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The Study of Best Slope Protection Method due to Slope Failure at Section 6 for East Cost Rail Link (ECRL)

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Abstract

Slope protection is a critical aspect of land and landform management, especially in steep areas that can cause collapse and endanger lives and infrastructure. Normally, slope protection used is close turfing and hydroseeding due to its cost effective and less construction time. However, the occurrence of slope erosion in the ECRL project where it involves the failure of the hydroseeding method as slope protection at CH408-CH409. Therefore, this study focuses on the settlement behaviour comparison between the herringbone and hydroseeding methods as slope protection by utilizing instrumentation and monitoring on the slope. The aim for this study is to study better slope stability in line with their purpose as slope protection methods within CH408-CH409 in the ECRL projects. Inclinometer has been chosen as instrument to conduct a monitoring on slope displacement on CH408 until CH409. The monitoring period began with the occurrence of slope failure and continued until the implementation of a new slope protection method, the herringbone technique. The results of this study demonstrate that the herringbone method outperforms the hydroseeding method for slope protection. The rate of slope displacement for both hydroseeding and herringbone methods was recorded to compare their stability as slope protection techniques. The study identifies the appropriate instrumentation and monitoring methods for assessing slope displacement between hydroseeding and herringbone techniques. By analyzing the rate of slope displacement using data from inclinometer instrumentation, the study provides clear insights into the effectiveness of each method. The comparative analysis based on instrumentation and monitoring readings reveals the relative performance of hydroseeding and herringbone in controlling slope displacement. The findings of this study will contribute to the construction industry, particularly in railway projects, where it can be applied to the construction of subgrades involving cutting and filling embankments.

1. Introduction

ECRL rail network will bridge the East Coast and the West Coast of Peninsular Malaysia by connecting Kota Bharu in Kelantan to Port Klang in Selangor [1]. The 665 km East Coast Rail Link (ECRL) will traverse the East Coast states of Kelantan, Terengganu, and Pahang before linking the Klang Valley on the West Coast of Peninsular Malaysia. Slope protection in the context of railways refers to measures taken to stabilize and protect the slopes or embankments along the railway tracks. These slopes can be susceptible to erosion, landslides, or other natural forces that can compromise the stability of the railway infrastructure. The method statement for East Coast Rail Link (ECRL) slope protection outlines five approaches for safeguarding slopes. Herringbone, Mass Concrete Retaining Walls, Hydroseeding, Soil Nailing and Rock Bolt Frame Beam structure. However, there is slope failure at CH408-CH409 due to heavy rainfall. It is found that the soil quality of grade one until four slopes is poor, which is gray and black peat soil. The soil quality is soft and becomes soft when exposed to water [2]. Malaysia Rail Link as an asset owner for ECRL project requested China Communications Construction Company to justify the existing slope protection design following that erosion and redesign, removing existing slope protection, and installing and come out with improved slope protection. As required, the contractor team has developed a new slope protection method called herringbone, which they claim can protect the slope even during heavy rain due to its design.

The study aims to identify the most suitable instrumentation and monitoring methods for assessing slope displacement between hydroseeding and herringbone techniques. By utilizing inclinometer data, the study will analyze the rate of slope displacement to understand the effectiveness of each method. Additionally, the research will compare the performance of hydroseeding and herringbone based on the collected instrumentation and monitoring readings, providing insights into their relative stability and efficiency as slope protection methods. Therefore, four points on Right Hand Side along the chainages have been selected, namely CH408+130, CH408+330, CH408+430 and CH408+530. The purpose of selecting these points is to study the rate of slope movement after the failure of the hydroseeding slope protection method until the herringbone is constructed as the new slope protection in that area. The method for data collection is by doing a literature review, reverse engineering on existing slope protection and soil investigation reviews. This project will be expected to find concrete retaining wall is the best slope protection for all soil conditions based on its strength. It is important to have suitable slope protection to ensure the safety and functionality of the railway system.

2. Slope Protection

Slope protection serves a crucial function in environmental and civil engineering by preventing soil erosion, landslides, and rock falls [3]. The primary purpose of slope protection is to maintain the natural and engineered slopes' stability, ensuring the safety of infrastructure and human lives. It also plays a vital role in preserving the environment by preventing the loss of soil and vegetation. Effective slope protection methods can mitigate the impact of natural disasters, such as heavy rainfall or earthquakes which can trigger slope failures. By stabilizing the terrain, slope protection techniques also help maintain the fertility of the soil, which is essential for agriculture and natural vegetation. There are various types of slope protection used on the subgrade along section 6. The track alignment in section 6 is 144.1km long which starts from CH313+900 and ends at CH458+000. Each slope protection used depends on the land investigation that has been carried out in the area along with the cost-benefit analysis that has been studied. This research only focusses on the two types of slope protection.

2.1 Hydroseeding

Hydroseeding is same as open turfing except that clumps or grass is placed near to each other's in most instances, covering the entire exposed slope. It is an effective method for surface soil erosion control where a rapid establishment of dense grass cover is required.

Hydroseeding, a commonly used slope protection method, functions effectively to mitigate erosion by forming a protective layer of vegetation on the slope surface [4]. The vegetation growth from the seeds in the mixture further reinforces the soil, as the developing roots bind the soil together, enhancing slope stability. This process involves spraying a mixture of seeds, mulch, fertilizer, and stabilizing agents onto the exposed soil surface using a high-pressure hose system. The hydroseeding mixture creates a stable matrix that binds soil particles together, reducing the risk of erosion caused by rainfall and surface runoff [5]. The seeds within the mixture germinate and establish vegetation, further stabilizing the slope by enhancing root penetration and soil cohesion. Additionally, the mulch and stabilizing agents help retain moisture, promote seed germination, and prevent soil erosion. This comprehensive approach not only provides immediate erosion control but also promotes long-term slope stability and ecological restoration, as evidenced by the findings of various field studies [6].

Fig. 1 *Hydroseeding Slope Protection*

Fig **1** shows how hydroseeding was constructed on ECRL project. Hydroseeding is a multifaceted technique that offers an integrated approach to slope protection. The process begins with soil stabilization, where the mulch in the hydroseeding slurry forms a protective layer on the slope, mitigating the impact of raindrops that can displace soil particles and initiate erosion. This is complemented by the moisture retention capabilities of the mulch, which is essential for seed germination and growth, particularly on slopes where water runoff is prevalent. The advantage of using hydroseeding is that it is cheaper and easy to handle. However, to maximize the effect of ecological slope protection, ecological slope protection should be the guideline of the slope protection while the engineering slope protection should be taken as the subsidy [7].

2.2 Herringbone

Herringbone-shape soil protection refers to a specific pattern used for stabilizing hillsides or slopes. It resembles the bones of a fish with a zigzag arrangement. Its function as stabilization by distributing loads evenly, herringbone formwork prevents slope movement and minimizes the risk of landslides. It also helps control soil erosion caused by rainfall and runoff and enhance the visual appeal of the slope.

This slope protection method applies to the soil and fully weathered rock slope surface to allow the groundwater to drain out and hence reduce the water pressure to the slope. Fig **2** below shows the illustration from the front view of Herringbone Shape Slope Protection.

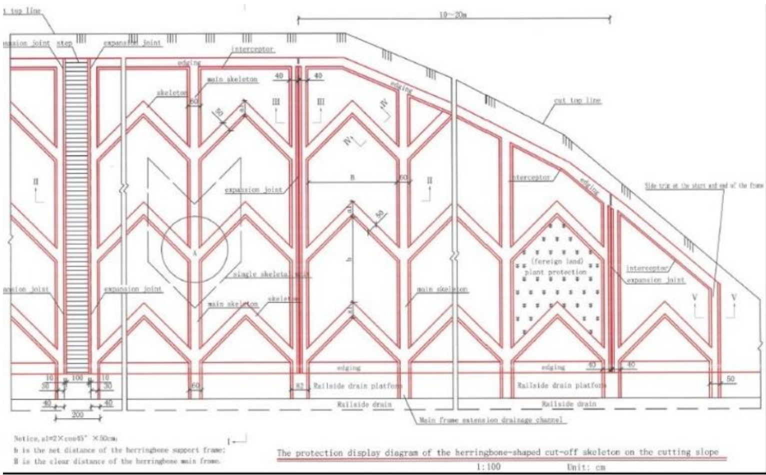


Fig.2 *Herringbone Slope Protection*

Furthermore, the herringbone shape promotes vegetation establishment and root penetration, further enhancing slope stability and erosion control. **T**he intersecting trenches of the herringbone design create microsites for seed retention and germination, facilitating the establishment of vegetation cover on bare slopes [8]. As vegetation grows within the trenches, its root systems penetrate the soil, binding soil particles together and reinforcing slope stability. This process not only reduces surface erosion but also enhances the overall resilience of the slope to external disturbances, such as heavy rainfall or wind erosion. Moreover, the presence of vegetation provides additional surface roughness, which dissipates the energy of flowing water and reduces soil erosion rates, ultimately contributing to the long-term sustainability of slope protection efforts.

2.3 Information about Slope Failure on CH408-CH409

According to constructing drawing for ECRL project for section that is located between CH408+275 and CH408+550, the right-side slope in this section has 3 to 5 levels. The height of the slope varies between 15 to 23 meters. The slope rate for the first three levels of the slope (CH408+275 to CH408+550) is given as 1:1.5. This means for every 1 unit of horizontal distance, there is a vertical rise of 1.5 units. Hydroseeding method has been applied on the slope to protect it. This is a common practice to prevent erosion and stabilize the soil on slopes.

The geological information indicates the layers of soil or rock encountered in this section. The aiming stratums (strata or layers) are described successively as follows the first layer is clay, characterized as stiff, with a normal stress (σ_0) of 150 kPa, and it is classified as type II. The second layer is 9(25) silty clays, characterized as very stiff, with a normal stress (σ_0) of 180 kPa, and it is also classified as type II.

Based on the Non-compliance Report related to the slope slip on CH408-CH409, the cause of the slope slip is the continuous seepage of groundwater from the cut slope eventually eroding the slope in the area. The survival rate of grass planting on slopes is low because the original soil is rocky. The roots of the plants used cannot creep into the slope. There are also areas where the soil is soft and becomes soft when exposed to water [18]. Fig 3 shows the situation of the slope slippage at CH408.

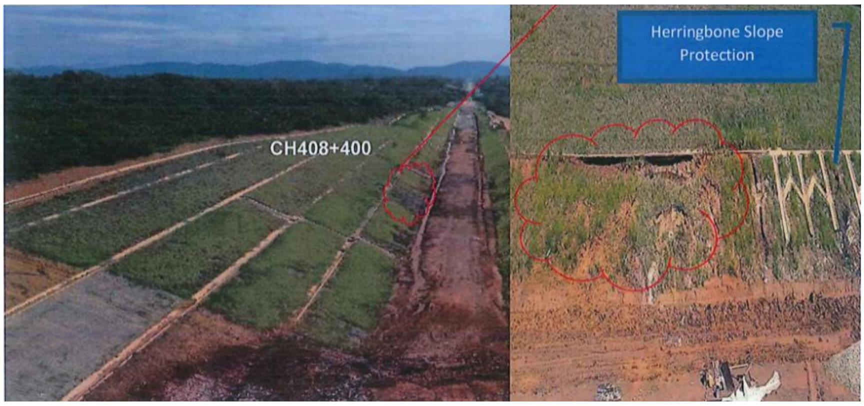


Fig. 3 *Slope slippage*

2.4 Instrumentation and Monitoring in Slope Protection

Principally where movement is occurring or where a major work would become endangered by a slope failure, instrumentation is required to monitor changing conditions and provide early warning of impending failure [9]. In unstable or moving slope, installment is installed to locate the failure surface and study the behavior measurement for slope movements. Instrumentation plays an important role in forensic geotechnical engineering [10]. The importance of doing instrumentation and monitoring in slope stability is to allow monitor changing conditions in slope and give early warning of impending failure [11][12]. From the live event of The Nicoll Highway Collapse in Singapore in 2004, caused by the failure of a retaining wall during subway construction, highlighted the crucial role of instrumentation and monitoring [13]. Recorded data on the deflection of the retaining wall provided vital insights. If the retaining wall had failed without this monitored data revealing the different performances between the walls, determining the cause would have required much more extensive work.

Instrumentation provides a range of options, from inexpensive short-term solutions to more costly long-term monitoring programs [14]. It also helps make informed decisions while managing the cost of a project. There are various types of slope protection, including reinforced concrete retaining walls, hydroseeding and skeleton herringbone. The choice of slope protection depends on the size of the slope, cost effectiveness and soil movement behavior. Therefore, conducting instrumentation and monitoring can save costs while ensuring the quality and functionality of slope protection.

2.4.1 Deep settlement gauge

Deep settlement gauges are used to monitor the settlement of various sub-layers of soil [15]. These gauges are installed in a borehole with necessary friction reducers. The two major types are the screw plate deep settlement gauge, and the Borros anchor deep settlement gauge. These instruments are essential for assessing potential problems and managing risks associated with ground displacement in surface or underground constructions.

They are crucial in geotechnical and civil engineering for monitoring soil behaviour under structures such as buildings, embankments, dams, and other infrastructure projects.

The suitability of deep settlement gauges depends on the type of soil and the nature of the construction project. For instance, sandy soils typically exhibit immediate settlement characteristics and consolidate very quickly, making them less suitable for monitoring with settlement gauges. Conversely, clayey soils exhibit complex but well-understood consolidation behaviour, making them more suitable for monitoring with these gauges. Organic soils, which contain relatively large amounts of non-soil materials, are generally treated as a distinct category

2.4.2 Inclinometer

An inclinometer (also known as a clinometer) is a sensor used to measure the magnitude of inclination angles or deformations in structures. It provides information about slopes, tilts, elevations, or depressions concerning gravity. An inclinometer is a high-precision instrument used to detect displacement along sliding zones [8][16][17][13][19]. Inclinometers are essential tools for assessing slope gradients and ground movement, suitable for both vertical and horizontal installations. When installed vertically, inclinometers monitor cut slopes, shoring walls, and embankments, such as tracking the stability of soil above tunneling sites. When installed horizontally, they measure settlement in soil or detect structural deformation.

The probe consists of at least one force-balanced accelerometer that measures the inclination of the casing relative to the vertical direction. Commonly used inclinometers feature two accelerometers and employ a biaxial probe. The probe is equipped with two wheels positioned at a fixed distance of 0.5 meters apart, allowing the device to move within specific grooves in the casing. One accelerometer is aligned parallel to the wheels, while the other is aligned perpendicular to them. These accelerometers measure the tilt of the casing with respect to the vertical direction in both horizontal directions. Fig **4** shows the typical layout of a probe inclinometer, along with the attached wheels and the measurement directions (A- and B- axes),

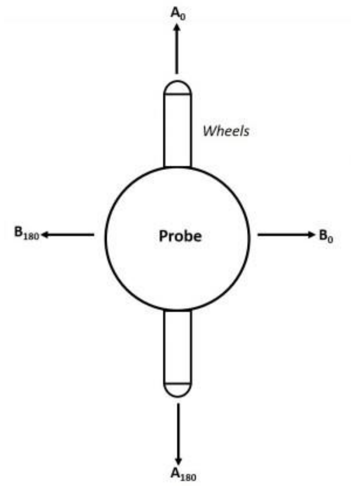


Fig. 4 *Orientation of the probe within the casing of a typical inclinometer and the directions of the horizontal movement measurements (A and B)*

3. METHODOLOGY

This research endeavors to assess the strength and stability of slope protection through a comprehensive methodology involving site assessment and instrument-based monitoring. The site assessment, encompassing soil properties, slope geometry, and existing conditions, serves to pinpoint the root causes of slope failure and contributing factors. A detailed topographic survey is conducted to map terrain features, including slope dimensions, drainage patterns, gradients, and contours, guided by construction drawings provided by the main contractor, China Communication Construction Company (CCCC).

Field inspections revealed significant signs of instability such as deep cracks and erosion, with groundwater seepage observed at multiple points. Soil analysis confirmed that the slope predominantly consists of clay soil, which is compact yet prone to substantial volume changes with moisture variations. This soil, characterized by low density and shear strength, is highly susceptible to landslides, particularly when saturated. Additionally, weather conditions, particularly rainfall and temperature fluctuations, are monitored to understand their impact on soil structure and slope stability. The chosen instrument for slope movement monitoring is the inclinometer. Inclinometers serve as indispensable tools for monitoring slope movement due to their unique combination of continuous monitoring capabilities, versatility, and precision measurement. Their ability to continuously track changes in slope angles over time enables the detection of subtle movements or deformations that may occur gradually, as well as sudden accelerations indicative of imminent instability. This continuous monitoring aspect ensures that slope behaviour is closely observed, and any emerging issues are promptly identified, allowing for timely intervention to mitigate potential hazards. Environments, including natural slopes, engineered structures, and embankments. They can be installed at multiple depths and orientations to monitor different layers of the slope, providing comprehensive insights into slope behaviour and stability. This versatility allows inclinometers to be adapted to a wide range of monitoring scenarios, making them invaluable tools for assessing slope stability and implementing effective risk management strategies.

The inclinometer deployed at four designated points along the Right-Hand Side at specific chainages (CH408+130, CH408+330, CH408+430, and CH408+530). The purpose of selecting these points is to study the rate of slope movement after the failure of the hydroseeding slope protection method, which has been replaced by the herringbone method. Data collection occurs weekly over an extended period from the initial slope failure on November 7, 2022, to December 12, 2023, following the implementation of the herringbone slope protection method. To obtain data on slope behaviours at that time, a data analysis from past slope monitoring was used to gather data for comparison. For hydroseeding, only slope movement records within a 2-month period, from October 7th to November 11th, 2022, were considered. The data was obtained from past monitoring records conducted by CCCC because slope protection erosion had occurred before this study was carried out. Similarly, for the herringbone method, only 2 months were initially required to collect data for pursuing this research objective. However, due to weather factors that could affect soil structure and the findings of this study, the monitoring period for herringbone as a slope protection method was extended to 8 months, from April 7th, 2023, to December 15th, 2023 and the data was collected independently through instrumentation and monitoring at four chosen points. The collected data are organized into Table 1, facilitating the analysis of slope movement dynamics and the assessment of slope protection effectiveness. The data contain element like time and coordinates. If erosion or slope movement occur the different coordinates between times will conduct to study the rate of slope movement. The data from the table will then be extracted to create a graph that illustrates slope displacement over time. This collected data will enable the study of slope displacement and provide a comparison of slope behavior with two different slope protection methods applied to the same location and soil conditions. Additionally, this data will help determine which slope protection method is more effective for the soil conditions in that area and will facilitate an analysis of how the slope displacement occurs.

Table 1 *Example of Construct Table for Slope Monitoring*

Chainage:					CH408+130 ~ CH408+530 Right Side		
Date and Time		Time interval (d)	Coordinates		Different between last time (mm)	Rate (mm/d)	Total Difference (mm)
YYYY/MM/DD	Time (24Hrs)		N	E			

4. Result Analysis

In this chapter, better slope protection is measured based on its stability due to conducted instrumentation and monitoring testing. The inclinometer has been chosen as instrument to conduct a monitoring on slope displacement for two types of slope protection which is Hydroseeding and Herringbone. The monitoring is being conducted on the same slope to determine which slope protection is more stable. All data obtained through the monitoring is collected and interpreted in term difference slope displacement between several dates. The results are then illustrated and plotted in the graph for data analysis.

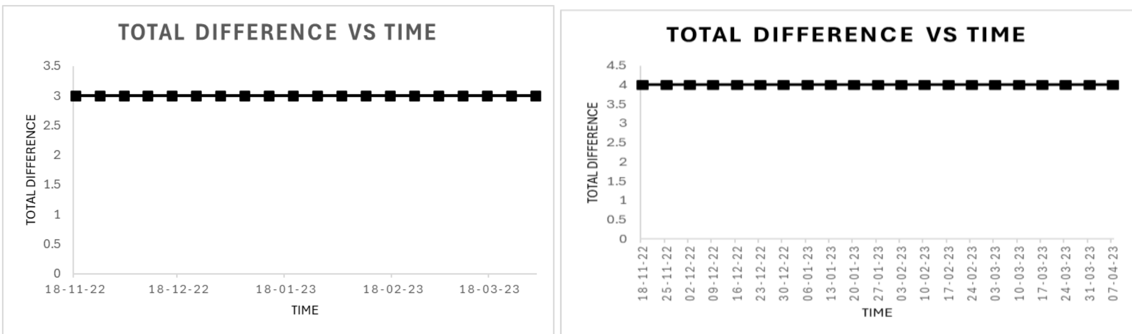
4.1 Instrumentation and Monitoring in Slope Protection

The instrumentation and monitoring were conducted using an inclinometer to study slope displacement between two types of slope protection. This monitoring was carried out over three different time periods.
First, during the initial 28 days from 7th October 2022 to 11th November 2022, the slope protection method used was hydroseeding. The study continued from 18th November 2022 to 14th April 2023, during which slope cutting was performed and the original slope protection was replaced with the herringbone method. The final monitoring period was from 21st April 2023 to 15th December 2023, during which the herringbone slope protection was completed, marking the end of the slope displacement monitoring for this research study.

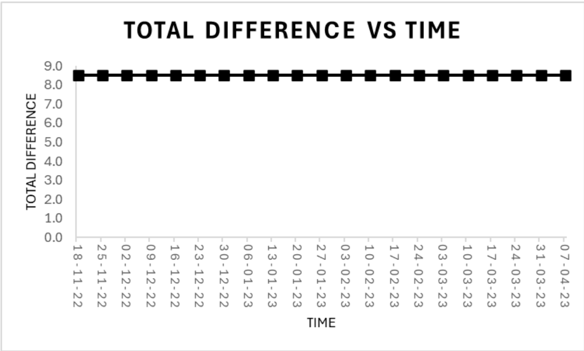
Instrumentation and monitoring were conducted at the same time, around 4 p.m., to ensure that weather conditions did not affect the study's findings. Slope displacement monitoring was performed at four chainage points involved in the failure of the hydroseeding slope protection displacement between several dates. The results are then illustrated and plotted in the graph for data analysis.

a) *b)* *c)* *d)*

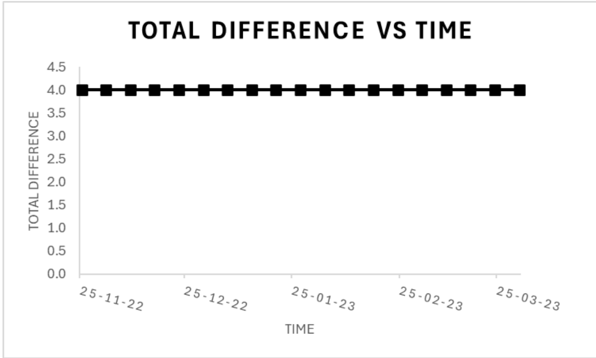
Fig 4: *Graph of total difference slope displacement for Hydroseeding for a) CH408+130, b) CH408+330, c) CH408+430 and d) CH408+530*



a) *b)*

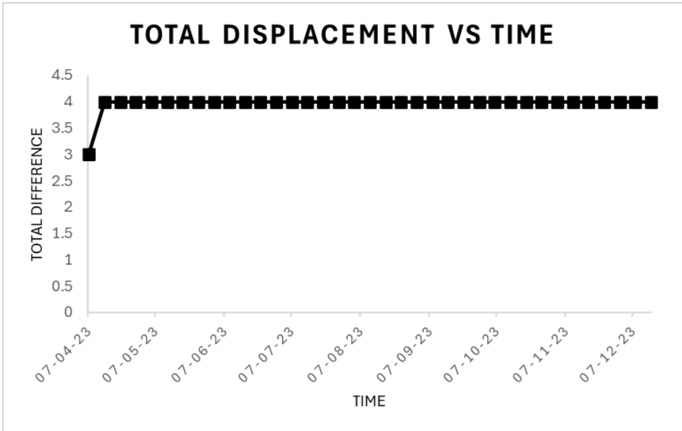


c)

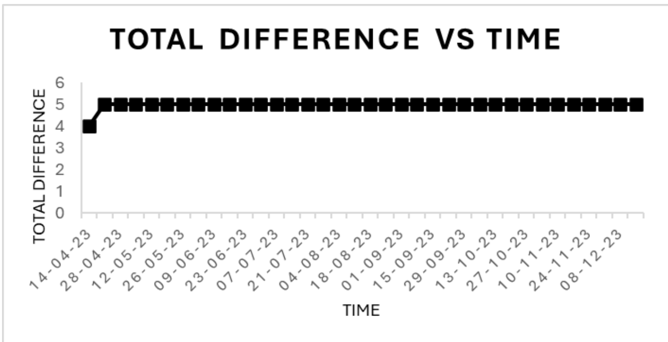


d)

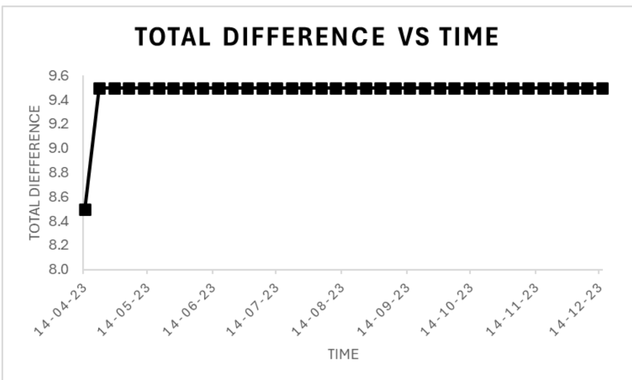
Fig 5: *Graph of total difference slope displacement during construction herringbone slope protection for a) CH408+130, b) CH408+330, c) CH408+430 and d) CH408+530*



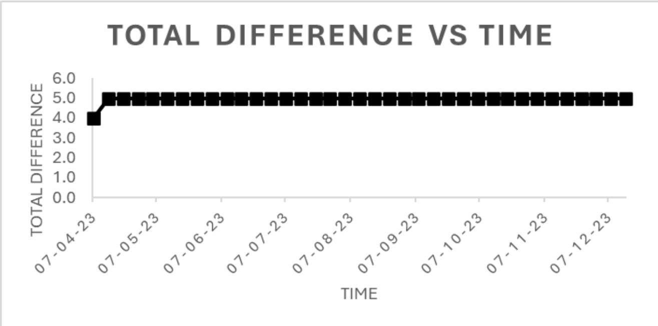
a)



b)



c)



d)

***Fig 6:** Graph of total difference slope displacement for herringbone slope protection for a) CH408+130, b) CH408+330, c) CH408+430 and d) CH408+530*

4.2 Findings

The analysis of slope displacement trends between CH408+130 until CH408+530 during the utilization of hydroseeding as a slope protection method reveals a consistent increase in total difference, showcasing the method's inability to withstand soft soil prone to water-induced softening. Notably, during heavy rainfall in November 2022, slope failure occurred, particularly on the right-side slopes between CH408+130 until CH408+530. See Fig 4 for CH408+130 the graph shows the total difference of slope displacement is directly proportional until the last peak value was 3.0 mm with rate of 0.1 mm/d for every movement. For CH408+330 the graph shows the total difference of slope displacement is directly proportional until last peak value of 4.0 mm with rate of 0.1 mm/d. For CH408+ 430 the graph also shows an increasing pattern for total difference until the peak value recorded was 8.5mm with the highest rate of 4.5mm/d on 21st October 2022. Finally, on CH408+530 the graph keeps increasing until 4.0 mm of total difference with rate of 0.1mm/d. This failure, observed through inclinometer data, underscores the ineffectiveness of hydroseeding due to poor grass survival rates in rocky soil, leading to insufficient slope stabilization.

Conversely, the subsequent implementation of the herringbone method resulted in stabilized slopes, evidenced by minimal slope displacement over an extended monitoring period from November 25, 2022, to April 7, 2023. Based on the results obtained on Fig 5, the graphs demonstrate the same pattern and trend for total difference of slope displacement for the entire 25th November 2022 until 7th April 2023. For CH408+130 the graph is constant on 3.0 mm as last time eroded. For CH408+330 the graph is constant on 4.0mm while the graph of CH408+430 keep constant on 8.5mm and lastly for CH408+530 the graph also constant on 4.0 mm. All graphs show a similar zero rate of movement for entire monitoring data taken.The herringbone method's effectiveness is attributed to the installation of impervious waterproof membranes, sheet piles, and grout pipes, providing immediate stability and reducing water runoff, thus minimizing erosion.

The graph on Fig 6 clearly demonstrates that the slope displacement is getting better by only increasing 1.0 mm before it keeps constant for over 8 months while this data is taken. As the graphs show the herringbone method is constant for long period of time it is proven that herringbone have better stability to keep the slope for that area in shape and prevent erosion even when facing heavy rainy season. It provides immediate stability and is particularly effective in areas with high erosion potential due to factors like steep slopes, loose soil, or heavy rainfall

The data comparison highlights the superior performance of the herringbone method in achieving slope stability, particularly in environments prone to heavy rainfall and soil instability, compared to the vegetation-dependent hydroseeding approach. This is because the physical structures of the herringbone pattern offer immediate resistance to soil movement. **T**he intricate pattern of intersecting trenches or furrows created by the herringbone design effectively intercepts and redirects surface water flow, minimizing erosive forces and soil loss on steep slopes. This shape facilitates the dispersion of rainfall and runoff across a larger surface area, reducing the concentration of water flow and preventing the formation of gullies or rills**.** This approach can be particularly effective in areas where underground water seepage is a concern, as it redirects water away from the slope, reducing the risk of erosion and instability due to water saturation.

On the other hand, the effectiveness of hydroseeding relies on the growth and establishment of vegetation, which can take time and may be less effective under conditions of high erosion. Therefore, in environments where erosion is a significant concern or where immediate stabilization is needed, the herringbone method may be a more reliable option

5. Conclusion

This research is primary comparing herringbone and hydroseeding as slope protection based on its monitoring on slope displacement has provided valuable insights into the effectiveness and suitability of these two methods of slope protection. In this study, the slope displacement has been successfully monitored by using an inclinometer as an instrument. The monitoring has been conducted through the area of event that slope failure occurred. All the monitoring was conducted on the same date and time. The comparison of better slope protection is made by comparing its stability and rate of its slope displacement.

Throughout the interpretation and analysis of data, the result implies that the total difference of slope displacement for hydroseeding type slope protection is generally directly proportional to the time. While herringbone has minor increasing trend which is 1.0mm of total difference of slope displacement before it remains constant for over the time this research was conducted.

The results obtained clearly demonstrate that the herringbone method offers superior stability compared to hydroseeding. This is evidenced by the lower frequency and magnitude of slope displacement observed with the herringbone approach. One key factor contributing to this superiority is the immediate resistance to soil movement provided by the physical structures inherent in the herringbone pattern. Moreover, herringbone drainage patterns effectively manage water runoff, directing it away from slopes and reducing the risk of erosion and instability due to water saturation. These features make the herringbone method highly suitable for areas with high rainfall and loose soils, where erosion and slope instability are prevalent concerns. Overall, the research underscores the effectiveness of the herringbone method as a reliable slope protection measure, offering enhanced stability and erosion control in challenging environmental conditions.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design:*** *Author I.A, Author M.N.Y;* ***data collection:*** *Author I.A, Author A.A.A.A;* ***analysis and interpretation of results:*** *Author I.A, Author M.N.Y, Author A.A.A.A;* ***draft manuscript preparation*** *Author I.A, Author M.N.Y, Author A.A.A.A. All authors reviewed the results and approved the final version of the manuscript.*

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