions, especially in the north-eastern and eastern regions. Both their terrain and susceptibility towards flooding may be different in these places. The terrain of the city is generally flat with 0-10% slope [23]. During the rainy seasons, the village of Ramar in Barangay San Agustin, San Fernando, Pampanga is often submerged in water. The unique terrain of San Fernando causes flood water in some of its barangays.

There is significant research on the effectiveness of various approaches for preserving flow slopes in reducing flood risks and erosion. However, additional research is required to fully understand the flexible effects of protecting stream slopes on aquatic ecosystems' overall health and long-term survival.

A retaining wall is necessary to prevent the slope from possible erosions further. The implementations from the National Structural Code of the Philippines (NSCP) 2015 Edition, American Concrete Institute (ACI), and the Department of Public Works and Highways (DPWH) Standard Specifications for Highways, Bridges, and Airport Volume II 2013 Edition benefited the researchers in the design proposal of retaining walls in San Agustin Creek, San Fernando, Pampanga. Based on published studies on civil engineering, geotechnical engineering, and hydraulic engineering, the design of a retaining wall in a creek requires attention to specific design considerations such as rainfall data, water flow patterns, geotechnical assessment in which the soil properties, stability, and bearing capacity are included.

III. METHODOLOGY

This chapter presents the methods that was utilized to conduct the study which includes the research design, study locale, population, development of the research instrument with a focus on establishing its validity and reliability, data collection methods, the application of appropriate statistical treatments, and the analysis of data gathered.

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A. Methodological Framework

The first phase, the problem identification, helped the researchers to state the research gap of the study and why it was identified as a challenge that needs to be addressed. The second phase, the review of related literatures, guided the researchers to identify the background of the study and the best practices on designing the retaining wall for soil erosion control. The third phase, which is specifying the research purpose, is also necessary in order for the researchers to state the objectives that the researchers intended to achieve. In the fourth phase, the data collection consisted of the primary (on-site surveying and instrument design for safe measurement validity) and the secondary data collection that were collected from government agencies. Lastly, after all of these processes, the data analysis interpretation enabled the researchers to achieve their research objectives. These phases required the researchers to analyse and interpret the data which provided design decisions, which was influenced by soil data and the results with the help of the software programs utilized in this study.

Phase 1: Problem Identification – Research Gap – Problem Statements – Study Limitations
Phase 2: Review of Related Literature – Retaining Wall Design Codes and Provisions – Journals
Phase 3: Specifying Research Purpose – General Objectives – Specific Objectives
Phase 4: Data Collection – Primary Data: Instrument Design, Surveying and Stream Gaging Data, Validity of the Research Instruments – Secondary Data: Government Data
Phase 5: Data Analysis Interpretation – Statistical Analyses: Frequency Analysis, Hydrologic and Hydraulic Analysis, Design, and Basic Slope Stability Analysis

Fig. 7 Methodological Framework

B. Research Design

This research is quantitative in design and experimental in nature as it objectively measured and quantified aspects of a new design through hydrological and hydraulic analysis, structural design metrics, and other measurable criteria. This study also involved gathering data from different government institutions, observations, surveys, and the use of different software program for the design of the retaining wall. The results subsequently interpreted data collected with numerical solutions to conclude structural criteria.

C. Research Instruments

The researchers used self-formulated questionnaire which was validated by a psychometrician, grammarian, and a statistician. Additionally, journals related to slope protection, field survey and stream gaging, and data from different government institutions for the assessment of the study were also utilized.

D. Data Collection Methods

The study adopted a quantitative research method to ensure that accurate data was collected for formulating the design proposal of the stone-pitched retaining wall, where various statistical tools were used to ensure accuracy and reduce error.

E. Sampling Technique

The study selected particular residents of Ramar Village in San Fernando, Pampanga by asking the homeowner's association for the participants' addresses. The researchers thereafter conducted interviews with these residents along Pearl Street. The creek was assessed using total station surveying.

F. Sample Size

Considering the importance of sample size in the research, the researchers adopted the Raosoft Sample Size Calculator as well as the Cochran Sample Size Formula to calculate the sample size. Both the methods used in this study confirmed the validity of the sample size determination in this study [24].

Based on the computations of Raosoft Sample Size Calculator, there is a sample size of 218 out of the total population of 501 with

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95% confidence level and a 5% level of tolerance[25]. Such computations were helpful for estimating the reliability of surveys concerning the sample's reliability and the accuracy of population estimations.

The target population in the current study consisted of 501 people living in Ramar Village in San Agustin. The sample size (n) was estimated from Cochran's sample size estimation formula with a 5% margin of error, 95% confidence level and 50% variability.

$$n_0 = \frac{(1.960)^2(0.5)(0.5)}{(0.05)^2}$$

n_0 = 384.16 ≈ 385 recommended sample size

Since the total target population is known, the Modified Cochran's Formula was used to determine the adjusted sample size.

$$n = \frac{385}{1 + \frac{385-1}{501}}$$

n = 217.949 ≈ 218 sample size

Thus, a sample size of n = 218 was administered to the families residing in Ramar Village, San Agustin with the subsisted purposive sampling method stated above.

G. Field Survey and Stream Gaging

The field survey, which was done with a city engineer using total station surveying equipment, gave detailed information on the topographical aspects including cross-section of the creek. A technique known as stream gauging was employed in hydrologic and hydraulic assessment of the land surface.

H. Secondary Data

The secondary data includes maps providing information on the physical features near the creek and other conditions contributing to its instability. It encompasses maps of the Pampanga River Basin, Landslide and Flood Hazard susceptibility, Angeles City Land Use, and Five-Year Flood Hazard. Annual rainfall data and information from NSCP 2015 Edition, ACI, and DPWH Standard Specifications were also used in the study.

I. Data Analysis

The total number of respondents involved in the survey in this study was 218 residents of Ramar Village. The methodology entailed surveying a ten-meter segment of the creek utilizing total station survey equipment. With regard to the data that was collected from the survey, frequency distribution was employed to analyze the data using Microsoft Excel. HEC-HMS for hydrological modeling, HEC-RAS for hydraulic modeling, AutoCAD for site survey and mapping, and GeoStudio for geotechnical analysis. Google Earth and Google Maps were used to locate the study area and to obtain high-resolution aerial images.

J. Hydrologic Engineering Center Hydrologic Modeling System (HEC-HMS)

Hydrologic Modeling System is a software that models the interaction of precipitation with a watershed, known as HEC-HMS [26]. This was used to predict the rainfall-runoff processes and provide data about the water flow in the creek. The data produced by HEC-HMS was then used in the River Analysis System as its input value.

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

HEC-RAS calculates 1D and 2D flow, sediment transportation, and mobile bed [27]. It has the ability for simulating temporal variations in flow and offers tools for calculating the sediment transport and changes in the bed topography of channels.

L. Autodesk AutoCAD

Autodesk AutoCAD is an application that can design in both two-dimensional and three-dimensional planes, and is useful in evaluating slope data. It enables the inclusion of geological and topographic information and specifies the characteristics of soil for slope construction. AutoCAD also is frequently deployed in engineering and geotechnical sides for integration and analysis of data from different sources [28].

M. GeoStudio

GeoStudio was used to analyze slope stability by taking into account of soil properties geology and

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geometry of slopes. Failure of materials under static stress condition is determined using Mohr-Coulomb criterion which is important in geotechnical engineering [29]. It has the application of designing various structures to support several types of loading. These software programs increase the simulation, design, and analysis speed that in turn improves the assessment of engineering designs of structures.

N. Ethical Considerations

Privacy concerns taken by the researchers included anonymity, informed consent, and adherence to the Data Privacy Act of 2012. The participants were well informed of the objectives of the study, data collection methods and benefits of the study to the society. In the process of the data collection and analysis, the principles of anonymity, confidentiality and non-malice were upheld.

III. RESULTS AND DISCUSSION

This chapter primarily focuses on the comprehensive results obtained from the data collection, analysis, and interpretation using suitable software programs that are necessary for statistical analysis, visualization, and interpretation. This chapter also presents the empirical outcomes and insightful discussions mainly based on this study's objectives. The researchers also supported and contextualized the results of this study by providing insights from related literature and studies.

A. Research Questionnaire Responses

TABLE II
Tally of Survey Questionnaire Responses

Part 1: Background Information	more than 10 years	7-9 years	4-6 years	1-3 years	less than 1 year
How long have you been residing in Ramar Village?	124	43	29	18	4
How long has it been since you first became aware of soil erosion issues in your locality?	63	43	54	17	41
How long have you been experiencing soil erosion in your area?	30	66	70	27	25
Part 2: Awareness and Experience	YES		NO		
Are you aware of the issue of soil erosion in San Agustin Creek?	148		70		
Have you personally witnessed or experienced issues related to soil erosion in San Agustin Creek?	135		83		
Over the past years, have you seen any government efforts or projects implemented to address soil erosion in your community?	118		100		
Do you think having slope protection will help you address erosion concerns?	211		7		
Given the benefits of slope protection, are you willing to support the proposal design of a stone-pitched retaining wall (a type of slope protection) as a countermeasure for soil erosion in San Agustin Creek?	213		5		
Part 3: Observations of the Impact of the Erosion in the Creek Slope	Always	Often	Seldom	Rarely	Never
How often do you experience soil erosion due to intensive rainfall?	119	45	39	9	6

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How often does soil erosion cause damage to your residential property?	31	83	53	31	20
In your experience, how frequently does soil erosion contribute to soil degradation?	109	44	40	17	8
How often do local communities possess awareness of and actively participate in initiatives to alleviate the impacts of soil erosion?	27	54	58	57	22
How often does the local government actively engage in efforts to mitigate the impacts of soil erosion in San Agustin Creek?	32	63	67	50	6

Majority (98%) of the respondents are in support of the proposal design of stone-pitched retaining wall as shown in table 2. Half of the respondents (50%) answered that soil erosion always contributes to soil degradation. Some respondents answered that they have not witnessed the local government to address the issues regarding soil erosion.

B. Hydrologic Engineering CenterHydriologicModeling System (HEC-HMS)

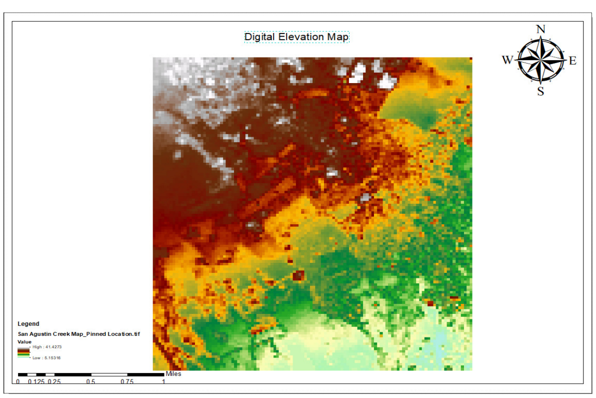

Fig.9 Digital Elevation Map

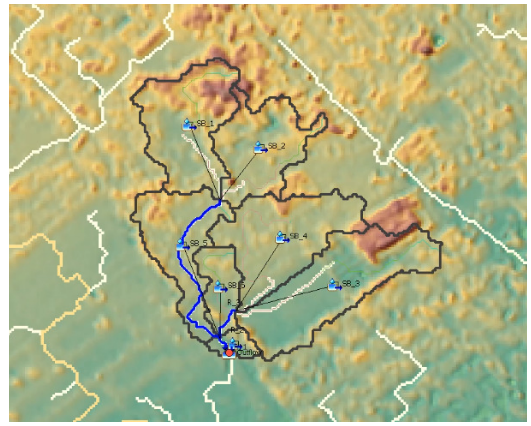

Fig.10 City of San Fernando, Pampanga Basin Model

The study utilizes the Digital Terrain Model (DTM) from NAMRIA, where the extracted topography and elevation of the channel was generated using ArcGIS. The delineation maps produced from ArcGIS was then verified through HEC-HMS, creating a Basin Model Map.

Fig.11 Final Simulation Summary of Results

The final simulation shown from the HEC-HMS in figure 11 suggests a minimal bias in predictions and acceptable variability in observed data. Thus, researchers can apply the observed flow of the model for simulating the Hydraulic Model of the creek in HEC-RAS.

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

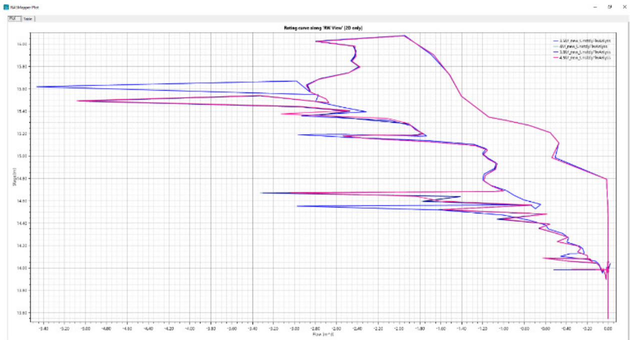

Fig. 12 Rating Curve Along 'RW View'

Figure 12 shows that when the water level is either rising or falling due to flow rate changes, the curve goes up or down. Based on the result, the 4m height has the steadiest flow among the tested heights, followed closely by 3.5m, 4.5m, and 3.8m. Generally, the Rating Curve Along 'RW View' plot clear things up on how water level reacts to flow rate varies, showing the relation between these two factors clearly.

All throughout the process, the 4m wall height consistently produced the steadiest results, with minimized total volume collection and uniform flow behavior. It also succeeded various aspects like the rating curve, volume accumulation, and water surface elevation. The 4m retaining wall height stands out as the ideal option for reducing flood risk and controlling flow due to its stability, less erosion risk, and unsteady flow patterns.

D. Autodesk AutoCAD

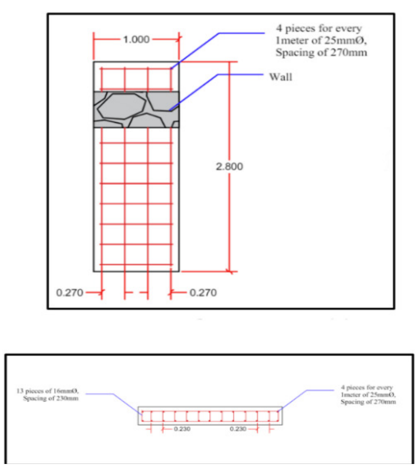

Fig. 13 Reinforcement of the Footing

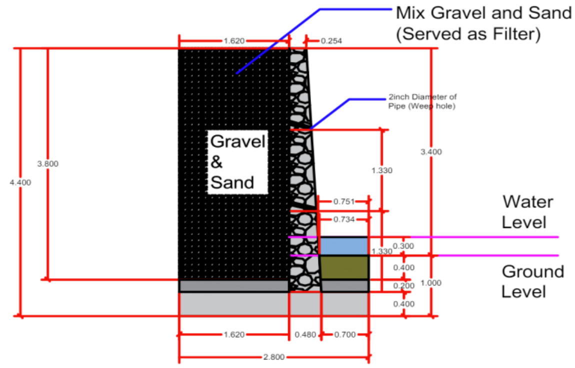

Fig. 14 Design of the Cantilever Retaining Wall

The dimensions from figure 14 are derived from the American Concrete Institute (ACI) standards. The ACI provides the standard dimensions of the footing as it has to support the weight of the wall and the soil behind it. The use of ACI standards is a common practice in the industry to guarantee that the footing can handle expected loads and pressures [30].

The design has been examined to several tests over the research process of this study to validate its safety and reliability, ensuring its suitability for construction. Then, the design of the retaining wall from AutoCAD was systematically carried out, considering multiple factors to guarantee its safety and stability. The design is both optimal and dependable, making it suitable for construction.

E. GeoStudio

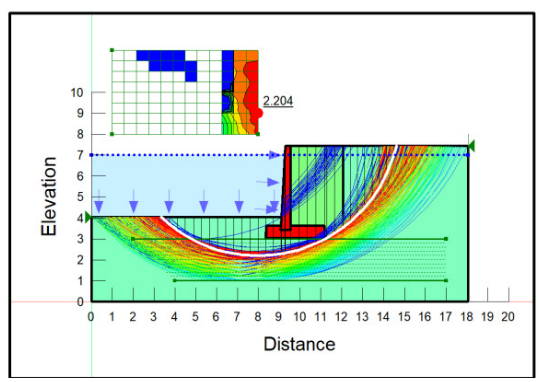

Fig. 15 Results of the Retaining Wall in GeoStudio

The result of the design that has been tested is 2.204, known as the Factor of Safety that is shown in figure 15. The Department of Public Works and Highways (DPWH)Blue Book stated that, a safe and accepted design of retaining wall should have greater than 1.2 Factor of Safety. This figure also shows all slip surfaces with different color lines that refer to sliding which may occur. All slip surfaces hold greater a value Factor of Safety than the critical slip surface; therefore, it is considered safe.

IV. CONCLUSION

Based on the survey findings, a considerable number of respondents have been aware of soil erosion concerns for at least a decade, demonstrating understanding of the challenges posed by soil erosion and a long-term involvement with the issue and according to the results gathered, there is a prevalent soil erosion caused by intense rainfall and experiences soil erosion-induced damage. With the design of stone pitched retaining wall in the creek, all these dangers and hazards will be prevented and will ensure the safety of the community specifically soil erosion. Utilization of HEC-RAS and HEC-HMS with the use of the data of San Agustin Creek gathered from local government agencies, a result of 4m retaining wall exposed height was achieved and considered the most adequate and safest height to use. With the use of AutoCAD and GeoStudio, the design parameters, specifications and results were obtained is safe as it can be concluded that the retaining wall's preliminary dimensions are adequate to resist overturning, sliding, and uplift. Result in GeoStudio shows that Factor of Safety is greater than 1.2 and considered safe and accepted. The design of the stone pitched retaining wall is considered safe and can withstand soil erosion as it follows the provisions and implementation guidelines from the National Structural Code of the Philippines (NSCP) 2015 Edition, American Concrete Institute (ACI) and the Department of Public Works and Highways (DPWH).

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