RESEARCHARTICLE OPENACCESS

A Proposed Design of Sheet Pile for the Arnedo Dike Using GEO5 at Purok 8, Sto.Tomas, SanLuis, Pampanga, Philippines

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Abstract:

This study develops a new design of sheet pile as slope protection for the Arnedo Dike with the utilization of GEO5 software after conducting an inspection to assess the current state of the dike. Observations regarding the deteriorating condition of the access route, instability of the dike crest, and damage to sheet piles highlight the pressing need for a redesign of the dike. The study evaluates four types of sheet pile configurations to determine the optimal choice in terms of effectiveness, lifespan, cost-efficiency, and life span. In the sheet pile statistical analysis, Z-type sheet pile resulted the most suitable. The design process involves analysis of different loading conditions such as earth pressure, hydrostatic pressure, surcharge, and seismic forces with the exception of hydrodynamic pressures. Furthermore, the re-design was reinforced with anchor rods spaced 1m on centre. The results showed that the design was optimal meeting all requirements including bending stress,shear stress, and slope stability with verification factors of 0.141< 1.0, 0.076 < 1.0,and 2.298 > 1.50 respectively.

Keywords—**SheetPile,SlopeProtection,Z-Type,GEO5, Slope Stability**

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I. INTRODUCTION

The Philippines is located within the Pacific Ring of Fire and the typhoon belt, making it prone to natural disasters such as earthquakes, volcanic eruptions, flooding, and droughts. Typhoons are particularly common, with an average of twenty impacting the country each year, causing significant damage. A study highlights that the province of Pampanga is especially vulnerable to natural disasters, notably flooding. Consequently, there is a critical need for protective measures like dikes to mitigate the effects of these disasters, particularly in Pampanga [1]. Flood control initiatives involve constructing earthen dikes along major rivers to safeguard people in low-lying regions, stabilize river banks, and boost agricultural productivity. This enables year-round cultivation of high-yieldrice Varieties through modern farming techniques[2].

Dikes face greater challenges as climate change is in pursuit. Climate phenomenasu chasrisingse a levels, changes in storm and rainfall patterns, and inundation scalate the susceptibility of dikes against damage, leading them to eventual failure [3].

This research aimed to create a new design for a failed section of the Arnedo Dike located at Purok8ofSto.Tomas,SanLuis,Pampanga.The36-kilometer-long dike, constructed in 1940, was built with a 50-year lifespan to serve as the primary defense against the over flowing Pampanga River[4]. The dike essentially acts as a barrier that helps manage and control the water levels in the Pampanga River, minimizing the risk of flooding during heavy rains or high water volume periods[5]However, the Arnedo dike has suffered breaches that caused significant flooding in nearby villages. In October and December2015, Typhoons Lando and Nonahit the Pampanga province, causing severe flooding. According to provincial officials, Typhoon Lando dumped 1.3 billion cubic meters of water, while Typhoon Nona produced 1.1billioncubicmeters of water. The floods damaged critical flood mitigation infrastructure, particularly the Arnedo dike [6]. Currently, the road along with the collapsed part of the dike is in accessible to four-wheeled vehicles and only open for motorcycles, bikes, and tricycles. Arnedo Dike, once the first line of defense, is no longer dependable due to extensive collapse, making it susceptible to further damage. Recent assessments reveal alarming concerns regarding slope stability and erosion susceptibility [7].

The researchers statistically studied four types of sheet pile: U-type, Z-type, Hat-type, and Straight Web for the new design of the failed section of the dike, and it was the Z-type sheet pile that stood out under four parameters: effectiveness, lifespan, availability and cost.

Fig.1ActualconditionofArnedoDikeatPurok8,Sto.Tomas,SanLuis

II. METHODS

The researchers used a quantitative research approach and simulation research (computational modelling) design to study the current condition of the Arnedo Dike's failed section and assessed the causes and issues of failure of the existing slope protection/sheet pile. The study was conducted to create a simulated necessary redesign of a slope protection of the said failed portion of the dike. In analyzing the data to be collected and the aim of a new and best-suited sheet pile design, the researchers were guided by utilizing the conceptual framework Of Input-Output-Process through the GEO5 – Geo technical Finite Element Software.

Preliminary Assessment
Conducted a preliminary assessment of the current state of the Arnedo Dike

⇩

Data Collection
Soil conditions, Pampanga River cross-section, DPWH standards and regulations

⇩

Dike Inspection & Sheet Pile Assessment
Evaluated the condition of the dike according to the DPWH Standard Checklist for Dike. Assessed the performance of different types of sheet piles.

⇩

Sheet Pile Design
Modelled and designed the dike.

Fig.2MethodologicalFrameworkofthestudy

A. *Data Collection Method*

Necessary data for the new design of the slope protection such as x-cross section of the river, water level, road width, and soil properties were gathered from Pampanga River Basin Flood Forecasting and Warning Center (PRBFFWC) and Department of Public Works and Highways (DPWH) to be applied to the modelling software – GEO5 Software. Other data like the physical condition including the length of the failed section and approximate depth of scoured soil of the dike were attained through face-to-face observation. For the collection of data for visual condition of the dike,the researchers used the DPWH's Dike Inspection Checklist to evaluate the current state of the dike physically, which was carried through face-to-face inspection.

B. *Dike Inspection Checklist*

The DPWH Region III inspection checklist analyzesdikeconditionsthroughfivesections:1)

Access, 2) Dike crest, slope, and fill, 3) Bank and erosion protection, 4) Appurtenant works, and 5) Vegetation management. The access route of the Arnedo dike has deteriorated, making it unsafe for heavy vehicles and only suitable for light ones. Slope instability and loss of surfacing material in the dike crest are due to erosion. Damaged sheet piles have exposed the bank fill to erosion, and the absence of appurtenant works like flood boxes or culverts weakens the dike's functionality. Overgrown vegetation worsens structural risks. Immediate redesign and maintenance are necessary to restore the dike's integrity and effectiveness.

C. Descriptive Statistical Analysis of Sheet Piles

This analysis evaluates different sheet pile types (U,Z,Hat, Straight Web)using means and standard deviations for key performance indicators: availability of materials, cost, effectiveness, and lifespan. The Z-Type sheet pile emerges as the best choice for the Arnedo dikes lope protection due to its highest mean scores in all metrics. Z-Type sheet piles offer superior structural performance, increased strength, stiffness, better resistance against bending and shear forces, efficient installation, minimal environmental impact, and long-term cost savings [8]. Their design ensures durability and low maintenance, making them cost-effective for various engineering projects.

D. Design of the Sheet Pile

The design of sheet pile structures involves consideration of input parameters to achieve desired outcomes. Input parameters typically include factors such as soil properties, water table level, and structural requirements. By analysing these inputs, the researchers can determine the appropriate sheet pile design to ensure structural stability.

1) ***Standards and Analysis Method:*** The analysis employed the Standard LRFD – 2003 for materials, standards, and pressure analysis. Load and Resistance Factor Design (LRFD) is a structural engineering method ensuring structures withstand various conditions, including different load levels and factors affecting integrity and functionality. LRFD-based construction codes specify required reliability levels, guiding engineers in the design process.The method enhances safety by precisely calculating dead loads with reduced safety margins while using higher safety margins for unpredictable live loads. This adaptive approach to safety factors addresses uncertainties In failure modes, often resulting in improved cost-effectiveness and efficiency in structural engineering [9].

2) ***Soil Profile:*** The soil conditions for the design of sheet piles in San Luis, Pampanga, are based on geotechnical data fromfourboreholesdrilledtoadepthof30.0meters,withsoil samplestakenatapproximately1.5-meterintervals.Laboratory results classify the soil/rock from 0m to 30.0m as silty sand (SM), which is gray, fine-grained, and non-plastic. There are two soil layers: the first is medium densesiltys and(0.33>Id < 0.67) extending to 24 meters, and the second is dense silty sand (Id > 0.67) from 24 meters to 30 meters.

3) ***External Loading Conditions:***

Earth Pressure Analysis – The predominant pressure on the structure was identified as active pressure, which is the horizontal force exerted by soil against a retaining structure. A minimum pressure criterion was set at 0.20 times the vertical stress(σz) to ensure structural integrity and safety. This criterion defines the lower limit of pressure the structure must withstand, guiding the design to maintain robustness against varying soil pressures. Minimum pressure consideration is vital for stability, accounting for changes in groundwater levels, soilcon solidation, and external loading. The Coulomb active earth pressure coefficient is influenced by factors such as wall inclination, soil- wall friction, and back fill slope. The over all lateral force computation requires considering the pressure distribution diagram on the wall surface. Passive earth pressure, which opposes failure, is calculated using the Caquot-Kerisel theory, incorporating non-planar failure surfaces depicted by a logarithmic spiral. This approach is especially crucial for passive earth pressure calculations involving soil-wall friction [10]. The triangular redistribution method was used for pressure determination, – The predominant pressure on the structure was identified as active pressure, which is the horizontal force exerted by soil against a retaining structure. A minimum pressure criterion was set at 0.20 times the vertical stress (σz) to ensure structural integrity and safety. This criterion defines the lower limit of pressure the structure must withstand, guiding the design to maintain robustness against varying soil pressures. Minimum pressure consideration is vital for stability, accounting for changes in groundwater levels, soilcon solidation,and external loading.The Coulomb active earth pressure coefficient is influenced by factors such as wall inclination, soil- wall friction, and back fill slope. The over all lateral force computation requires considering the pressure distribution diagram on the wall surface. Passive earth pressure, which opposes failure, is calculated

using the Caquot-Kerisel theory, incorporating non-planar failure surfaces depicted by a logarithmic spiral. This approach is especially crucial for passive earth pressure calculations involving soil-wall friction [10]. The triangular redistribution method was used for pressure determination, redistributing soil pressure in a triangular manner to reflect changing stress distributions. This approach is crucial for understanding load distribution and ensuring structural stability.

Water Analysis (Hydrostatic Pressure) – Hydrostatic pressure increases with depth, following the equation P=ρgh, where P is the pressure, ρ is fluid density, g is gravitational acceleration, and h is fluid column height. It is predictable and easy to measure. Water table depths were reported as 3m behind the structure and 5min front, with a minimum river water table of 7m below the dike top. The sub grade at 24.01-30.00m is dense and impermeable.

Surcharge Analysis – The weight of the road concretes lab was the considered to be acting on the surface under examination. This dead load is the permanent weight of the structure itself, including the concrete slab and any additional components. To quantify the impact of this weight on the surface, it was transformed into pressure, which is the force distributed over a given area. This pressure was denoted in units of kilo-Pascals (kPa), which is a common measure of pressure in engineering contexts. DL=(0.23m×24kN/m3)=5.52k Pa. The live load, which represents the maximum design load expected to be applied to the surface, was also taken into consideration. This ultimate limit design load accounts for the most severe loading conditions the surface is anticipated as 80kN for private and shared residential property, which is suitable for vehicular and pedestrian loafs to endure during its operational life[11].To assess its impact on the surface, this live load was also converted into kilo-Pascals (kPa). LL = 80kN / (1m × 5m) = 16 kPa.

Pseudo-Static Analysis – During an earthquake, active pressure increases while passive pressure decreases. The study uses the Mononobe-Okabe theory for calculating lateral earth pressure in cohesion less soils, excluding water influence [12]. This method, a modification of Coulomb's theory, applies a pseudostatic approach to earthquake forces. The horizontal acceleration factor is 0.1, based on Corps of Engineers' recommendations, with the vertical acceleration factor being two- thirds of the horizontal factor, [13].

Kv=0.1000×(2/3)=0.0667

III. RESULTSANDDISCUSSION

A. *Geometry of the Design*

The sheet pile design consists of a total length of 25.13 meters, with 20.13 meters embedded underground, providing crucial stability for the slope protection system. A 6-meter anchor rod, or dead man, reinforces the structure, enhancing its bending capacity. The slope of the structure is set at 1:5 (11.31°) with a 2-meter base. The Z-type sheet pile selection is determined iteratively, considering factors like cost-effectiveness and performance. The AZ 50-700 sheet pile is chosen as the most suitable option, with specific properties easily accessible within the Geo5 software.

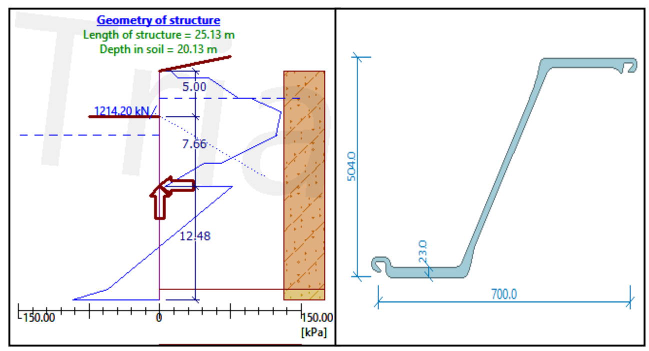

Fig.3DesignedGeometryandCross-SectionoftheStructure

B. *Internal Loads*

Resultsshowthemaximuminternalforcesper1m length: maximum bending moment of 299.78 kNm/m, minimum bending moment of 209.58 kNm/m, and maximum shear force of 0 kN/m and minimums hear force of -193.73 kN/m withits steel sectionanalyzedandverifiedaccordingtoEN1993- 1-1 (EC3) which has a partial factor of 1.0. Verification of bending and shear were both analyzedassatisfactorywith0.141<1.0and0.076< 1.0 respectively, making the design satisfactory. Additionally, the verification of the plane state of stress in bending is 0.019<1.0, which has a normal and shear stress of 54.97 MPa and 13.92 MPa respectively, while the verification of the plane state ofstressinshearis0.019<1.0,whichhas54.97MPa of normal stress and 13.92MPa of shear stress.

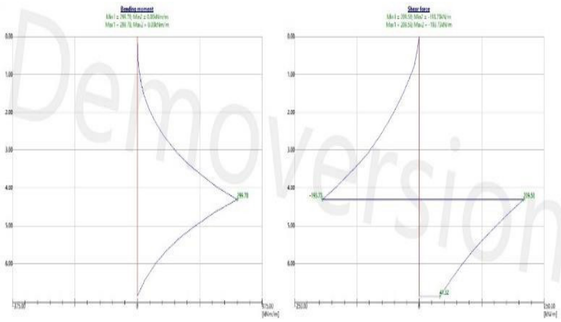

Fig.4. Structural Stresses of the Designed Sheet Pile

C. *Slope Stability Analysis*

The results illustrate the critical failure surface, assumed to be a circular slip surface. Limit equilibrium methods, like the Bishop method used here, segment the soil mass above the slip surface into blocks, where forces act on each block. The Bishop method assesses slope stability by comparing resisting forces (soils hear strength) to driving forces (slope geometry and loads),assuming circular failure surfaces. It's valued for its simplicity and minimal data requirements, providing conservative stability estimates. Factors considered include soil shear strength, slope geometry, external loads, groundwater conditions, and geological characteristics. While it's integral to software like GEO5forslopeandexcavationstabilityassessment, it may not directly address conditions like piping or liquefaction [14].

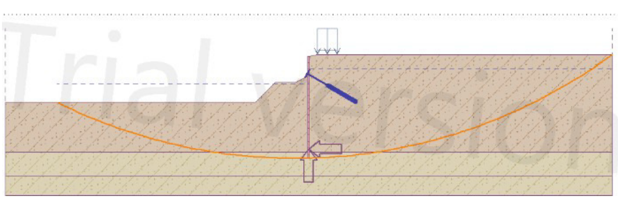

Fig.5 Slip Surface of the sheet pile design

TABLE I
SLOPE STABILITY VERIFICATION (BISHOP)

Sum of active forces	**Fa = 3626.94 kN/m**
Sum of passive forces	**Fp = 8334.30 kN/m**
Sliding Moment	**Ma= 378652.82 kNm/m**
Resisting Moment	**Mp= 565565.40 kNm/m**
Factor of Safety	2.298 >1.50
Slope Stability **ACCEPTABLE**	

IV. CONCLUSION

In light of the comprehensive analysis conducted, the subsequent conclusions sum upthe key findings and implications discovered regarding the structure and management of the Arnedo dike. The following conclusions were drawn:

1. The study, particularly the first phase – dike inspection, confirmed the dire need of a redesign of the Arnedo dike slope protection because of obvious reasons such as material deterioration primarily due to erosion. This led the community, protected by the dike, to a state of concernment as the current condition of the dike might fail completely on a following hydrological calamity.
2. This study also arrives at the conclusion that the sheet pile design, utilizing Z-type piles chosen through a comparative analysis, specifically omits consideration of hydrodynamic pressures. This limitation focuses the design criteria on accommodating hydrostatic pressures, surcharge loads, seismic forces, and both active and passive earth pressures. This approach ensures that the sheet pile design is designed to withstand these particular forces while acknowledging the exclusion of hydro dynamic pressures that might arise in different scenarios.
3. The study found that the design of the sheet pile effectively addresses various mechanical stresses, ensuring that it can withstand bending, shear, and plane stress without compromising structural integrity. Furthermore, the evaluation confirmed that the design maintains adequate slope stability, providing a reliable solution for soil retention and protection against potential land slides

or erosion. This analysis highlights the design's capability to meet the necessary engineering standards and safety requirements.

A. *Recommendation*

Based on the conclusions reached from the study, several recommendations were proposed to enhance the effectiveness and reliability of future sheet pile designs for slope protection:

1. There searchers advise that future designs for slope protection explicitly include the analysis of hydrodynamic pressures, which were omitted in the initial project. Hydrodynamic pressures, which result from water flow against the sheet pile, can significantly influence the structural integrity and stability of the slope protection system, especially since it is the Pampanga River that the Arnedo dike is protecting communities from. By incorporating these pressures into the design process, engineer scan ensure that the sheet pile structure is adequately durable to withstand these dynamic forces, reducing the risk of failure and extending the lifespan of the slope protection.
2. Consequently, it is recommended to use different method or programs other than geotechnical engineering software to simulate water flow such as computational fluid dynamics or integrated hydraulic models to resolve this study's lacking.
3. Additionally, the researchers also recommend future designs to consider different types of sheet pile and innovative sheet-piling method as this study limited the selection of type of sheet piles to use based on what are the common and available in the country as of the moment. Future designs should consider utilizing advanced or hybrid types of sheet piles to achieve stronger and more cost-effective solutions.
4. Finally, the researchers propose government bodies that supervise structures such as the Arnedo dike to promptly initiate reconstruction efforts for the dike and ensure that the design of the sheet piles aligns with broader flood management plans for the area. Coordinate with relevant agencies to integrate the proposed design into existing flood protection infrastructure effectively.

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AUTHOR'SNOTE

The authors confirmed that the paper was free of plagiarism and that the numbers in this paper regarding the rubric survey were statically formulated, solved, and reviewed by a professional statistician. The data from different institutions were treated with utmost confidentiality according to Philippines Republic Act No. 10173, or the Data Privacy Act of 2012.Authors also declare that there is no conflict of interest regarding the publication of this article.

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