# Design and Simulation of Natural-Slope Reinforcement using Non-Frame Method: A Case Study in Davao City, Philippines

Mardione Aalbert Mozo
Department of Civil Engineering, School of Engineering and Architecture, Ateneo de Davao University

Jan Earl A. Lanzar
Department of Civil Engineering, School of Engineering and Architecture, Ateneo de Davao University

Lindsay D. Sefuentes
Department of Civil Engineering, School of Engineering and Architecture, Ateneo de Davao University

Diane Therese O. Villa-Abrille
Department of Civil Engineering, School of Engineering and Architecture, Ateneo de Davao University

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# Design and Simulation of Natural-Slope Reinforcement Using Non-Frame Method: A Case Study in Davao City, Philippines

Mardione Aalbert Mozo[1], Jan Earl A. Lanzar[1], Lindsay D. Sefuentes[1], Diane Therese O. Villa-Abrille[1]
[1]Department of Civil Engineering, School of Engineering and Architecture, Ateneo de Davao University, E. Jacinto Davao City 8000, Philippines
Corresponding author email: maracmozo@addu.edu.ph

**Abstract:** *Slope failure happens when the shear resistance along the slip plane is exceeded which could result in landslides. This study aims to provide a design and simulation of natural-slope reinforcement as the solution to prevent such hazards. Using Non-Frame Method, also known as Soil Nailing method is a practical approach for it is cost efficient, environmentally friendly and does not require deforestation. Soil Nailing uses passive bars that can withstand tensile and shearing forces as well as bending moments. A geo-technical software is used to evaluate the intersection points between soil nails and possible slip surfaces that will help achieve the appropriate design. The calculated factor of safety is equivalent to 1.84 which is greater than the design factor of safety for slope stabilization used in the Philippines while using the allowable tensile strength of the full-threaded steel bar reinforcement to the slope.*

**Keywords:** Natural-Slope Reinforcement; Slope Failure; Non Frame Method; Slide2; Soil Nail

## 1. INTRODUCTION

### 1.1. Background of the study

Landslides are the movement of soil or rocks down a slope. Landslide takes place due to natural calamity or man-made activities. It is one of the phenomena that we cannot avoid because heavy rain and earthquakes are part of the works of nature. For this reason, the disturbance of soil can affect its stability wherein a single earthquake or heavy rain could add up to the possibility of a landslide [1]. The primary factors that induced these hazards are the soil moisture content and its properties that quantitatively represent its shear strength values. According to Bujang, frequent intense rainfall as such in short periods of time can cause landslides or slope failures [2].

Experts warned that the risk of landslides in the Philippines has intensified, with the statement from the Philippine government agency, Mines and Geosciences Bureau (MGB) mentioning that with the changing climate, the number of landslide occurrences has increased.

Davao City, a highly urbanized city in the Davao region, Philippines is bounded by areas with elevation of less than 200 meters above mean sea level (MAMSL) to over 1,500 MAMSL. There is also predominance of very steep slopes that cover 26% of the city's total land area [3]. On July 13, 2017, continuous rainfall triggered a minor landslide in Shrine Hills, Diversion Road in Matina Pangi, Davao City making it impassable. The Department of Public Works and Highways (DPWH)-Davao declared road closure along the Carlos P. Garcia National Highway (also known as Diversion Road) from Maa to Matina Pangi including Shrine Hills intersection from all types of vehicles. Also, after three months, slope failure occurred in the same area due to successive rainfall and earthquake. Slope failure happens when the slope collapses abruptly due to the weakening of the ground's capacity to withhold its natural surface from the influence of successive rainfall or earthquake. In a 2018 article, there are a number of processes that shear stresses can be built up in a slope [4]. Shear stress is defined as the force tending to cause deformation of a material by slippage along a plane or planes parallel to the imposed stress. It is intimately related to the downslope movement of earth materials and to earthquakes.

There are four climate types that are recognized based on the distribution of rainfall, namely; Type I which has two major season, dry (November to April) and wet season during the rest of the year, Type II has no dry season and has a pronounced rain period between December to February, Type III has no pronounced maximum rain period and with a dry season lasting only from one to three months, and lastly the Type IV which has an evenly distributed rainfall throughout the year. The climate and weather conditions of the Philippines were greatly influenced by typhoons, identifying a great portion of the rainfall, humidity and cloudiness [5].

It can be seen in Fig. 2. that Davao del Sur, province of Davao City, has the Type IV rainfall distribution.

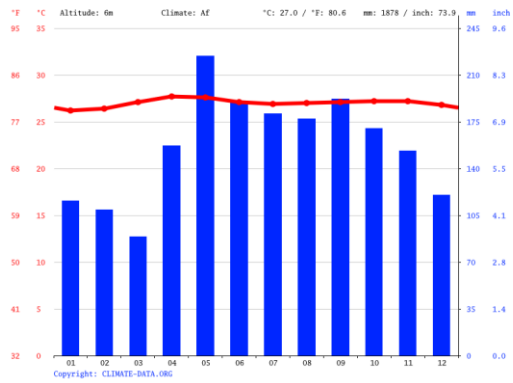


Fig. 1. Davao City Climate Graph. Weather by month.

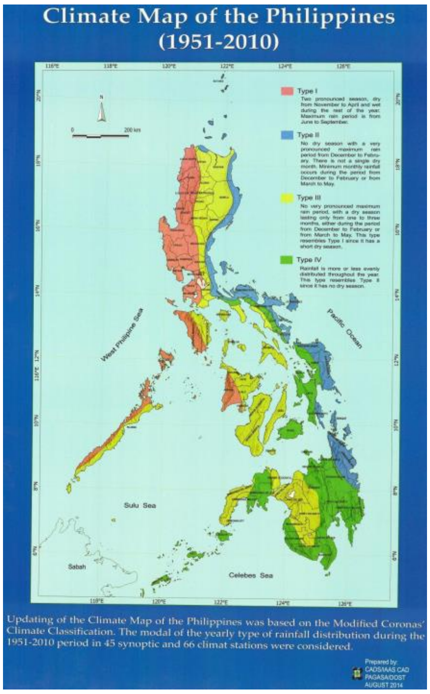


Fig. 2. Climate Map of the Philippines (1951-2010)

As landslides are usually common in some terrain areas, it is good to find new methods on how to prevent it. The landslide incident in Shrine Hills caused a huge impact to the transportation as well as the economy of Davao City. The slopes along the road or even in some steep areas were left untreated. Using Google Earth Pro, we can get the coordinates of Shrine Hills, Diversion Road, which is 7°05’31.2”N 125° 34' 09.2”E.


Fig. 3. – Photos taken in Diversion Road, Matina Pangi, Davao City, Philippines

**1.2. Statement of the problem**

The topographic area of Shrine Hills, Diversion Road has been identified as one of the danger zones prone to landslides by the Mines and Geo-Sciences Bureau (MGB). It is situated at the center of the city resulting in a major effect on lower areas since the road of Shrine Hills is vital to neighboring towns and cities. The surface area of the roadside slope is mostly covered with trees, since conventional slope reinforcement method requires clearing out of vegetation, hence unsustainable.

According to the Mines and Geosciences Bureau (MGB), Shrine Hills has been identified as unsafe in the geohazard survey. Davao City has at least five areas declared as danger zones which are prone to landslides and one of which is the area in Shrine Hills [6]. A state geologist, Beverly Brebante said that, “one of the possible causes of the landslide was the tension cracks found within the Seventh-Day Adventist church’s retreat house and adjacent properties”, the same property houses were radio stations. The City Disaster Risk Reduction Management Center (CDRRMC) added that there had been movements in the landslide-prone area that could have accredited the weakening of slope material and also the event of undercutting of the base slopes due to the development of the roadway. “The slope failure on the area may also be aggravated by the almost vertical slope as a result of the road cut”, according to the ocular inspection conducted by the MGB with the City Engineer’s Office and the Department of Works and Highways (Davao) on October 6, 2017 [7].

On October 10 of the same year, Thea Penguit, a DPWH geologist explained that the portion where the minor landslide occurred was already an escarpment or an ‘old landslide’. She said that the ground surface is already weak and made up of unconsolidated materials, and the main cause of the occurrence of landslide was the development of the upper side, adding more weight to the land [8].

Fig. 4. Landslide in Shrine Hills Davao City [9]

**1.3. Objectives of the study**

The objective of this study is to evaluate and design a slope reinforcement focusing on the roadside slope of Shrine Hills, Diversion Road, Matina Pangi, Davao City that runs to 200 meters in length.

Specifically, the study aims to:

1) Characterize and evaluate the slope of the said area.
2) Evaluate the natural slope reinforcement using the non-frame method based on slope stability through soil reinforcement friction, the normal earth pressure and materials to be used using geo-technical software.
3) Design and provide a computer simulation of the natural-slope reinforcement using a geo-technical software for slope stability program with a Soil Nail support type.

### 1.4. Significance of the study

This study is designed to investigate the effect of natural slope reinforcement using the Non-Frame method as a way of stabilizing slope and restricting the movement of unstable soil mass in the roadside area of Shrine Hills because there is a substantial need to introduce slope reinforcement to prevent the downhill movement of soil. Non-Frame method is a construction method that stabilizes steep slopes using reinforcements that do not require deforestation. This method can stabilize the forested slope structure while protecting the vegetation. One of these Non-Frame methods is the soil nail method. It is used to reinforce soil structure by increasing soil shear strength.

The success of this research study benefits the residents of Davao City, travelers, tourists as well as its economy. This would give a significant advantage to the local community because this will serve security and safety in terms of the re-occurrence of slope failure in the said area. In the year of 2007, the Mines and Geo-sciences Bureau (MGB) declared that the Davao Shrine Hills is a landslide-prone area but still the development on the slopes of Shrine Hills for high-end subdivisions continued. It was in 2013 that the City Council revised Davao City Comprehensive Land Use Plan (CLUP) and Zoning Ordinance proclaimed the area as an Urban Ecological Enhancement Sub-Zone [10].

The Office of the Sangguniang Panlungsod of Davao City amended an ordinance to adopt the City's Comprehensive Land-Use Plan (CLUP) in the year 2019-2028, amending ordinance no. 0546-13, series of 2013. Under Article V, Zone Regulations, Section 12.6.16 known as the Urban Ecological Enhancement Sub-Zone (UEES-Z). This refers to the environmentally critical areas in the urban center such as pocket ridges, sharp slopes of 18 percent or higher that pose a hazard to people but can serve as areas intended for massive greening program for ecological enhancement, for a precautionary and proactive approach to climate change adaptation and also to be a part of risk reduction management program against flooding, landslide and inundation, declared protected at all times to any development in the area and must strictly comply with the requirements [11].

Part of the UEES-Z Amendment, this zone may be turned into other allowable use or activities, such as for: Forest Zone (FZ); Nature and Ecotourism Projects; Improvement and Maintenance of all Waterway Easement; Greening Projects; Reforestation Development Projects; Residential Purposes; Subdivision Development Projects; Utilities, Transportation, and Services; and, Activities Approved under the Additional Allowable Use Mode. One of the additional regulations for activities within the Shrine Hills area is to strictly implement landslide protection and surface erosion control measures.

The proposal of the development strategy or development thrust for specific land use for the Shrine Hills area is assigned to mitigate the development of the area. Slope reinforcement is an efficient way to conserve mass-wasting resulting in major casualties. It has been used as a risk management for the downhill movement of soil. The stability of slope is quantified by the factor of safety having the ratio between the natural shear strength of the ground surface to the shear strength needed for achieving equilibrium along the potential failure surface. This could be done by either introducing a stabilizing force or limiting driving forces [12]. Slope stabilization with reinforcement increases the shear strength of the slope or reduces the sliding behavior along the slip surface of the slope with various types of structures: including retaining walls, dowels, micropile systems, anchors, soil nailing, etc. [13].

Providing natural-slope reinforcement using the Non-Frame method in the Shrine Hills area will be helpful in nature preservation while it also works as a reinforcement to stabilize the slope. Technological innovation boosts the quality of the environment by minimizing energy usage and carbon emissions by adoption and transfer of environment friendly technologies and production processes. There is evidence that technological advancement reduces $CO_2$ emissions and increases environmental standards [14].

The information resulting from this research study will also guide educators and civil/structural engineers in selecting and designing natural slope reinforcements for their learning objectives and also to be used as a future reference.

## 2. METHODOLOGY

### 2.1. Conceptual framework

In this research study on natural slope reinforcement using Non-Frame method mapping, the aim was to find the correlation of risk management for the occurrence of mass-wasting, also known as landslides (dependent variable), and a set of independent parameters such as the type of soil in the area, characterization of soil, factor of safety, pressure or the resisting force and shear stress. The independent variables in this model are the presumed cause or predictor of the dependent variable. Among the control variables are the slope length, the steepness of the slope and the Topographic Relative Moisture Index (TRMI), these elements will not change throughout the study. Any change of the control variables will invalidate the correlation between the dependent variable and independent variable [15]. However, the confounding variables are the natural disasters, particularly in the occasion of earthquakes and heavy rainfall or rainstorms. These variables can ruin the results of the study because it is a phenomenon that is inevitable.

The necessary data including the characterization and evaluation of soil as well as the topographic map will be based on the laboratory test results and site survey. The soil data that we will acquire will be input to the geo-technical software, the Slide2 Software of Rocscience, which will then analyze, evaluate, and design the efficient reinforcement of the stabilization of slope. This research paper will provide a computer simulation representing the function and application of the natural-slope reinforcement using Non-Frame method. Also, to provide a percentage error between our software design and actual computation provided by PNS-Advanced Steel Technology, Inc., a steel manufacturing company in Japan for Non-Frame method.

Soil nails are composed of steel bars, rods, cables, or tubes that are driven or are grouted into pre-drilled boreholes into the natural soil or slopes designed by fixing unstable soil into the bedrock. The three components in reinforcing are; 1) axial components within the effects of skin friction of nail and vertical settlement of fixed plate, 2) shear reinforcement occurs at slip surface, and 3) tension occurs in the connecting wires between nail heads. Non-Frame method also contributes to CO2 reduction and biodiversity conservation and also because the construction is done without modifying the slope [16].

In an overview of soil nailing for slope stabilization, soil nailing is an in-situ reinforcement technique by using passive bars that can withstand tensile forces, shearing forces and bending moments [17]. Most of the effectiveness of these resistances comes from the development of axial forces or tension forces. However, shear forces and bending moments have been assumed to provide enough contribution in providing resistance [18]. "The effect of soil nailing is to improve the stability of slope or excavation through: a) Increasing the normal force on the shear plane and hence increasing the shear resistance along slip plane in friction soil. b) Reducing the driving force along slip planes both in friction and cohesive soil" [19].

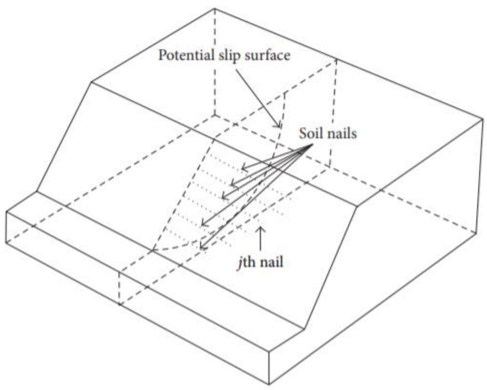


Fig. 5a. Schematic illustration of soil nails and potential slip surface in a soil-nailed slope

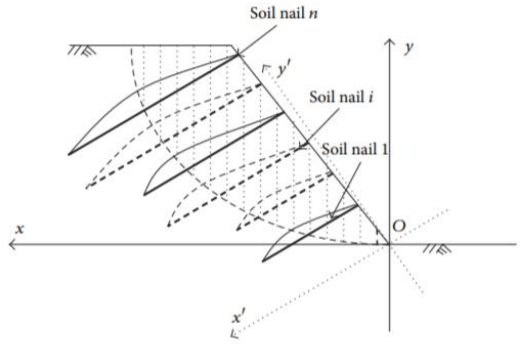


Fig. 5b. Cross section of a slope reinforced with soil nails

In this ideal model, the relative location of the soil nails and the spherical form of the possible slippery surface can be viewed as constraints. The ideal model should then be used to determine the intersection points between the soil nails and the circular possible slippery surface as shown in Fig. 5a. and Fig. 5b.

### 2.2. Materials

There are three primary materials for the Non-Frame Method construction: Soil nail, steel plate and steel cable. The soil nails, composed of steel bars, rods, and tubes that are driven into pre-drilled boreholes to stabilize the slope. Each soil nail has a base plate, which is made of steel, used to lock the soil into the slope. The steel cables are used to connect each soil nail heads to strengthen the support between soil nail and slope, and where tension forces develop.

### 2.3. Research design

A meticulous mitigation must be implemented in order to prevent soil erosion at the same time preserving the natural habitat present. There are different types of mitigations for landslides but the most efficient is the Non-Frame Method.

The Non-Frame Method is a construction method that stabilizes steep slopes using reinforcements such as soil nails that do not require deforestation.

PNS-ASTech provided us with information regarding the actual calculation to further understand how the Non-Frame method works. The construction of Non-Frame are greatly influenced depending on the ground condition, expected collapse scale, collapse mode and many other factors involved. Investigation of the soil properties like unit weight, internal friction angle and cohesion are required in the design condition. The reinforcing agent must have sufficient tensile capacity, flexural rigidity and durability to achieve the stability of the slope against failure. In order to achieve the stability of the slope, the design factor of safety must be greater than 1.5 (according to the specific standard factor of safety for slope stabilization used in the Philippines). The Factor of Safety is the ratio of the Resistance force, R to the Sliding force, P.

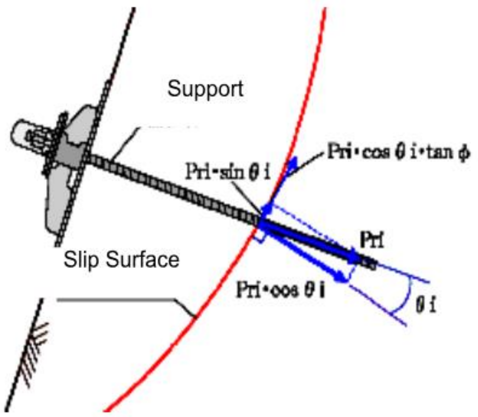


Fig. 6. Non-Frame method from PNS-ASTech

$$\frac{R}{P}=\frac{W\cos\theta\tan\phi+CL}{W\sin\theta} \qquad \text{Eq. 2.1}$$

Where;
W = Unit Weight of the Soil (kN/m3)
C = Cohesion (kN/m2)
L = Slope Length (m)
θ = Slope Angle (°)
ϕ = Internal Friction Angle (°)

To get the value of Cohesion, the safety factor is set to 1.0 for the current condition of the slope where it shows that there is a possibility of failure and no reinforcing agent constructed. The first calculation is the deterrent force which shall be calculated from the balance on the sliding surface in the design cross-section and shall satisfy the design factor of safety.

$$Tr = (FS \times P) - R \qquad \text{Eq. 2.2}$$

Where;
Tr = Required deterrent force (kN/m)
FS= Design Factor of Safety equivalent 1.5 (Standard safety factor for slope stability in the Philippines)

The placement of the reinforcements are spaced between 2 meters, vertical and horizontal as a general rule so that the capability of the reinforcements can be fully exerted. Anchorage length of the reinforcing agent is also calculated, set to satisfy the deterrent force.

$$Tr_i = \frac{Tr\times B}{n} \qquad \text{Eq. 2.3}$$

Where;
$Tr_i$ = Required deterrent force per reinforcement (kN/pc)
B = Horizontal spacing
n = number of reinforcement in a specific cross-section

This value will generate an equation to calculate the required tensile force. Once the required tensile force is obtained, the anchorage length determined by the adhesive strength between grout and the reinforcement or $Lc_a$ and also the anchorage length determined by the adhesive strength between grout and ground or $Lp_a$ are calculated.

$$Tr_i = Pr_i\sin\theta_i + Pr_i\cos\theta_i\tan\phi \qquad \text{Eq.2.4}$$

Where;
$Pr_i$ = Required tensile force
ϕ = Internal friction angle of slip surface
θ = Angle between the normal of the slip surface and the reinforcement at the intersection of the reinforcement and slip surface.

In the design of Non-Frame reinforcements, the strength of the steel bars must suffice the required tensile force and the required deterrent force. The allowable tensile load and allowable shear stress of the reinforcing agent are checked against the required tensile force and required deterrent force as follows:

$$P_a \geq Pr_i \qquad \text{Eq. 2.5}$$

$$\tau_a \geq \frac{Tr_i}{A} \qquad \text{Eq. 2.6}$$

Where;
$P_a$ = Allowable tensile load of reinforcement (kN)
$\tau_a$= Allowable shear stress of reinforcement (N/mm2)

Calculation of the reinforcement force of the immobile layer (stable layer) and moving soil mass (unstable layer) is to be considered for the stability verification of the reinforced slope. Considering the stable layer, the reinforcement force is to examine the pattern of the reinforcing agent collapses with the moving soil mass. The smaller value of bond force between grout and reinforcement, $Pb_1$ and bond force between grout and soil, $Pb_2$ is chosen for calculating the tensile force of the reinforcement of the stable layer.

$$Pb1 = L_a \times \tau_{ca} \times U_{ca} \qquad \text{Eq. 2.7}$$

$$Pb2 = \frac{L_a \times \tau_{pa} \times U_{pa}}{F_{pp}} \qquad \text{Eq. 2.8}$$

Where;
Pb = Pull-out resistance force of the stable layer (N) where
smaller value governs
$L_a$ = Depth of the stable layer
Referring to Eq. 2.4, the reinforcement force arise from the stable layer is:

$$Tb = Pb_i\sin\theta_i + Pb_i\cos\theta_i\tan\phi \qquad \text{Eq. 2.9}$$

On the other hand, consideration for the unstable layer is to examine the pattern of the slipping soil mass with the remaining reinforcement in the foundation. Same as for unstable layers, the smaller value of bond force between grout and reinforcement, $Pm_1$ and bond force between grout and soil, $Pm_2$ is chosen for calculating the tensile force of its reinforcement. Using Eq. 2.7 for $Pm_1$ and Eq. 2.8 for $Pm_2$.

$$Tm = \alpha(Pm_i\sin\theta_i + Pm_i\cos\theta_i\tan\phi) \qquad \text{Eq. 2.10}$$

Where;
Pm = Pull-out resistance force of the unstable layer (N) where smaller value governs
$L_a$ = Depth of the unstable layer

α = Coefficient of base plates and wire mesh equivalent to 9.0

The purpose of the base plates is to hold the unstable soil mass at the slope surface. It improves the capacity of the support to exert axial force and shear resistance on the slope. The connection between reinforcements is composed of wire mesh and turnbuckle. It served to withstand tensile forces from the slipping force of the soil. Specifically, the wire mesh controls the amount of ground movement, restrains the bending strain of the reinforcement and also holds the loose soil in the event of heavy rains.
For the final verification of the design of slope stability, the new deterrent force per reinforcement is chosen from the smaller value of Tb and Tm while the reinforcement per slope length, Tr is also calculated from Eq. 2.3,

$$Tr_i = Min(Tb, Tm) \quad \text{Eq. 2.11}$$

$$Tr = \frac{Tr_i \times B}{n} \quad \text{Eq. 2.12}$$

Therefore, the stability of the reinforced slope is checked using this equation:

$$\text{SAFETY FACTOR} = \frac{R + Tr}{P} \quad \text{Eq. 2.13}$$

The value of the safety factor with reinforcement must be equal or greater than the design safety factor to satisfy the slope stabilization. Otherwise, there is a need to change the reinforcement arrangement.

### 2.4. Research simulation

The soil sample data identified will then be used in the software for the simulation of the soil strength. Slide2 is a Rocscience software that helps in the technical design for slope stability infused with reinforcements in the structure of the slope to reach a certain safety factor. Slide2 analyzes the stability of slip surfaces using vertical slice or non-vertical slice limit equilibrium approaches. It is possible to evaluate individual slip surfaces, or search methods which may be extended to find the critical slip surface for a given slope. This design software enables to design what type of reinforcement will be efficiently needed to a certain type of slope condition.
As designated data had been provided from three different trials, Slide2 will then analyze the stability of the slope showing what dimensions of soil nail needed for in order to reach a certain factor of safety.
When all data is gathered the next thing to do is to design and plan the network. The software evaluates alternate design scenarios to ensure that the subsurface data used were efficient for a desired project. There are different types of slope reinforcement that can be modeled in Slide2, including geo-textiles, drilled or launched soil nails, tiebacks, rock bolts, piles and micro piles. We will use the Soil Nail support type with the properties from the actual calculation provided by PNS-ASTech.

Table .1 Reinforcement Properties from PNS-ASTech

| Reinforcement Specification | Units | |
|---|---|---|
| Diameter | 22 | mm |
| Cross-sectional Area | 387 | mm2 |
| Grade | SD490 | |
| Standard | JIS | |
| Allowable Tensile force | 96.8 | kN |
| Yield Tensile force | 190 | kN |
| Allowable Yield stress | 160 | N/mm2 |
| Drilling diameter | 70 | mm |

Since the program of Slide2 software differs from the values calculated from the PNS-ASTech, we will make three different trials in designing the non-frame method using Slide2 software. The results of the trials will be evaluated based on the guideline and specification of PNS-ASTech. We will choose the best design from the different trials considering the safety factor and also if the application of the reinforcement satisfies the stability of the slope.

## 3. RESULTS AND CONCLUSIONS

The structures on the upper vicinity of Shrine Hills added more load on the ground surface which developed localized weakness and overstress. The characterization and evaluation of the roadside-slope of the project area is suitable for introducing a countermeasure for the re-occurrence of landslides since the lower slopes will eventually become steeper when heavy rainfall happens and the ground surface will become weaker as time goes on. We provided three different trials to 11 stations with soil nail support. With variation of the angle of soil nail reinforcement from the horizontal of both lower and upper slopes, tensile capacity and also the length of the soil nail reinforcements.
Since the slope cross-section is composed of two different adjacent slope angles, we used the minimum accepted value of factor of safety equivalent to 1.84 which is the calculated design of the lower slope, based on the manual computation of PNS-ASTech. Experimental value in the x-axis refers to the results from the value of the design safety factor from Slide2 software while the y-axis are the stations of the 200 meter roadside-slope.

### 3.1. Trial 1

For Trial 1, we used a -35° angle of soil nails from the horizontal and 3.5 meter length for station 0+00 to station 01+40 and 4.5 meter length for station 01+60 to station

02+00. Although some stations satisfy the design safety factor. The tensile strength of the soil nails exerted its full capacity but the soil nails did not reach the stable layer at critical points, making it ineffective and useless. Trial 1 does not suffice the design for Non-Frame method. The percentage error is constantly large at station 0+00 to 0+80 and fluctuates at station 1+00 to 2+00 between the Slide2 design and the actual computation of the Non-Frame method. This explains that because the reinforcement length used is way shorter than the calculated reinforcement length.

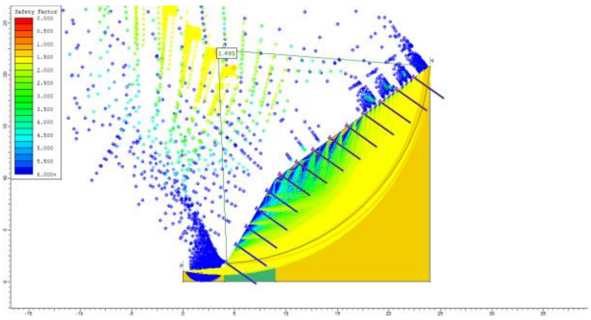

Fig. 7. Trial 1 of Slide2 at STA 0+00

### 3.2. Trial 2

Changing the values of the angle of soil nails from the horizontal to -40° for lower slopes and -15° for the upper slopes and also the length of the soil nails with varying length based on assumption to sort out if this length will bear in Trial 2. The lower slope reinforcements are injected to the stable layer, however, the upper slope reinforcements still did not reach the stable layer. This design will only be good for the lower slopes but eventually, the reinforcements in the upper slopes will not take effect plus it will only add more load to the upper slope which will still lead to failure. The tensile strength of the soil nails also reached its yield point. The value of the factor of safety varies largely between stations and also the percentage error greatly fluctuates in this trial, since we only assumed the reinforcement length at different stations. Therefore, trial 2 is not successful.

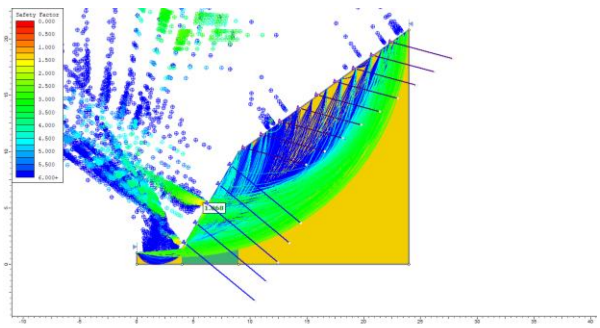

Fig. 8. Trial 2 of Slide2 at STA 0+00

### 3.3. Trial 3

In Trial 3, we used a -10° and -30°angle of soil nails from the horizontal for lower and upper slopes and a uniform 8-meter length soil nail for both slope reinforcements. This length is based on the manual calculation from PNS-ASTech considering the larger value of anchorage length of the reinforcing member for both lower and upper slopes. The tensile strength of the reinforcement used in this trial is the allowable tensile force equivalent to 96.8 kN. The soil nail reinforcements hold the unstable soil layer of the slope and also, the value of Slide2 design safety factor exceeds the minimum design safety factor of 1.5 while having its permissible load capacity.

In summary of percentage errors, Trial 1 is consistently high for all stations, Trial 2 varies differently for all stations, Trial 3 is appreciatively consistent to have a lower percentage error than to all trials.

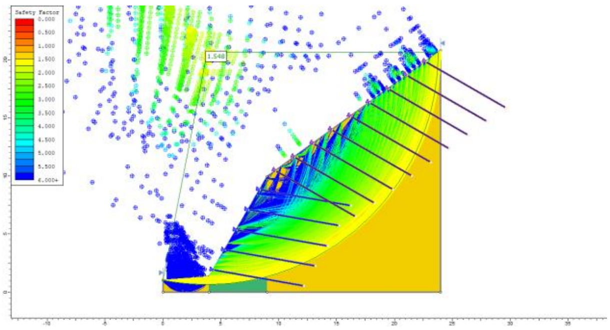

Fig. 9. Trial 3 of Slide2 at STA 0+00

We conclude that Trial 3 is applicable as a natural-slope reinforcement to the project area because the reinforcements are projected to the stable layer while using the allowable tensile strength of the full-threaded 22 mm steel bar. The angle of soil nails from the horizontal are smaller which entails that the soil nails intersect normally to the slip surface at a relatively large angle. In this case, the tensile strength of the reinforcement is developed and can be utilized to resist slippage or slope failure considering an allowable tensile force of the reinforcement. Designing for slope stability program in Slide2 software specifically for a soil nail support type, the variables such as length, angle from horizontal and tensile strength of the reinforcement makes a huge effect in achieving a successful design and these factors also influence the increase or decrease of the percentage error between experimental value and accepted value from PNS-ASTech. Larger angles of soil nail from horizontal are highly discouraged because the reinforcement will intersect the potential failure surface at a small angle exerting little tensile stress from the soil nails.

With the use of geo-technical software, it is easier to evaluate and design a slope reinforcement in a specific project. From the actual computation of the Non-Frame Method of PNS-ASTech, the simulation design of the two different adjacent slope angles from Slide2 were adequate. Having a safety factor of 1.84 for the lower slope and 2.24 for the upper slope. Both values satisfy the 1.5 design factor of safety for slope stabilization used in the Philippines.

Data gathering such as soil and slope properties are necessary, therefore it is best to gather actual soil samples and perform actual site surveys in order to provide the accurate information needed. Slope angle with less than 30° has no risk or event of failure and no need for reinforcements. With steeper slopes, a larger value of the reinforcement angle from the horizontal must be considered respectively. There are instances that if the slope length is very long, the design length of the soil nails must be longer as well in order to suffice the stability.

Since there are already non-frame method projects implemented here in the Philippines, it is easier and accessible to administer. For construction and installation purposes of non-frame method at the roadside-slope of Shrine Hills in Diversion Road, this research proposal is open for recognition to serve as a prevention for the risk of recurrence of slope failure at the roadside-slope area. Additionally, the data used are ostensible for the objective of this study only and this paper is open for verification.

## 4. REFERENCES


[1] National Geographic Society. (2012). Landslide. Available: https://www.nationalgeographic.org/encyclopedia/landslide/

[2,14] IEICES website: http://www.tj.kyushu-u.ac.jp/en/igses/ieices/ (accessed 01.07.24)

[3,11] City Government of Davao. Comprehensive Land Use Plan 2019-2028 Vol. 1. The Planning Process. 2013

[4] Kormanyos, C., & Kormanyos, C. (2018). Additional Reading. Real-Time C++,357–360. Available: https://doi.org/10.1007/978-3-662-56718-0_18

[5] Climate of the Philippines. Available: http://bagong.pagasa.dost.gov.ph/information/climate-philippines

[6] Cayon, M. (2019). Davao City Urges Evacuation of Families Living On Steep Slopes. Available: https://businessmirror.com.ph/2019/11/11/davao-city-urges-evacuation-of-families-living-on-steep-slopes/

[7] Manlupig, K. (n.d.). Grief. Available: https://www.rappler.com/newsbreak/iq/list-deadly-landslides-philippines

[8] Tangcawan, A. (n.d.). Search and Rescue. Available: https://www.rappler.com/newsbreak/iq/list-deadly-landslides-philippines

[9] Revita, J. (2017). Landslide closes Davao Diversion Road. Available: https://www.sunstar.com.ph/article/152983

[10] Directo, J. (n.d.).Guinsaugon. Available: https://www.rappler.com/newsbreak/iq/list-deadly-landslides-philippines

[12] Yang, G., Zhong, Z., Zhang, Y., & Fu, X. (2015). Optimal design of anchor cables for slope reinforcement based on stress and displacement fields. Journal of Rock Mechanics and Geotechnical Engineering, 7(4), 411–420. Available: https://doi.org/10.1016/j.jrmge.2015.04.004

[13] Dong, J. H., & Zhu, Y. P. (2008). Seismic behavior of a slope protected by a soil nailing retaining wall during an earthquake. Chongqing Jianzhu Daxue Xuebao/Journal of Chongqing Jianzhu University, 30(6), 90–95.

[15] Control Variable. Available: https://en.m.wikipedia.org/wiki/

[16] Trees are cut down (n.d.). About Non-Frame construction method. Available: https://www.non-frame.com/about/index.html

[17] Budania, R., & Arora, R. P. (2016). Soil Nailing for Slope Stabilization : An Overview. International Journal of Engineering and Computing, 6(12), 3877–3882.

[18] Dey, A. (2015). Issues and Aspects of Soil Nailing.

[19] Villalonga, R. (2002). Stabilization of slopes. Technology, 239, 235–239. Available: http://onlinepubs.trb.org/Onlinepubs/sr/sr247/sr247-017.pdf