Design and Analysis of Shredded Expanded Polystyrene (EPS) Mixed Clays Based Slope Stabilization Measures

FINAL YEAR PROJECT UG 2020

By

Leader – 331427 – Hassan Ijaz
Member 1 – 334373 – Sinan Ahmad Khan
Member 2 – 333691 – Muhammad Bilal Khaliq
Member 3 – 339771 – Usman Khalid

NUST Institute of Civil Engineering
National University of Sciences and Technology, Islamabad, Pakistan

YEAR
2024

This is to certify that the

Final Year Project Titled

Design and Analysis of Shredded Expanded Polystyrene (EPS) Mixed Clays Based Slope Stabilization Measures.

submitted by

Leader – 331427 – Hassan Ijaz
Member 1 – 334373 – Sinaan Ahmad Khan
Member 2 – 333691 – Muhammad Bilal Khaliq
Member 3 – 339771 – Usman Khalid

as been accepted towards the requirements for the undergraduate degree

in

BE Civil Engineering

Advisor Name Designation
(Assit Prof)

NUST Institute of Civil Engineering
National University of Sciences and Technology, Islamabad, Pakistan

ABSTRACT

Population growth and the expansion of settlements and infrastructure into areas prone to unstable landslides significantly increase the potential for damage, impacting both developed and developing countries. Limited resources often hinder developing countries' ability to implement expensive preventative measures. Moreover, Polystyrene represents a considerable portion (around 10%) of total plastic waste, posing a significant environmental burden due to its poor recycling rates. This study investigates the potential use of this waste-expanded polystyrene (EPS) mixed with clays in shredded foam as a sustainable and cost-effective solution for slope stabilization. This approach utilizes 0% to 2.5% shredded EPS mixed with low plastic as lightweight fill materials for slope reinforcement, alongside benching techniques. The effectiveness is evaluated using stability analysis software (Slide2D).

Key findings demonstrate that incorporating 1.5% EPS-clay mixtures significantly improves the Factor of Safety (FOS) in various slope scenarios. Notably, FOS increased from 0.83 to 1.4 in Danna Sahotar and 0.335 to 1.42 in Qalandarabad. This research highlights the potential of EPS-clay mixtures as a sustainable alternative for slope stabilization, offering advantages like reduced material weight, improved drainage, and potential internal shear strength benefits. The findings suggest that the technique might be particularly effective on gentle slopes like, while steeper slopes might require additional reinforcement.

Table of Contents

List of Figures

List of Tables

CHAPTER 1

INTRODUCTION

1.1 Background

1.1.1 Landslides

The majestic mountains of Pakistan, particularly the Himalayas, Karakorum, and Hindu Kush ranges, are not only breathtaking landscapes but also areas susceptible to a significant natural hazard: landslide is the primary hazard occurring in the mountainous area. These strong movements of rock, earth, or debris, which change the land and are a major danger to life, property, and infrastructure, are the factors that determine the hazards of natural disasters [1].

The landslides in Pakistan's mountainous regions are a complicated danger which is caused by the combination of natural and human factors. The heavy rainfall and the rapid snowmelt increase the soil saturation, thus, the friction of the soil decreases, and at the same time, the unstable slopes become more vulnerable to collapse. Earthquakes are another source of risk that shakes and breaks the rocks creating the slopes, thus, causing the slopes to be riskier [2].

Besides the natural causes, human activities also constitute a substantial factor in the augmentation of landslide risks. The cutting of trees, which are the main support of the soil, is a widespread practice that causes deforestation. Farming practices that are not sustainable like over-irrigation and bad drainage in agriculture can make the soil saturated, and activities like hill cutting and mining that are not sustainable also make the slopes weak. Besides, infrastructure development that does not consider the slope stabilization techniques first will be an added problem [3].

The consequences of landslides in Pakistan are extremely bad. The destruction of human lives and the crisis of demolished houses, buildings, and infrastructure are the major problems. The landslides can also block the roads and communication lines which isolate the communities and consequently hamper the rescue efforts. Landslides cause environmental damage, which is huge, with secondary effects like floods and mudflows resulting in the devastation of ecosystems and agricultural land [4].

The economic effect also, in terms of both the direct costs like property damage and infrastructure repair and the indirect costs like lost productivity and environmental damage is substantial. These items affect the well-being of a community, making it less [5,6].

Some prominent landslides in Northern Pakistan are:

1) **Othar-Nala Landside.**

In northern Pakistan's Khyber Pakhtunkhwa province on 8 April 2016, a landslide destroyed a village and buried 25 people alive [7].

Figure 1 Othar-Nala Landslide [7]

2) **Jhika Gali Landslide.**

A landslide was triggered along Jhika Gali road which disrupted Jhika Gali's intersection which connects the streets leading to the most visited and beautiful places located on either side of the temporary bridge like Nathia Gali, Ayubia, Patriata, Bhurban, Expressway, New Murree, Lawrence College Bypass and Upper Jhika Gali [8].

Figure 2 Jhika Gali Landslide [8]

3) Azad Kashmir Landslides.

The October 2005, Kashmir earthquake main event was triggered along the Balakot Bagh Fault which runs from Bagh to Balakot and caused major landslides inflicting large damages in both terms of infrastructure and casualties. These landslides were mainly rock, and debris falls. The Hattian Bala rock avalanche was the largest landslide associated with the earthquake which destroyed a village and blocked the valley while creating a lake [10].

Figure 3 Azad Kashmir Landslides [10]

1.1.2 EPS Waste

Annually, millions of tons of refuse pollute our landfills, hence the severe environmental and economic problems. A typical example of this culprit is Expanded Polystyrene (EPS), or as most people call it, Styrofoam. According to the figures, the EPS production worldwide in the year 2016 was 6. 6 million metric tons (MMT) – a huge volume knowing that the substance is so light.

The issue is in what your EPS is being used after it is first utilized. Many EPS items, especially those that are for packing and storing, get thrown away and finally end up in landfills. The material is very light but takes up a lot of space - it's only a heavy 15 kilograms per cubic meter. Imagine a landfill full of numerous EPS containers – the massive volume that comes with this situation is a real waste management issue for the cities and the municipalities [11].

Besides, the major problem is the bad recycling rate for EPS. EPS is not like other plastics which have an easier and cheaper way to recycle the material. Research indicates that in the last ten years, EPS has been the major component of global plastic waste, some 10% of it. This means that a big part of plastic waste with scarce recycling opportunities is dumped into landfills for a very long time, thus becoming a pollutant [12].

The environmental catastrophe caused by the ever-increasing EPS waste is unquestionable. Plastics like EPS, which are the traditional ones, are known for their long degradation rates. Scientific studies show that it can take hundreds of years for EPS to decompose under natural environmental conditions. This in simple words means that every EPS container ever produced is probably still there somewhere and it is probably taking up a lot of space in the landfills and possibly discharging harmful chemicals to the environment [13].

The economic side of this waste management problem also has a lot to it. Landfills are not free to run - the cost of managing and containing the growing volume of waste is put on the local authorities and in the end, the taxpayers bear the burden. Besides, the non-utilized chances of recycling EPS thus mean a lost possibility to reclaim valuable resources and decrease the dependency on virgin materials [14, 15].

Figure 4 EPS waste [13]

1.1.3 EPS Waste and Clays

Clayey soils are extensively and frequently used in building materials. Due to their high compressibility, poor strength, and lower drainage characteristics, these soils pose challenges. Researchers and engineers have investigated a variety of stabilization approaches by applying additives to improve the engineering characteristics of clayey soils.

A recent study at the NUST Institute of Civil Engineering, a renowned institute, inquired about the possibility of the use of shredded polystyrene (EPS), which is also known as Styrofoam, to decrease the weight of clay-based fill materials. They experimented with three kinds of clay having different plasticity levels (low, medium, and high) and they added them with different amounts of shredded EPS.

The main discoveries of the research are the results that can be used in the establishment of the lightweight fill. Three types of clay demonstrated a significant weight loss when the EPS quantity increased. For instance, the clay with the least plasticity (densest) experienced a decrease in weight of up to 22% when it was mixed with the highest percentage of EPS (3%). Same as the above the medium and high plasticity clays also experienced a reduction of 19% and 17% respectively, at the level of 3% of EPS.

Though it is a way of losing weight, it also influences the strength properties of the clay. The angle of friction, which stands for the material resistance to sliding, was increased with EPS content in all clay types. This is probably because of the higher contact between the EPS and the clay particles. The cohesion, which denotes the attraction between particles, is the other way round, dropped with more EPS. The reason for this is that the EPS is a disruptor of the interaction between the clay particles.

Even though this study has observed a reduction in the cohesion of the EPS-treated clays, the strength is increased which allows the use of EPS-treated clays as fill material with the required strength. The perfect number of EPS with the most shredded clay for maximum strength was different for every clay type. The low plasticity clay produced the most effective outcome with a limit of up to 1. 5% EPS works the worst for the 5% plasticity clays, while the medium and high plasticity clays performed the best with 2% EPS. This indicates that the reduced cohesion is compensated by the increase in friction angle from the EPS which is the reason for the adequate strength maintained.

Lastly, the researchers put forward a scheme for the suitable choice of the volume of shredded EPS depending on the specific project needs for both strength and density. This model is a useful instrument for engineers and construction professionals who are seeking a lightweight and possibly more sustainable clay-based fill alternative [16].

Figure 5 EPS waste and Clay [16]

1.2 Problem Statement

Landslides, a highly destructive natural disaster, cause mayhem in different parts of the earth. They cause the deaths of people, damage the infrastructure, and bring about economic loss to a great extent. These falling domino effects make the communities pale and this reveals the critical necessity of good mitigation plans [17].

However, the challenge is compounded by another pressing environmental issue: The ever-increasing problem of the Expanded Polystyrene (EPS) waste which is also known as Styrofoam is the time of the problems of the planet. EPS is a soft plastic that is the most popularly used material in packaging and construction. Nevertheless, at the same time, its advantages are overshadowed by its harmful effects on the environment. EPS is low on the scale of recycling, and it will be thrown away in the hells for hundreds of years to decompose in landfills the chemicals will be released into the environment and the space will be occupied. The continuous disposal of this waste is a major cause of long-term environmental damage [18].

The two major problems of these two issues are closely linked together and this is the problem that must be solved. Landslides are the major cause of damage to the road network in mountainous areas where infrastructure development is the need of the hour. Yet, the traditional slope stabilization methods are very costly and are also bad for the environment. Would fill made of clay and EPS waste, a present environmental problem, be a sustainable method for slope stabilization?

Addressing this complex convergence requires a multi-pronged approach:

Continued research is crucial to refine and validate the use of shredded EPS in slope stabilization. studies will assess its effectiveness and identify potential drawbacks. Some key questions which need to be answered include:

- Can the structural integrity of landslides be increased with the use of shredded EPS-clay mixtures?
- What is the optimal ratio of shredded EPS to clay for different slope compositions and structural conditions?
- What kind of landslides can be better stabilized with the use of waste-shredded EPS clay Mix?

Can we transform a persistent environmental burden into a solution that protects lives and landscapes? The answer lies in this research.

1.3 Objectives

The key purpose of this research is to stabilize different landslides modelled on slide 2D using a lightweight fill made up of waste-shredded EPS mixed with clay. This is to be achieved through the following objectives:

The first objective is to choose the landslide sites carefully, acquire access and copy the data. This process is the key to the understanding of the specific problems that landslides are in a certain place. finding of those regions which have been struck with landslides in the past or have geological features that make them prone to slope failures. After these sites are selected, visiting them is possible only after getting permits and working closely with the authorities of the area. Data acquisition is the gathering of the soil characteristics at the location of the site under study. This encompasses geotechnical testing that assesses various aspects such as grain size distribution, water content and shear strength. Furthermore, the geometry of the slide is carefully considered. The mentioned factors are the slope angle, height, and the presence of any weaknesses or cracks in the slope. Nevertheless, the study in question is based on the literature review of past publications for this Data.

By getting the vital site data on hand, the next thing to do is to model the possible behaviours of the slope in two dimensions (2D) using the special software called Slide 2D (Limit Equilibrium Method). These computer models facilitate the simulation of various scenarios, i.e., different geometry and stabilization techniques, and foresee the slope's reaction. The model combines the collected soil properties and the geometry data of the slide to produce a virtual type of slope. Through the study of the model's output, we discover the areas of weakness and check the overall stability of the slope when it faces different conditions.

The goal is to improve the design of the slopes stabilized with the shredded EPS-clay mix. In this way, we apply the results from the 2D modelling to establish the best and the best position of the EPS-clay mixture in the slope. This means the analysis of the trade-off between stability and cost-effectiveness is the main point. The higher EPS content that is higher might reduce the weight but at the same time, it also lowers the shear strength of the fill. The design optimization process is the process that gives the best of all three: EPS fill quantity, Factor of safety and slope geometry.

CHAPTER 2

LITERATURE REVIEW

2.1 Selected landslides

Based on the availability of data and the criticality of landslides two landslides were selected which are explained below:

2.1.1 Danna Sahotar

The Danna-Sahotar landslide is in the villages of Danna and Sahotar, approximately 45 km from the city of Muzaffarabad in Pakistan. Its geographical coordinates range from latitude 34.151°N to 34.129°N and longitude 73.543°E to 73.575°E. This area falls within the Muzaffarabad District, characterized by plains, mountain ranges, valleys, lakes, and rivers, with a humid to subtropical climate. The unstable conditions of the region, exacerbated by the prolonged monsoon rainy season, lead to weathering processes, soil structure weakening, and slope failures. Landslides in this area are often triggered by heavy rainfall, causing damage to roads, and infrastructure, and posing risks to humans.

The triggering reason for the Danna-Sahotar landslide includes:

1. Prolonged monsoon rainy season causing weathering processes, weakening of soil structure, and slope failure.
2. Rainfall is the primary cause that triggered landslides, damaging roads, causing road closures, and destruction of infrastructure, leading to loss of human lives.
3. Variations in slope angle and fluctuations in groundwater have a prominent effect on the nature of landslides.

The location and size of this landslide could be better understood by the following images:

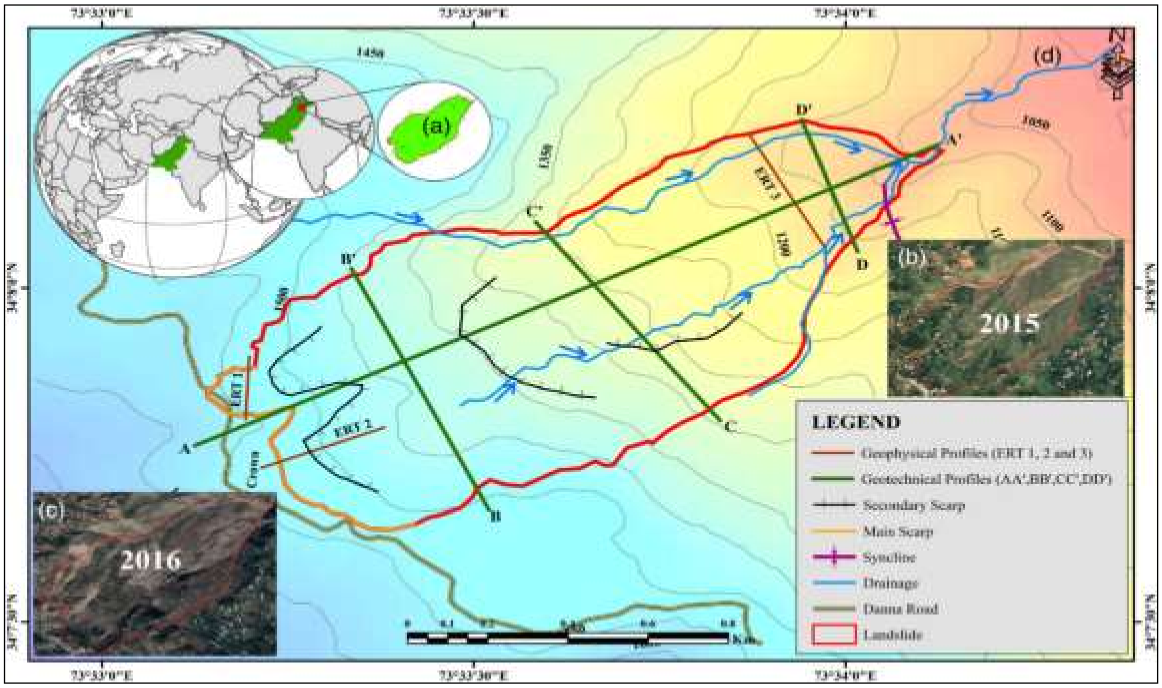

Figure 6 Location of Danna Sahotar [19]

Figure 7 Danna Sahotar Landslide [19]

The soil properties of the Danna-Sahotar landslide include a surface layer that is mainly sandy with clayey and silty content. Additionally, geotechnical investigations revealed that the landslide site has a possible slip surface where the resistivity values change. The two-dimensional electrical resistivity tomography (ERT) showed low resistivity in the crown of the landslide due to water seepages, which increase the degree of saturation and pore water pressure, ultimately leading to slope failure [19].

2.1.2 Qalandarabad Landslide

The Qalandarabad active landslide is in Abbottabad, Pakistan. It was identified as the most critical and geotechnically unstable area under both gravity and seismic loading conditions. The landslide is considered unstable as the factor of safety (FOS) values for all methods of analysis are less than 1, indicating a high risk of failure. The FOS values for gravity loading are 0.383 in dry conditions and 0.383 in saturated conditions, while for seismic loading, the values are 0.332 in dry conditions and 0.333 in saturated conditions. It is considered one of the most critical landslides in the region because of its vicinity of population. The Unified Soil Classification System (USCS) categorized the soil samples from the Qalandarabad landslide fields into different groups Silty Clayey Sand (SC-SM), Silty sand with gravel (SM), and Silty Sand (SM). Each of these classifications has its characteristics that can impact the stability of slopes [20].

The visuals of the Qalandarabad landslide are as follows:

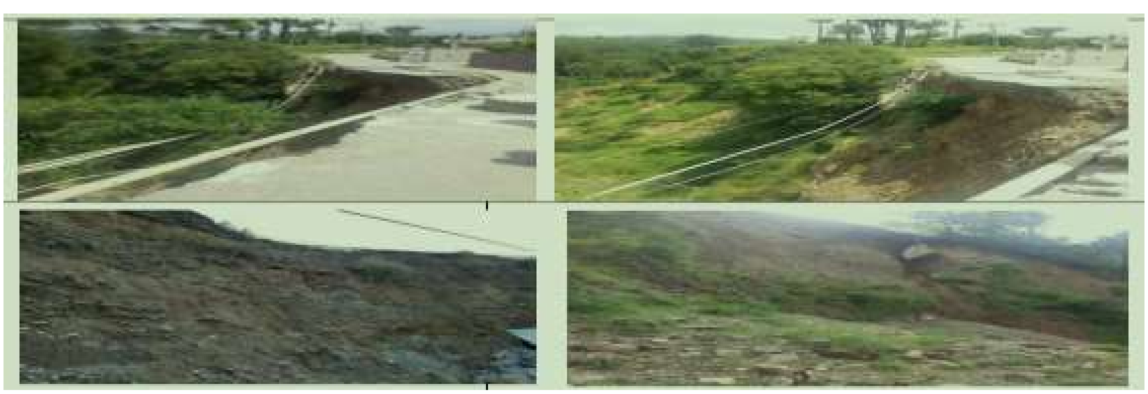

Figure 8 Qalandarabad Landslide [20]

Representation of both landslides can be shown below:

Figure 9 Map of Pakistan showing selected landslides

2.2 Waste Shredded EPS mixed Clays.

Clayey soils are abundantly present on sites specifically in Pakistan, and generally all over the world. Shredded EPS can be utilized in different plasticity clays as per weight and strength requirements. From recent studies, it is evident that 1 to 2,5 % shredded EPS by weight is the most favorable due to its high strength and considerable reduction in unit weight for all three types of clayey soils [16].

This criterion can be applied to projects where lightweight soil with improved bearing capacity /strength is required i.e., structure of weak soils, slope stability, and embankments. 0 to 1% and 2.5 to 3.5% EPS can help in achieving the criteria of lightweight fill with slightly compromised strength i.e., behind a retaining wall where minimal weight of soil is required to reduce lateral earth pressure, replacement with weak soil layers with high densities to reduce load underneath.

EPS beads and shredded EPS have their distinctive properties. Shredded-EPS shows considerable gain in UCS in LP and MP soils at 1.5% and 2% respectively. Whereas the addition of EPS beads causes a reduction in UCS in clay samples. The studies have revealed that fine beads tend to decrease UCS in clayey soils as compared to coarser beads [9].

Similarly, shear strength parameters are significantly affected by the addition of EPS beads and shredded EPS. Replacing clayey particles with smooth and spherical beads tends to decrease the angle of internal friction. However, the inclusion of shredded-EPS angular and rough particles in fine-grained soils causes an interlocking effect with soil silt particles which maintain and increase the angle of internal friction. The cohesion of clay-clay particles is greater than the cohesion of clay-EPS particles [21]. In both beads and shredded EPS cases, cohesion decreases with an increase in EPS content.

2.2.1 Previous studies on slope stabilization using EPS (Beads & Geofoam).

Lightweight fill mixtures are produced for landslides /embankment construction to achieve similar flexibility to ordinary soil, reducing the weight of the embankment by 30% to 50%, improving slope stability, and decreasing ground pressure on retaining structures. The mixture's strength and stiffness can be tailored by changing the type and content of the binder, allowing for customization based on soil type and project requirements. Lightweight fill materials, especially those with EPS beads, help control settlement, prevent bearing capacity failure, and provide an attractive solution for highway construction [22, 23].

A similar lightweight fill was used for the Embankment construction of the road having the following characteristics:

The lightweight fill consists of clay soil, fly ash as a binder, and EPS beads as the lightweight material offering benefits such as reduced weight of the soil, improved slope stability, and the ability to adjust strength and stiffness by changing the binder content. The addition of EPS beads can decrease the weight of the soil by 6 kN/m3 to 15 kN/m3, reducing the total weight of embankment construction by 30% to 50%. Fly ash acts as a binder to increase the shear strength of the mixture, compensating for the reduction in strength caused by the addition of EPS beads [22].

Another study investigated the incorporation of significant volumes of particulate EPS beads in clayey sand soil to produce lightened fill material for engineering applications. The experimental results focused on the behaviour of the soil when mixed with EPS beads in varying percentages. The main effect of the addition of EPS beads was a substantial decrease in the compacted dry density of the soil. And only 0.5% EPS beads cause mechanical failure. The study also highlighted the environmental consequences of using EPS-sand/clay mixtures, especially in terms of the fate and transmission of microplastics in the food chain [24].

Another case study explains the use of Geofoam blocks for embankment replacement for road construction. To rehabilitate the 20 m high embankment after failure during road construction, the fill was excavated to reduce driving loads acting on the sliding plane and EPS geofoam was used as lightweight material to replace soil fill to reduce the driving forces acting on the soil [25].

2.2.2 Research Gaps.

The research concentrating on the efficiency of EPS beads and geofoam blocks in the top of the slope stabilization is very broad. These materials have several advantages such as their being lightweight which in turn lowers the total slope. Moreover, their closed-cell structure is why they can drain well, hence, they do not have a problem with soil saturation which is the main reason why landslides occur. Nevertheless, the former conventional methods are limited. The production of EPS beads and geofoam blocks is a very energy-intensive process, which has brought about environmental issues in terms of carbon footprint. Moreover, these products can also be costly, especially for big projects [8,9,10].

This is where, by shredding the waste-generated EPS, a widely accessible waste product, we get a special chance to convert it into an alternative. Shredded EPS is different from its manufactured counterparts in that it could be a solution for both the environmental and economic issues of slope stabilization. This way we are using the waste EPS, which would otherwise be in the landfills, and thus sustainability is being promoted and the reliance on virgin materials is reduced. Moreover, shredded EPS is usually much cheaper than EPS beads or geofoam blocks since only transportation costs are considered and sometimes even if it is not considered, thus it could be a more cost-effective solution [16].

Although no research has been done on any of the practical applications of this, it can be said on limited research that the outcomes of it look promising. Studies should be done to find out the best ratio of shredded EPS to clay for a different slope and environmental conditions.

CHAPTER 3

METHODOLOGY AND MODELLING

3.1 Landslide Analysis of Qalandarabad and Dana Sahotar.

The Qalandarabad landslide occurred near the Muzaffarabad Fault, known for potentially triggering vertical movements that can destabilize slopes. Initial assessments suggest the landslide involved a steep (45-degree) slope composed of weak rock, weathered rock, or very dense soil.

In contrast, details about the Dana Sahotar landslide (also located in Khyber Pakhtunkhwa) are limited. However, analyzing both landslides together can provide a broader understanding of slope failure mechanisms and the importance of site-specific investigations.

3.2 Significance of this Study

This research holds significant value for several reasons. Firstly, by examining these landslides, we can gain crucial knowledge about similar slopes, especially those near fault lines or with steeper inclinations. This information can help us proactively identify vulnerable areas and implement preventive measures.

Secondly, understanding the triggers behind these landslides is essential. Finally, evaluating these landslides allows us to assess the effectiveness of existing stabilization techniques. For instance, the Qalandarabad case highlights the potential limitations of relying solely on conventional methods for slopes with marginally stable materials. This opens doors to exploring innovative solutions like EPS-clay mixes and determining their suitability for different slope types and triggers.

3.3 Data Used in Slope Stability Analysis

Slope stability analysis typically relies on data from research papers, including:

- **Slope Geometry:** Slope angle, height, length, presence of benches, and overall slope profile as documented in the research.
- **Water Table Level:** The depth of the water table within the slope, as reported in the specific research project.

3.4 Material Properties:

- **Unit Weight:** The average weight per unit volume of the soil or rock layers, as documented in the research.
- **Friction Angle:** The internal friction resistance for each soil layer, as reported in the research paper's findings.
- **Cohesion:** The value of cohesion for each soil layer, representing the attraction between particles, as documented in the research.

3.5 Modeling and Analysis of Landslides

This chapter presents the modelling and analysis of two landslide scenarios: Danna Sahotar and Qalandarabad. The analysis employed Slide 2D software and the Limit Equilibrium Method (LEM) to assess slope stability.

3.5.1 Modelling Approach

Software and Method Selection:

Slide 2D software was chosen for its user-friendly interface and compatibility with LEM analysis. LEM is a well-suited approach for analyzing rotational landslides, which was the focus of this study. The selection was further justified by the availability of data suitable for LEM input (unit weights, friction angles, cohesion).

3.5.2 Model Setup:

- Slope geometry (inclination, height, length) was defined in Slide 2D based on available data (metric or imperial).
- Material properties (unit weight, friction angle, and cohesion) for each soil/rock layer were assigned based on data analysis.
- Boundary conditions, including fixed points and loading conditions (slope weight, water surcharge), were specified.
- Assumptions and simplifications were documented, such as neglecting pore water pressure and assuming homogeneous material properties within each layer.

3.5.3 Limit Equilibrium Methods

Multiple LEM methods available in Slide 2D were utilized, including Bishop, Spencer, Morgenstern-Price, Janbu (simplified and corrected), and GLE (Generalized Limit Equilibrium). This approach provided a comprehensive understanding of slope stability by considering the strengths and limitations of each method. The critical factor of safety (FOS) obtained from each method was used to assess overall stability.

3.6 Danna Sahotar Landslide (Model 1)

3.6.1 Geometry:

- Vertical extent (height): 550 meters
- Length: 1850 meters
- Slope angle (α): 27 degrees (relatively gentle)
- Three distinct material layers.

3.6.2 Initial Stability Analysis:

- Critical FOS: 0.83 (potentially unstable)
- Driving forces are close to overcoming resisting forces.

3.6.2 Failure Prone Locations:

- Slide 2D identified two critical locations with weaker material properties, steeper inclinations, or other factors such as water table level contributing to instability.

3.6.3 Model of Danna Sahotar Slope

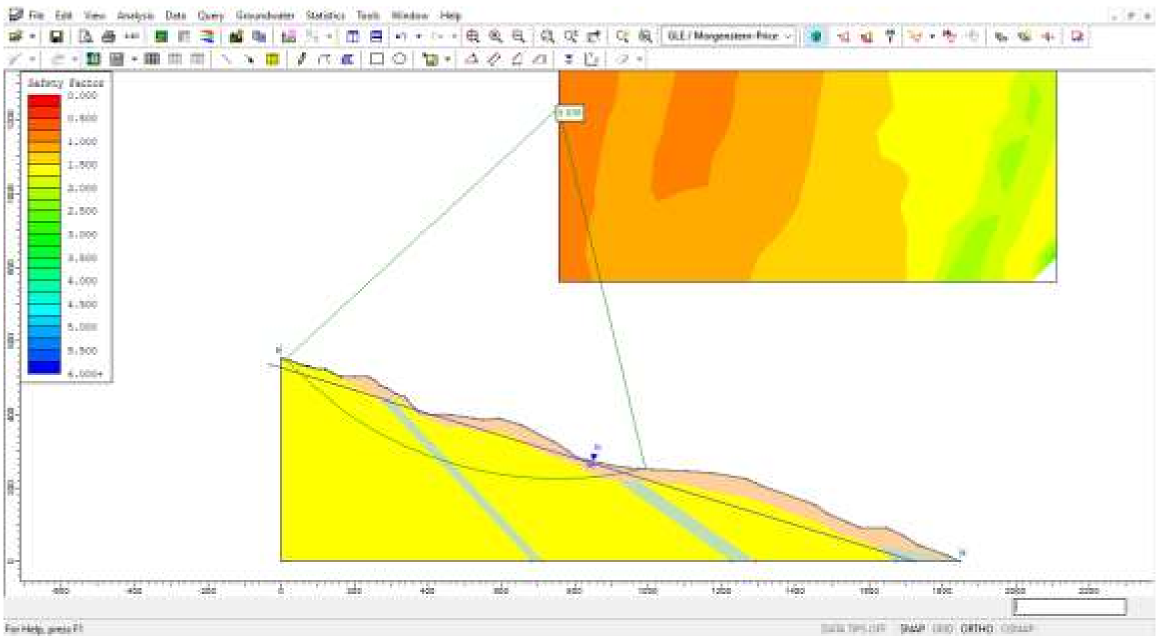

Figure 10 Danna Sahotar Landslide Existing condition

Table 1 Material Properties of Danna Sahotar

Material	Shale	Sand-Stone	Clayey Debris	1.5% EPS Clay
Weight (KN/m3)	15	23	17	16.12
Cohesion(kPa)	23	28	15	15.23

Friction Angle	23	24	30	33.55
Colour	Yellow	Grey	Peach	Red

The analysis revealed a critical FOS of **0.83**, indicating a **potentially unstable slope**. This low FOS value suggests that the driving forces (forces tending to cause failure) were close to overcoming the resisting forces (forces that oppose failure) within the slope. FOS and Slip surfaces from different slope stability analysis methods are attached in Appendix 1.

3.7 Proposed Stabilization Solution:

Lightweight fill material is strategically placed at critical locations to increase resisting forces and enhance overall stability.

3.7.1 Lightweight Fill Analysis:

- Reduced weight of lightweight fill compared to traditional fill materials leads to a decrease in driving forces.
- Strategic placement minimizes additional downward force on critical zones, potentially improving their effective angle of internal friction (α) and localized shear strength.

3.7.2 Post-Stabilization Analysis:

- Re-analysis with lightweight fill showed a significant increase in critical FOS to approximately 1.4, demonstrating the effectiveness of the solution.
- The image on the next page shows the model with lightweight fill material used strategically to stabilize the slope.

Model of Danna Sahotar slope stabilized with lightweight fill shown ahead.

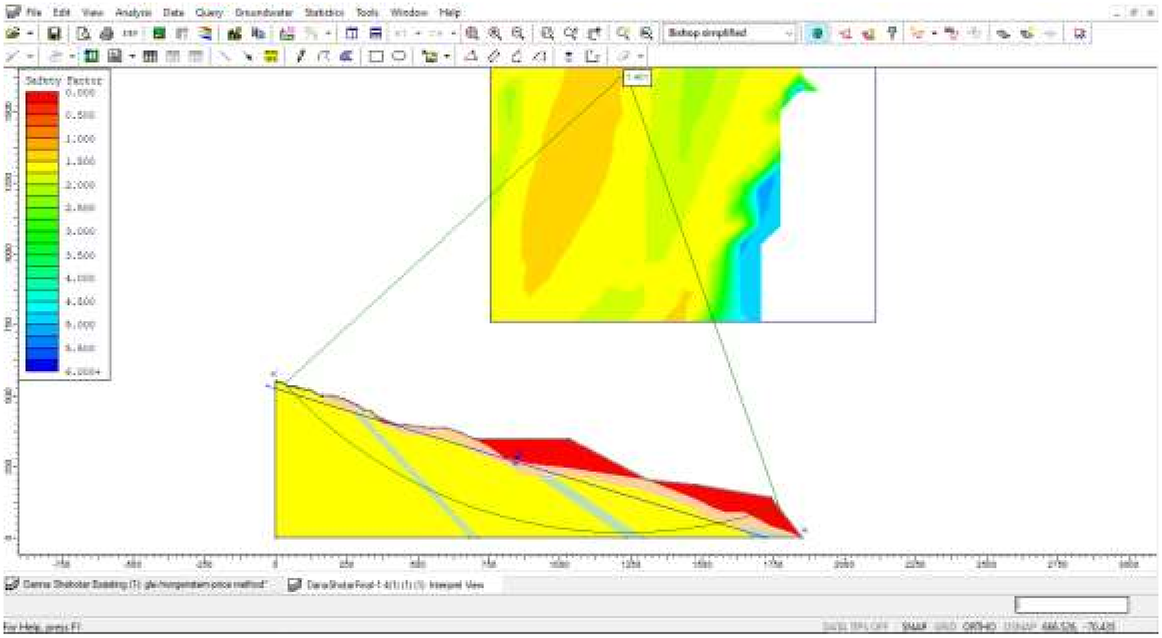

Figure 11 Danna Sahotar Landslide Final Design

This image shows the application of lightweight fill at the toe and head of the toe to improve the factor of safety of the Danna Sahotar landslide. This strategic placement plays an important role in decreasing the driving force, hence increasing the factor of safety. More details are discussed below.

3.7.3 Strategic Placement:

The proposed solution involves strategically placing the lightweight fill at two critical locations within the slope identified through the Slide 2D model. These critical locations likely represent zones of wseakness with lower shear strength or steeper inclinations. Placing the lightweight fill in these specific areas has a targeted effect:

- **Reduced Angle of Internal Friction (α):** In some cases, the critical failure zones might exhibit lower internal friction angles (α), signifying a reduced resistance to shear forces within the soil matrix. The lightweight fill, by not adding significant weight itself, minimizes the additional downward force acting on this zone. This can indirectly help maintain or even improve the effective angle of internal friction (α) in the critical zone, thereby enhancing the overall shear resistance of the slope.

3.7.4 Mechanism of FOS Improvement:

By strategically adding lightweight fill, we achieve two key benefits:

- **Reduced Driving Forces:** The lightweight nature of the fill minimizes the additional downward force exerted on the slope. This reduction in driving forces directly contributes to an increase in the overall FOS.

- **Localized Shear Strength Improvement (indirect):** In critical zones with potentially lower internal friction angles (α), the lightweight fill placement avoids overburdening the area. This can help maintain or even improve the effective α in these zones, leading to a localized increase in shear strength and indirectly contributing to a higher FOS.

The combined effect of these mechanisms is evident in the re-analysis after incorporating lightweight fill. The critical FOS increased significantly from 0.83 to 1.4, demonstrating the effectiveness of the proposed solution in enhancing slope stability.

3.8 Modelling & Analysis of Qalandarabad Landslide

3.8.1 Geometry:

- Vertical extent (height): 175 feet
- Length: 230 meters
- Average slope angle (α): 45 degrees (steep)
- The slope is susceptible to landslides.

3.8.2 Initial Stability Analysis:

- Critical FOS: 0.355 (highly unstable)
- Driving forces significantly exceed resisting forces.

The analysis revealed a critical FOS of **0.355**, indicating a **potentially unstable slope**. This is a very unstable slope. During the hit and trail analysis, we deduced that the entire slope was unstable and slip surface would pass through different locations along the slope. Hence, hinting at the stabilization of the whole slope.

3.8.3 Failure Prone Locations:

Slope stability analysis revealed critically unstable zones with lower FOS than the rest of the slope. Multiple parts of the slope were identified. All extent was considered unstable for analysis because of weak material and steep angle. Slip surface or failure could occur from multiple locations along the slope extent.

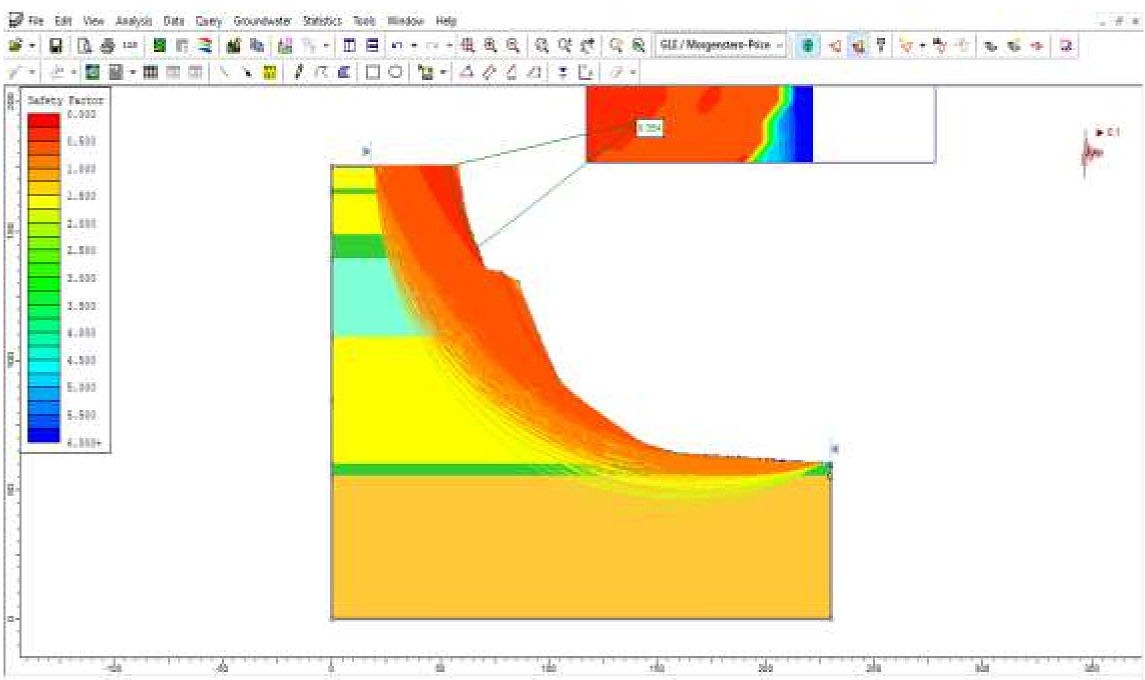

Figure 12 Qalandarabad Landslide Existing Condition

Table 2 Qalandarabad Landslide Soil Properties

Material	SM	Coarse Gravel	SC-SM	Bedrock
Weight (lb/ft³)	160	150	170	177
Cohesion (Psf)	33	62	52	2600.67
Friction Angle	36	37	32	40
Colour	Yellow	Aqua	Green	Brown

3.9 Staged Stabilization Analysis (Qalandarabad):

3.9.1 Lightweight Fill:

- Factor of Safety with fill only: **1.03 (moderate improvement)**
- Because the slope angle was very steep
- The model with lightweight fill applied is shown ahead

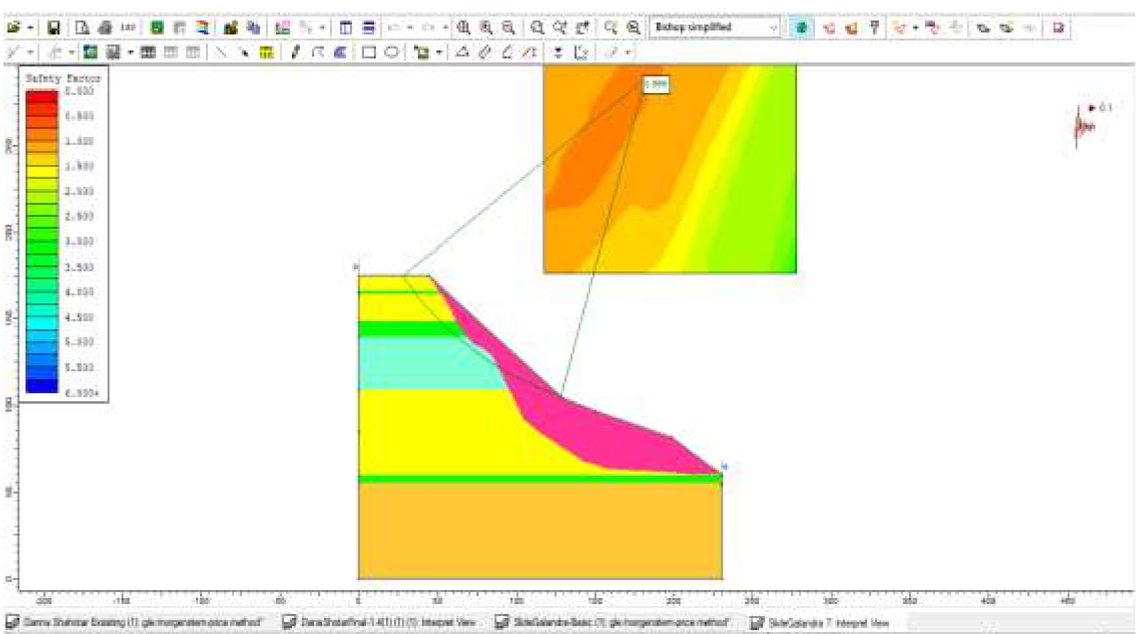

Figure 13 Qalandarabad Landslide Stabilized with Fill

3.9.3 Grouted Tiebacks:

- Factor of safety with tiebacks only: 0.962 (limited improvement)
- The slope was very unstable.
- Failed from different locations each time a support pattern was provided.
- The FOS could only be improved to 0.96 considering the economical constraints.

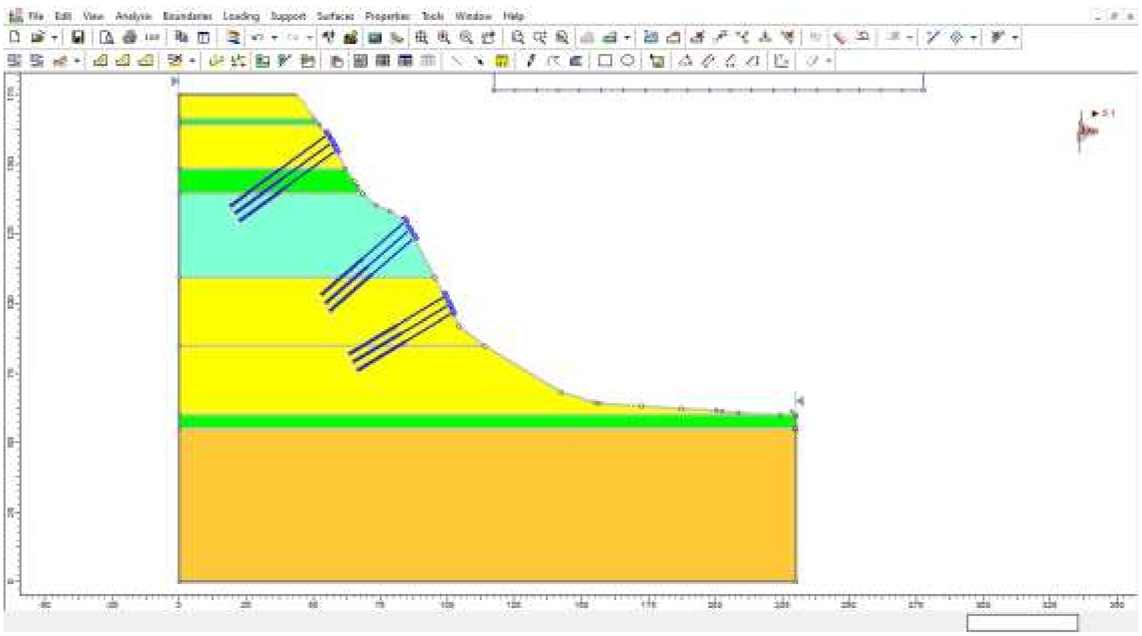

Figure 14 Qalandarabad landslide with grouted anchors

3.9.4 Combined Approach:

- Factor of Safety with combined approach**: 1.3 (significant improvement)**
- Due to support to prevent the sliding mass from sliding at strategic locations.
- Lightweight fill reduces the driving forces to effectively increase FOS

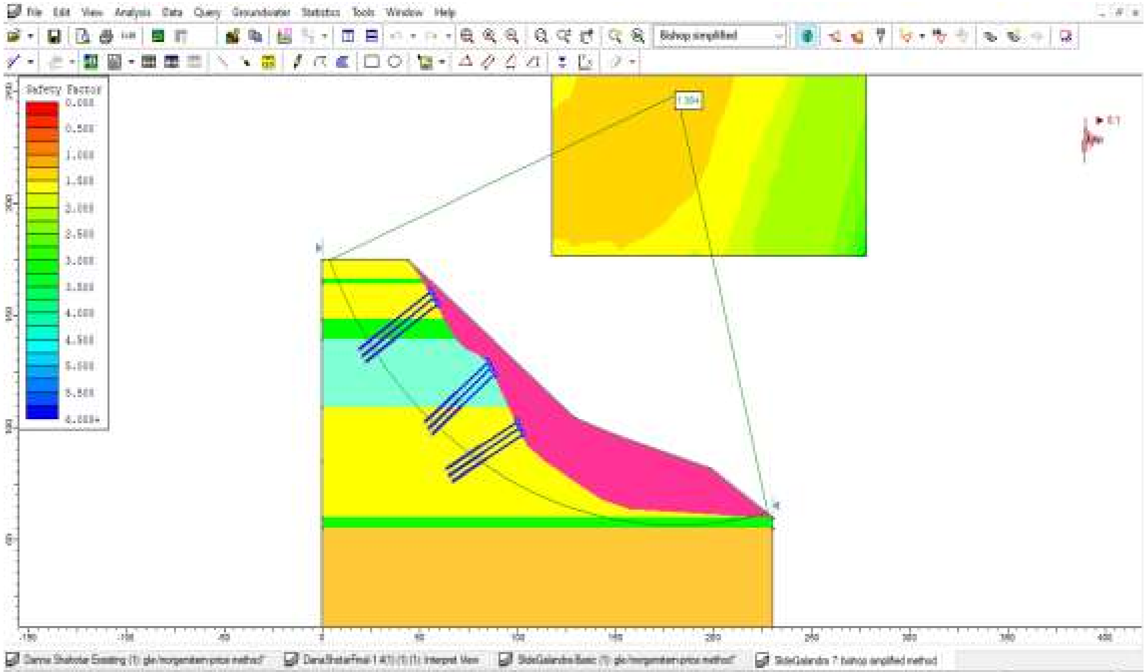

Figure 15 Qalandarabad landslide final design

3.9.5 Enhanced Stability through Combined Measures:

The initial use of lightweight fill achieved a moderate improvement. To achieve a more robust solution, the strategy was enhanced by incorporating grouted tiebacks and reducing the overall slope angle**:**

- **Slope Angle Reduction:**

Reduced average slope angle from 45 degrees to 30 degrees directly decreases driving forces acting on the potential failure plane.

- **Grouted Tieback Support:** These function as long, slender elements anchored in stable ground behind the failure zone. They act in tension, pulling the failing slope material back towards the stable zone, and reducing driving forces.

CHAPTER 4

RESULTS AND DISCUSSION

This study employed Limit Equilibrium Method (LEM) analysis through Slide 2D software to evaluate the effectiveness of lightweight fill, with and without additional support methods, for stabilizing the Danna Sahotar and Qalandarabad landslides.

4.1 Stability Analysis Results:

The LEM analysis yielded critical Factor of Safety (FOS) values for each landslide scenario are summarized below.

Table 3 FOS of Danna Sahotar and Qalandarabad

LEM Methods	**Danna Sahotar**		**Qalandarabad**	
	Existing FOS	Final FOS	Existing FOS	Final FOS
GLE / Morgenstern-Price	0.839	1.408	0.354	1.299
Spencer	0.84	1.417	0.352	1.31
Bishop Simplified	0.83	1.401	0.352	1.302

4.1.1 Danna Sahotar:

- Initial FOS: 0.83 (unstable)
- Post-lightweight fill FOS: 1.4 (stable)

4.1.2 Qalandarabad:

- Initial FOS: 0.355 (highly unstable)
- Lightweight fill FOS: 1.03 (moderately stable)
- Combined (lightweight fill + tiebacks) FOS: 1.3 (stable)

The addition of tiebacks along with lightweight fill achieved a more substantial increase in FOS (1.3) for Qalandarabad, demonstrating the effectiveness of combining these techniques for precarious slopes. These results highlight the significant role of lightweight fill in improving slope stability, particularly when used strategically with additional support methods for highly critical scenarios.

The analysis yielded critical Factor of Safety (FOS) values for each landslide scenario. The initial FOS for both slopes indicated instability (Danna Sahotar: 0.83, Qalandarabad: 0.355). The implementation of lightweight fill significantly improved stability in both cases. In Danna Sahotar, the FOS increased to a stable condition (1.4) with lightweight fill alone. For Qalandarabad, lightweight fill provided moderate improvement (FOS: 1.03), but the combination of lightweight fill and tiebacks achieved a more substantial increase in FOS (1.3), demonstrating the effectiveness of this combined approach for highly unstable slopes.

Furthermore, the analysis successfully identified critical zones within both landslides that exhibited lower FOS due to specific geotechnical conditions. Slide 2D's ability to pinpoint these critical locations enabled the targeted application of the stabilization measures.

4.2 Discussion: Model Performance and Rationale for Lightweight Fill

While a sensitivity analysis to assess the impact of environmental factors like rainfall intensity was not performed in this study, it represents valuable future work for understanding the slopes' response to various conditions. Additionally, the applicability of the model in replicating historical landslide behaviour could be further evaluated if historical data on actual failure zones is available. Comparing the model's predicted failure zones with documented landslide locations would provide valuable insights into the model's accuracy.

The substantial improvement in FOS observed with lightweight fill in both scenarios supports the initial selection of EPS-clay mix as a suitable stabilization material. The key advantage of lightweight fill lies in its reduced weight compared to traditional materials like soil or rock. This translates to a decrease in driving forces acting on the slope, particularly beneficial in critical areas where additional weight can exacerbate instability.

4.2.1 Effectiveness of Lightweight Fill with Support Methods:

The analysis emphasizes the effectiveness of combining lightweight fill with other support methods, particularly for stabilizing steep slopes. Here's a breakdown of their complementary roles:

- **Lightweight Fill:**
    - Reduces driving forces by minimizing the additional weight added to the slope.
    - Can potentially improve the effective internal friction angle (α) in critical zones, leading to localized shear strength enhancement.
- **Support Methods (e.g., Tiebacks):**
    - Provide additional mechanical support by counteracting driving forces and pulling failing material back towards stable zones.

The Qalandarabad case study exemplifies the successful use of grouted tiebacks as a support method in conjunction with lightweight fill.

4.3 Advantages of Conventional Measures:

Compared to conventional concrete walls, the approach of lightweight fill combined with targeted support methods offers several advantages:

- **Reduced Cost:** Lightweight fill and selective support methods are often more cost-effective solutions compared to constructing extensive concrete walls.
- **Reduced Load:** They add less overall weight to the slope, minimizing the risk of overloading critical areas, a major concern with concrete walls.
- **Greater Applicability:** This approach can be more adaptable to complex slope geometries compared to rigid concrete structures.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The research was aimed at finding out if the mixture of shredded EPS (Expanded Polystyrene) and clay could be used as an effective lightweight fill material in the mitigation of landslides. The research results indicate an increase in a crucial factor called the "Factor of Safety" that is after the application of the new fill material. For instance, in Danna Sahotar's scenario, the Factor of Safety went up from 0. 83 to 1. 4, to improve the stability measures. In the same manner, the factor of safety of Qalandarabad, one of the landslide areas, increased from 0 as well. 335 to 1. 42.

This research acts as proof of the high efficiency of EPS-mixed clay-based fills, especially on gentle slopes like Danna Sahotar. The major benefit of this lightweight material is that its weight is less, which in turn places a lower load on the slope, thus improving stability. On the other hand, it should be kept in mind that the Swat Motorway cut slope may need a different method because it is a steeper slope. Steeper slopes demand less fill material to be deposited mainly at the base of the landslide, which is called the toe of the landslide, to achieve the desired level of stability.

The main message of the study is the encouraging result that mixed EPS shredding with clay can be used as a possible fill material for landslide mitigation. This approach not only has a practical application but also gives a solution for waste management through recycling the readily available EPS waste. The analysis, nevertheless, reveals the necessity of integrating this method with other existing support systems, especially when working on steeper slopes is considered. A comprehensive approach which utilizes the benefits of EES-clay fillings in conjunction with other stabilization techniques will be more effective in addressing landslide risks and protecting vulnerable communities.

Summing up, the study provides an incisive argument for the use of EPS-clay mixture in the form of shredded EPS-clay mixtures as a potential weapon against landslides. By grasping the efficiency of this technique on various slope gradients and making use of it alongside the existing methods, we could be on our way towards a future with more secure and stable slopes.

5.2 Future Works

The analysis acknowledges the limitations inherent to modelling approaches. Data gaps or uncertainties in material properties, pore water pressure, and precise slope geometry can influence the model's accuracy. Additionally, the assumption of homogeneous material properties within each layer might not fully capture the heterogeneity present in natural slopes.

Future research endeavors could focus on incorporating additional data types, such as pore water pressure measurements, to refine the model and enhance its predictive capabilities. Furthermore, exploring more complex failure mechanisms within the model, such as progressive failure, could provide a more comprehensive understanding of slope behaviour.

Appendix-1

Below are the slip surfaces of Danna Sahotar and Qalandarabad models from different analysis methods along with respective FOS.

Danna Sahotar Landslide

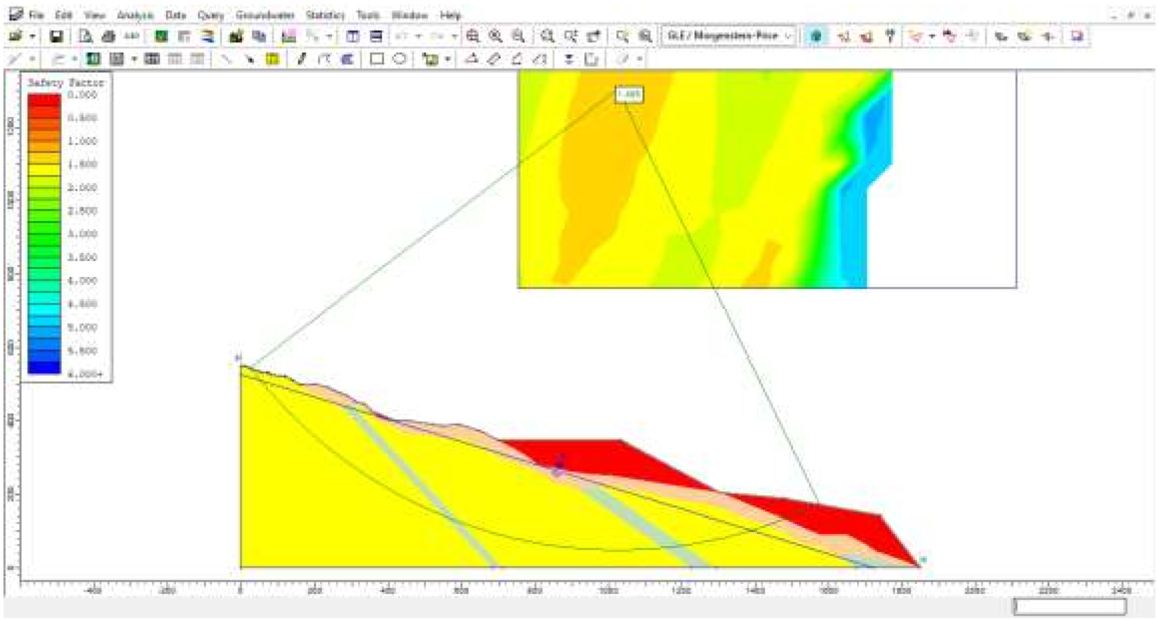

Figure 16 Danna Shaotar, GLE / Morgenstern Price with FOS 1.405

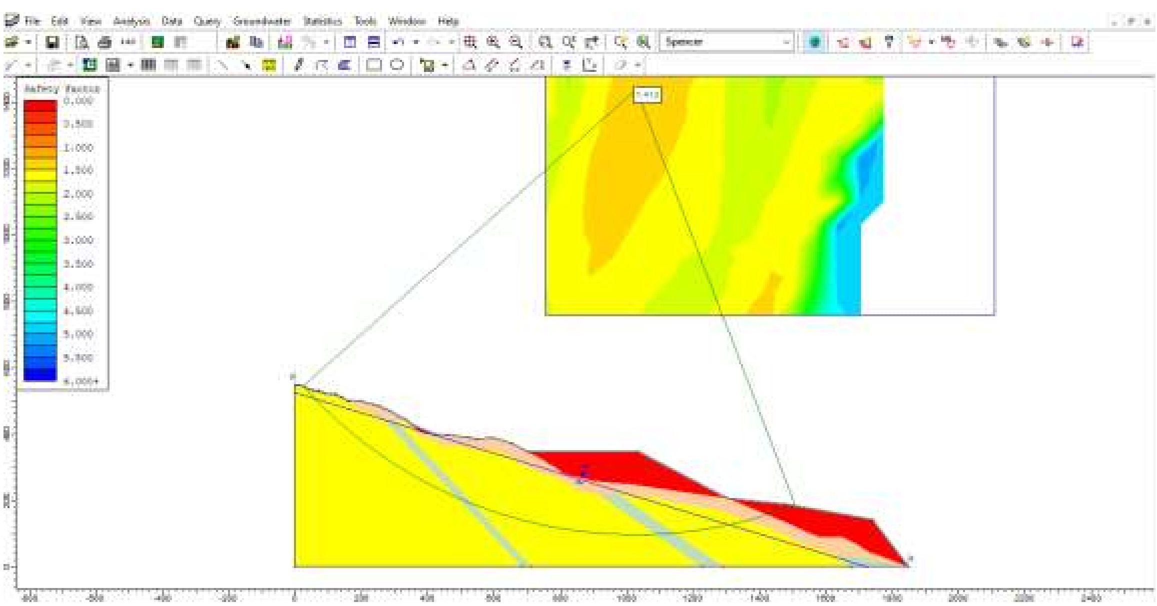

Figure 17 Danna Shaotar, Spencer with FOS 1.413

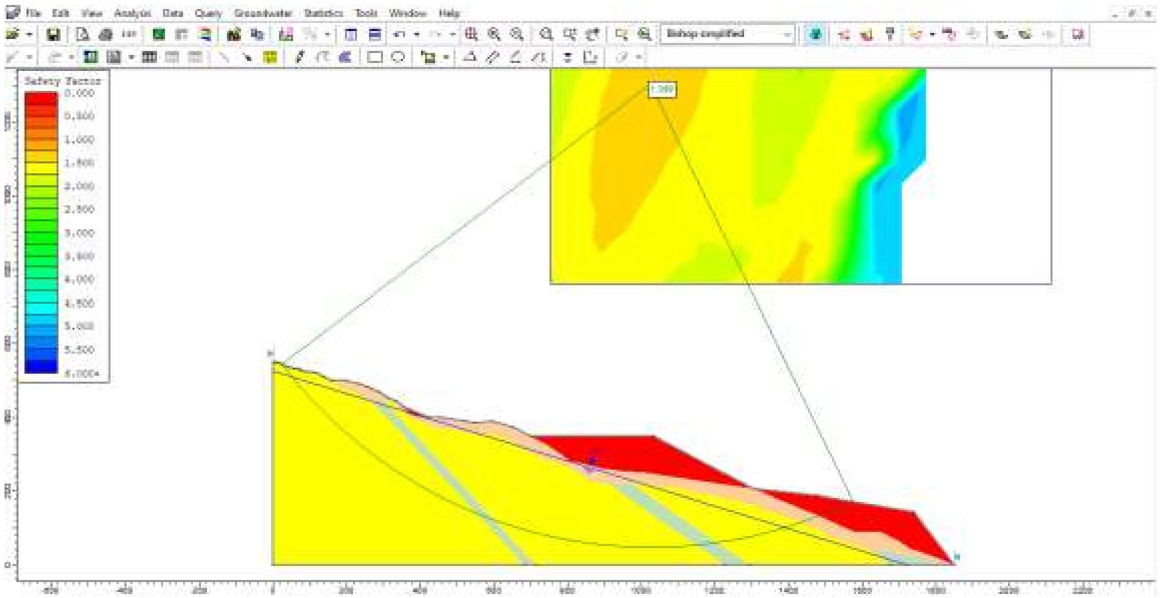

Figure 18 Danna Shaotar, Bishop Simplified with FOS 1.400

Qalandarabad Landslide

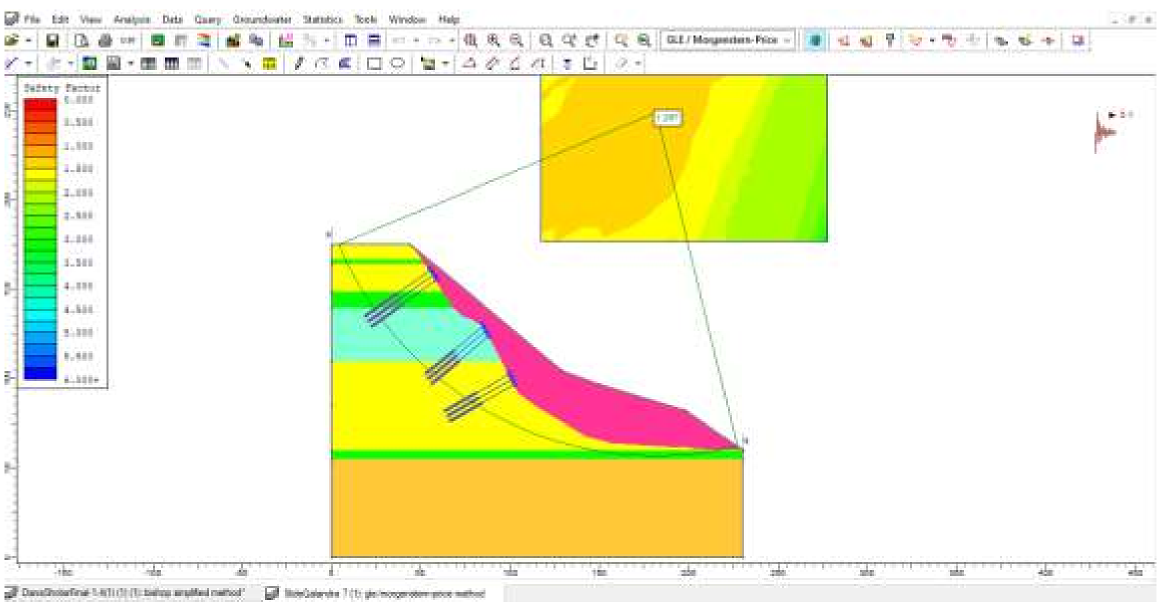

Figure 19 Qalanadarabad, GLE / Morgenstern Price with FOS 1.290

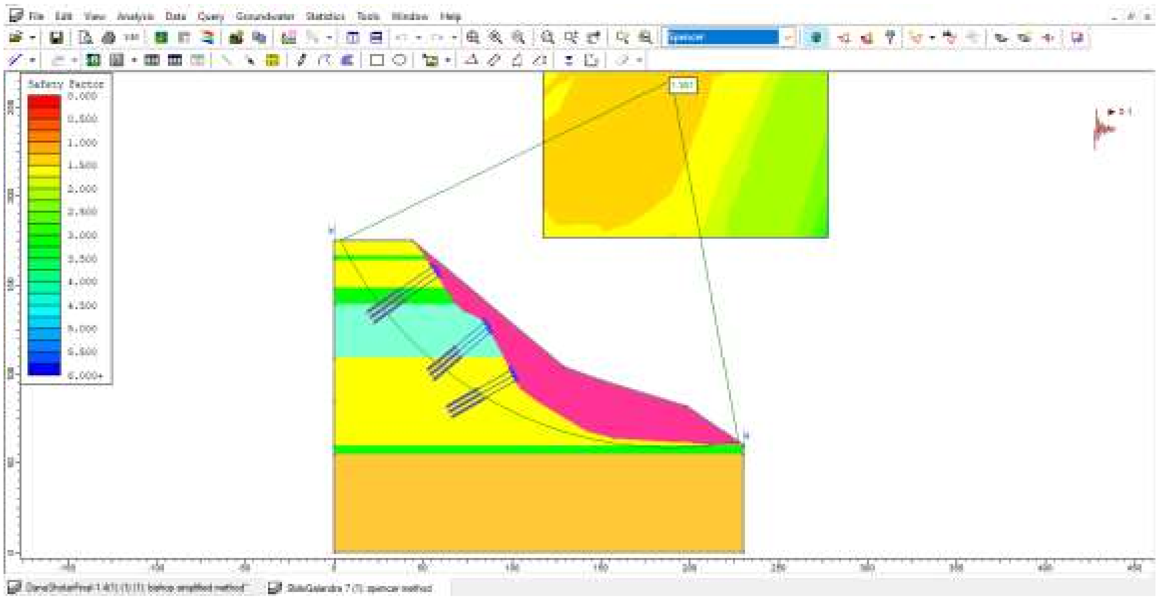

Figure 20 Qalandarabad, Spencer with FOS 1.301

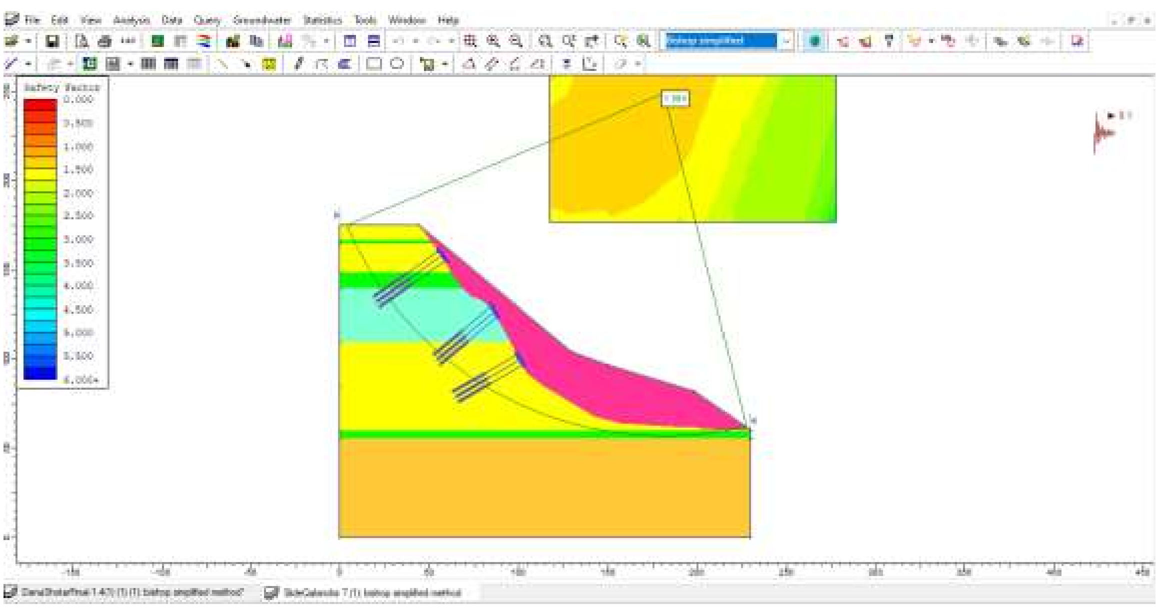

Figure 21 Qalandarabad, Bishop Simplified with FOS 1.304

References

[1] Islam, F., Riaz, S., Ghaffar, B., Tariq, A., Shah, S. U., Nawaz, M., ... & Aslam, M. (2022). Landslide susceptibility mapping (LSM) of Swat District, Hindu Kush Himalayan region of Pakistan, using GIS-based bivariate modelling*. Frontiers in Environmental Science, 10, 1027423*

[2] Khan, H., Shafique, M., Khan, M. A., Bacha, M. A., Shah, S. U., & Calligaris, C. (2019). Landslide susceptibility assessment using Frequency Ratio, a case study of northern Pakistan. *The Egyptian Journal of Remote Sensing and Space Science*, *22*(1), 11-24.

[3] Li, Y., Wang, X., & Mao, H. (2020). Influence of human activity on landslide susceptibility development in the Three Gorges area. *Natural Hazards*, *104*, 2115-2151.

[4] Shabbir, W., Omer, T., & Pilz, J. (2023). The impact of environmental change on landslides, fatal landslides, and their triggers in Pakistan (2003–2019). *Environmental Science and Pollution Research*, *30*(12), 33819-33832.

[5] Guzzetti, F., Carrara, A., Cardinali, M., & Reichenbach, P. (1999). Landslide hazard evaluation: a review of current techniques and their application in a multi-scale study, Central Italy. *Geomorphology*, *31*(1-4), 181-216.

[6] Clague, J. J., & Stead, D. (Eds.). (2012). *Landslides: types, mechanisms and modelling*. Cambridge University Press.

[7] B. Walker, "Northern Pakistan faces worst landslides in history," *Dialogue Earth*, Apr. 08, 2016. https://dialogue.earth/en/climate/pakistan-landslide

[8] Amin, M. N., Umair Ashfaq, M., Mujtaba, H., Ehsan, S., Khan, K., & Faraz, M. I. (2022). Computer-Aided Slope Stability Analysis of a Landslide—A Case Study of Jhika Gali Landslide in Pakistan. *Sustainability*, *14*(20), 12954.

[9] Amin, M. N., Umair Ashfaq, M., Mujtaba, H., Ehsan, S., Khan, K., & Faraz, M. I. (2022). Computer-Aided Slope Stability Analysis of a Landslide—A Case Study of Jhika Gali Landslide in Pakistan. *Sustainability*, *14*(20), 12954.

[10] Owen, L. A., Kamp, U., Khattak, G. A., Harp, E. L., Keefer, D. K., & Bauer, M. A. (2008). Landslides triggered by the 8 October 2005 Kashmir earthquake. *Geomorphology*, *94*(1-2), 1-9.

[11] Jambeck, J. R., Geyer, R., Wilcox, C., Siegler, T. R., Perryman, M., Andrady, A., ... & Law, K. L. (2015). Plastic waste inputs from land into the ocean. *Science*, *347*(6223), 768-771.

[12] Joseph, T. M., Azat, S., Ahmadi, Z., Jazani, O. M., Esmaeili, A., Kianfar, E., ... & Thomas, S. (2024). Polyethylene terephthalate (PET) recycling: A review. *Case Studies in Chemical and Environmental Engineering*, 100673.

[13] Ho, B. T., Roberts, T. K., & Lucas, S. (2018). An overview on biodegradation of polystyrene and modified polystyrene: the microbial approach. *Critical reviews in biotechnology*, *38*(2), 308-320.

[14] Hidalgo-Crespo, J., Moreira, C. M., Jervis, F. X., Soto, M., Amaya, J. L., & Banguera, L. (2022). Circular economy of expanded polystyrene container production: Environmental benefits of household waste recycling considering renewable energies. *Energy Reports*, *8*, 306-311.

[15] Lithner, D., Larsson, Å., & Dave, G. (2011). Environmental and health hazard ranking, and assessment of plastic polymers based on chemical composition. *Science of the total environment*, *409*(18), 3309-3324.

[16] Muhammad Haseeb (2023) “Mechanical Behaviour and Compaction Characteristics of Shredded Expanded Polystyrene Mixed Clayey Soils”, Master in Geotechnical Engineering, Department of Geotechnical Engineering, NUST Institute of Civil Engineering (NICE), (NUST), Islamabad

[17] Ho, B. T., Roberts, T. K., & Lucas, S. (2018). An overview on biodegradation of polystyrene and modified polystyrene: the microbial approach. *Critical reviews in biotechnology*, *38*(2), 308-320.

[18] Marten, B., & Hicks, A. (2018). Expanded polystyrene life cycle analysis literature review: an analysis for different disposal scenarios. *Sustainability: The Journal of Record*, *11*(1), 29-35.

[19] Khan, M. A., Basharat, (2021). An integrated geotechnical and geophysical investigation of a catastrophic landslide in the Northeast Himalayas of Pakistan. *Geological Journal*, *56*(9), 4760-4778.

[20] M. Waseem, M. Safdar, (2024) View of Slope Stability Analysis of the Qalandarabad Landslide. *Technical Journal, University of Engineering and Technology (UET) Taxila, Pakistan*

[21] Fredlund, D. G. (1967). Comparison of soil suction and one-dimensional consolidation characteristics of a highly plastic clay (pp. 193-201). Ottawa, Ontario, Canada: *National Research Council Canada, Division of Building Research.*

[22] Somantri, A. K., & Febriansya, A. (2019, December). The effect of EPS addition to soil stabilized with fly ash as lightweight fill materials for embankment construction. In *Journal of Physics: Conference Series* (Vol. 1364, No. 1, p. 012077). IOP Publishing.

[23] Holtz, R. D., & Schuster, R. L. (1996). Stabilisation of soil slopes. *Landslides Investigation and Mitigation, Eds. Turner AK and Schuster, RL, Special Report*, *247*.

[24] Abbasimaedeh, P., Ghanbari, A., O'Kelly, B. C., Tavanafar, M., & Irdmoosa, K. G. (2021). Geomechanical behaviour of uncemented expanded polystyrene (EPS) beads–clayey soil mixtures as lightweight fill. *Geotechnics*, *1*(1), 38-58.

[25] Rahardjo, P. P., Anggoro, B. W., Wijaya, M., & Seourin, D. P. (2023, October). EPS-Geofoam as Lightweight material for Replacement of Embankment Fill to Overcome Landslide Problems at STA 40+ 200 of Cisumdawu Toll Road, West Java. In *IOP Conference Series: Earth and Environmental Science* (Vol. 1249, No. 1, p. 012001). IOP Publishing.