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*Research Article*

# Analysis of the Stability of Reinforced Plastic Waste Treated Clay as Embankment Fill on Soft Soils

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The purpose of this study is to analyze the suitability and stability of clay soil treated with plastic waste as an embankment fill. Plastic wastes are used to stabilize the locally found weak clay. The locally found weak clay soil is stabilized with plastic waste. The stability analyses of the proposed slope have been done by finite element method using geotechnical software PLAXIS 2D. The stability analyses were performed for different conditions considering the geometry of the embankment, characterization of fill material, and the strength of reinforcement. Different models were analyzed to determine the safe height, side slope, and tensile strength of geogrid required to stabilize the embankment in addition to that of unreinforced embankments. The factor of safety of each trial is taken to check the stability of the modeled embankments. Accordingly, the factor of safety increases as geogrid axial stiffness increases greater than 500 kN/m. The analysis results revealed that with increasing slope height and slope angle the factor of safety decreases. This study found that plastic waste treated clay could be used as embankment fill when reinforced with geogrid.

## 1. Introduction

Now a day, all over the world many flexible and rigid pavements are constructed. These flexible and rigid pavements need to have stable embankments. Most of these flexible and rigid pavements are constructed on natural soft soils. Geotechnical engineers are facing many problems related to the complex behavior of soft soils. The embankments constructed over soft soils have been exposed to slope instability and large settlements, which cause huge damages [1, 2, 3].

The stabilization of soft soils has been implemented to overcome the erratic behavior of soft soils using various stabilizing agents. Mechanical and chemical stabilizations are the most commonly used stabilization techniques [4, 5, 6]. Recently, due to its serious environmental pollution, plastic wastes have been considered hazardous materials. Many pieces of research have been conducted to choose the best way of avoiding plastic environmental pollution. Techniques such as landfilling, recycling, and avoiding plastic use are the commonly recommended way. However, recent research was conducted to adapt the utilization of plastic wastes for soft soil stabilizations [7, 8, 9, 10]. In addition to this, to be cost-effective during embankment construction, using the locally available material with high shear strength is the best choice. Therefore, many scholars have been introducing plastic waste stabilized soil as an alternative. Various research studies done on the stabilization of weak soils using plastic waste products have revealed the suitability of plastic waste to stabilize the weak soils. These studies found that using plastic waste treated soft soil help to reduce plastic waste environmental pollution and to improve the shear strength properties of clay soils. The addition of plastic strips/chips to soft soils increases the shear strength parameters, minimizes the plasticity behavior, and modifies the permeability; which played an important role in keeping the stability of an embankment [7, 11, 12, 13, 14].

Recently, the structural performances of maintained and newly constructed flexible pavements have been improved by utilizing geosynthetic reinforcements. Geogrid reinforcements are the widely used types of geosynthetic products that are used to reduce fatigue strain and rutting strain. Mostly Geogrid reinforcements are placed at the interface between subgrade and subbase, base course and

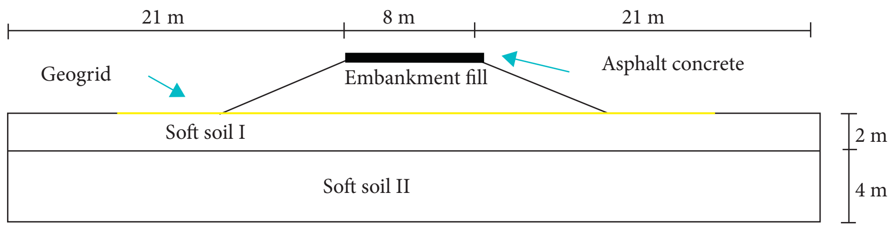



Figure 1: Modeled geometry of the unreinforced embankment.

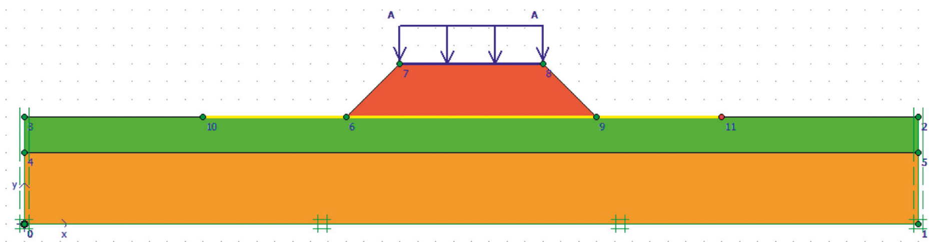


Figure 2: Modeled geometry of an embankment on PLAXIS 2D.

subbase, or within the subgrade layer [15, 16, 17]. Since the 1970s, the use of geogrid as soil reinforcement becomes popular. Many analytical and experimental studies have been investigated to quantify the effects of geogrid reinforcement on the performance of roadways. Field investigations, laboratory tests, and numerical modeling methods were performed to examine the effects of geosynthetic reinforcements on strength parameters and structural performances of the pavements [18, 19, 20].

The study has investigated the integration of geogrid in different pavement layers as reinforcement under both dynamic and static conditions. The study intended to examine the behavior of geogrid reinforced and unreinforced pavement layers subjected to both loading conditions. The study found that the reduction in horizontal strain was obtained when geogrid was placed at the interface between base course and bituminous concrete while a reduction in vertical strain was obtained when geogrid was placed at the interface of subgrade and base layers. The investigation on performance evaluation of geogrid reinforced and unreinforced pavement layers under cyclic loading conditions were done using different laboratory experiments on vertical deformation basis. The study found that the placement of geogrids at the bottom and interface of the base with subgrade resulted in a better reduction in vertical deformation [21, 22, 23, 24, 25, 26].

The purpose of this study is to determine the suitability of the plastic waste treated soil as embankment fill by determining the strength parameters of geogrid required to keep the stability of the embankment.

## 2. Method of Analysis

*2.1. Geometry Model.* For this study, an embankment with a horizontal width of 50 m, which was obtained by trials considering highly stressed zones and vertical width varies from 2 m to 4 m, was modeled as shown in Figures 1 and 2.

Table 1: The physical properties of plastic waste treated clay.

| Properties | Plastic waste treated clay embankment fill | Unit |
|---|---|---|
| Maximum dry density | 1.68 | ($g/cm^3$) |
| Optimum moisture content | 23.6 | (%) |
| CBR value soaked | 6.3 | (%) |
| Friction angle | 30 | (°) |
| Cohesion | 45 | (kPa) |

Table 2: Mechanical properties of geogrid reinforcement.

| Material | Elastic axial stiffness (KN/m) | Poisson' ratio |
|---|---|---|
| G-1 | 200 | 0.25 |
| G-2 | 500 | 0.25 |
| G-3 | 900 | 0.25 |
| G-4 | 1500 | 0.25 |

Two layers of soft clay with a thickness of 2 m and 4 m were considered as foundation soil. The water table is at the ground surface. The embankment was constructed from plastic waste treated clay subgrade, and asphalt concrete was assumed. The surcharge load of 50 $kN/m^2$ was considered as traffic load.

*2.2. Material Modeling.* A 15 node triangular elements and plane strain condition were considered for analysis. The right and left boundaries vertical displacement were allowed and horizontal displacement was fixed. Mohr–Coulomb criteria material model is considered for embankment fill and soft foundation soils. The required parameters for this model such as cohesion, Poisson's ratio, friction angle, elasticity modulus, and dilatancy angle are determined in the laboratory. The geosynthetic reinforcement is used to assess its effects on the subgrade layer strength of the embankment. Interface elements are used on both sides to model the

Table 3: Material properties of embankment and foundation soils.

| Soil properties | Foundation soil I | Foundation soil II | Embankment fill/plastic waste treated clay | Unit |
|---|---|---|---|---|
| Behavior | Undrained | Undrained | Drained | |
| ɣunsat | 15.5 | 16 | 18 | kN/m$^3$ |
| ɣsat | 17.5 | 18.5 | 20 | kN/m$^3$ |
| kx | 1.00E-04 | 5.00E-03 | 0.01 | m/day |
| ky | 1.00E-04 | 5.00E-03 | 0.01 | m/day |
| Eref | 2000 | 2500 | 11000 | kN/m$^2$ |
| v | 0.35 | 0.35 | 0.32 | |
| Cref | 24 | 28 | 45 | kN/m$^2$ |
| $\varphi$ | 10 | 8 | 18 | degree |
| $\psi$ | 0 | 0 | 0 | degree |
| Material model | Mohr-coulomb | Mohr-coulomb | Mohr-coulomb | |

Table 4: Material property of asphalt concrete.

| Asphalt concrete | EA (kN/m) | EI (kNm$^2$/m) | w (kN) | v |
|---|---|---|---|---|
| | 1,570,000 | 171,000 | 1.9 | 0.15 |

interaction between soil and geogrid. Mohr–Coulomb model is used to model the behavior of interfaces by considering interfaces' material properties same with adjacent soil material properties. The finite element analysis was performed for each construction sequence of an embankment. The geogrid reinforcement is placed at an interface of soft subsoil and embankment fill.

*2.2.1. Physical Properties of Plastic Waste Treated Clay.* The physical properties of the plastic waste treated clay were determined in the laboratory as shown in Table 1. The weak clay is stabilized using plastic waste strips with fixed dimensions of the strip. The plastic waste strips made of water bottles are used to stabilize the soil following the mechanical stabilization procedures. Plastic strips are manually cut and added to stabilize the expansive soil with percentages of 0.25%, 0.5%, 1%, 1.5%, and 2%. The optimum percentage of plastic waste strips required to stabilize the expansive soil for this study is found to be 1.5%. The addition of plastic waste strips resulted in significant improvement of strength parameters such as CBR value, and unconfined compressive strengths.

*2.2.2. Geogrid.* Geogrid is one type of geosynthetic polymeric product that is mostly used as a reinforcement material to increase soil strength. The nature of geogrid makes it suitable for this application since it has high durability, available in required various forms and ranges. They are widely used in roads, embankments reservoirs, minings, and agriculture areas. In this study, geogrids with different axial stiffness are used as shown in Table 2. The geogrid is placed at the interface of the embankment material and soft soil or at the toe level of the embankment.

*2.2.3. Material Properties of Embankment and Foundation Soils.* The properties of materials used in the model embankment are obtained from laboratory tests conducted on local soils. Accordingly, the material properties of foundation soils, and plastic waste treated clay soils are shown in Table 3.

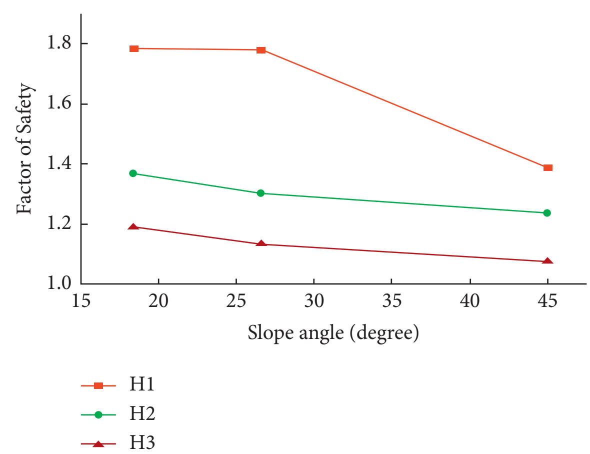



Figure 3: Factor of safety for unreinforced embankment geometry.

*2.2.4. Asphalt Concrete (AC) Layer.* In the present study, the behavior of asphalt concrete is described as the linear elastic model. The detailed material properties of the asphalt concrete are presented in Table 4.

*2.3. Traffic Loading.* The study included the application of gravity loads in the first load step of an analysis, and considering equivalent single axle load (ESAL) of 80 kN single axle wheel loading, as loading representative as per ERA recommends. Then, the equivalent single axle load (ESAL) of 80 kN is converted to a working linear distributed load as 50 kN/m$^2$. The 50 kN/m$^2$ load is distributed over the road lane at the top of the embankment over the asphalt concrete as shown in Figure 2.

## 3. Method of Analysis

The suitability of plastic waste treated clay soil as subgrade material was analyzed for both reinforced and unreinforced conditions were analyzed by PLAXIS 2D. The embankment was modeled at different embankment height varying from 1 m to 3 m (H1 = 1 m, H2 = 2 m, and H3 = 3 m) with varying

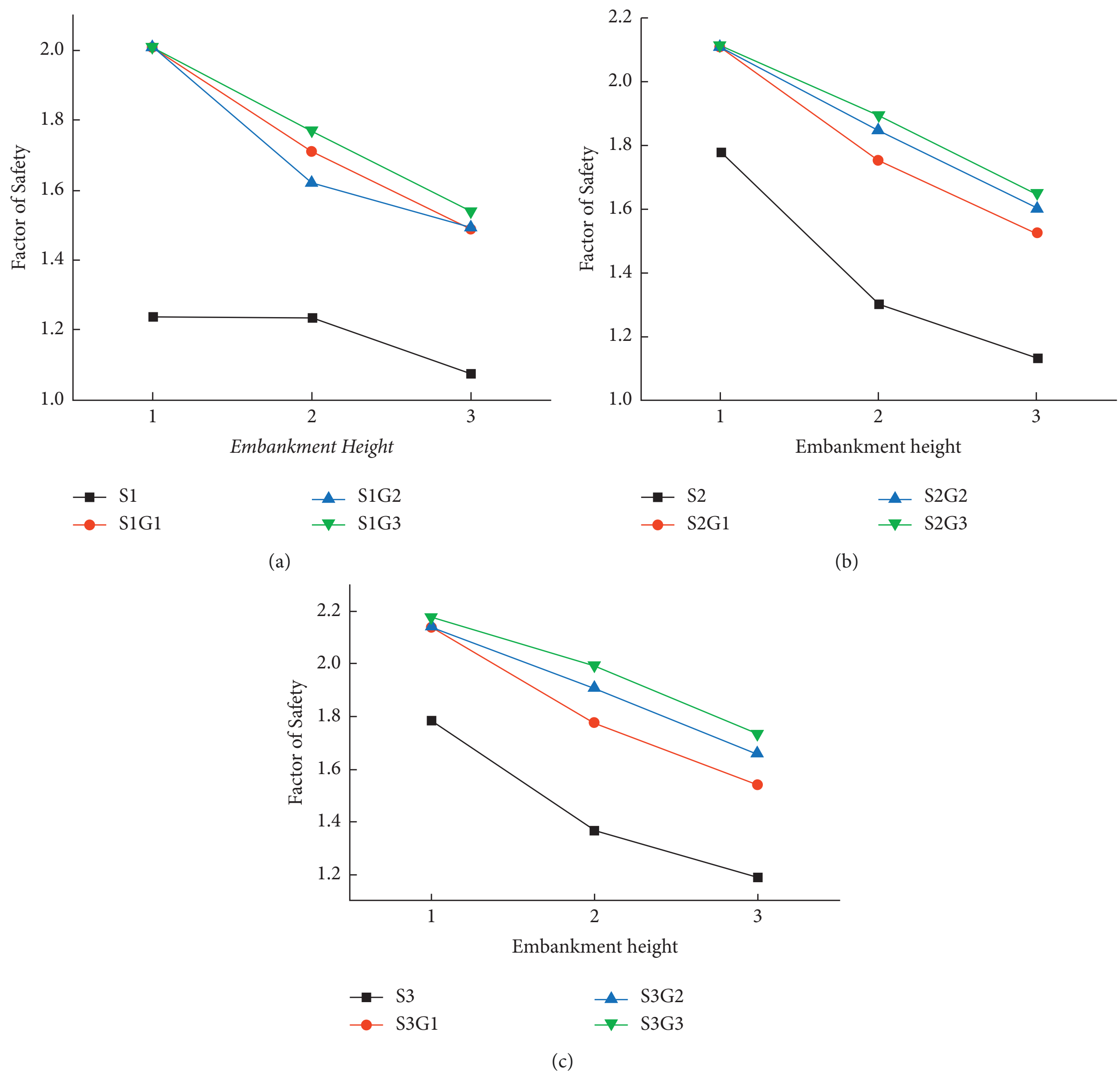



Figure 4: The effect of slopes on a factor of safety of the embankment (a) for S1 (b) for S2 and (c) for S3.

side slopes (S1 = IV : 1H, S2 = 1V : 2H, S3 = IV : 3H). The stability of the embankment was analyzed with and without geogrid of varying tensile strength ranges from 200 kN/m to 900 kN/m.

Stability analysis is performed to assess and determine the safe design of natural slopes and human-made slopes such as embankments at equilibrium conditions. The design of road embankment is highly dependent on the determination of the factor of safety. In most cases, the acceptable value of the factor of safety is 1.5 and more in the design of a stable embankment slope. In this study, the finite element method that uses the stress-strain behavior of the soil is selected to analyze the embankment.

## 4. Result and Discussion

Embankments on soft soils made up of lightweight fill materials require careful slope stability analysis. So, an in-depth slope stability analysis is performed in this study since the embankment fill material is lightweight plastic waste treated clay soil. In case, when the factor of safety of an embankment is analyzed to be lower than required, additional reinforcement can be provided. Many pieces of research proved that providing geosynthetic reinforcements was found effective in improving the factor of safety and minimizing the displacement of the embankments. In this study, the effects of providing geogrid reinforcement on the factor of safety and displacement of the embankment are analyzed.

*4.1. Analysis of Unreinforced Embankment.* The factor of safety for unreinforced embankment fill is determined to check the stability of the embankment. The analysis shows that with an increase in embankment height and slope angle, the stability of the embankment decreases. The factor of safety decreased from 1.78 for 1 m embankment height to 1.19 for 3 m embankment height at a side slope of IV : 3H. The details of these analyses are shown in Figure 3.

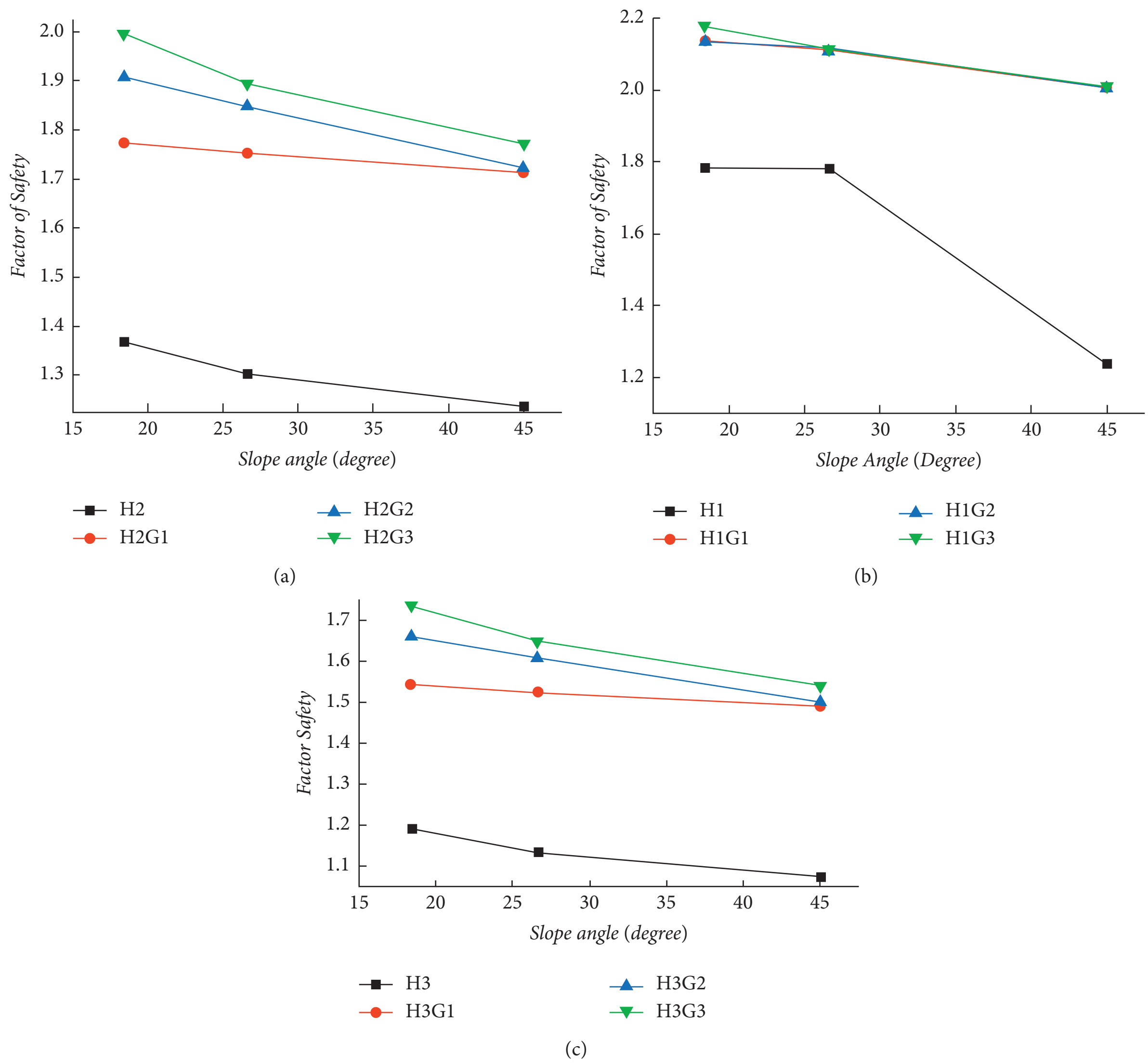



FIGURE 5: Effects of embankment heights on its stability (a) for H1, (b) for H2, and (c) for H3.

### 4.2. Factor of Safety

*4.2.1. Slope Height and Factor of Safety.* The first analysis was done to determine the safety factor of an embankment by increasing the slope height from 1 m to 3 m gradually by considering other parameters as constant. The analysis was performed for 1 m, 2 m, and 3 m slope heights for different side slopes, geogrid stiffness, and reinforced and unreinforced embankment conditions. The analysis shows that the factor of safety decreases with an increase in slope height. From the statistical analysis, the coefficient of correlation shows an opposite strong relationship between factors of safety and slope height. An increase in slope height leads to a linear decrease in the factor of safety as shown in Figure 4. The slope height and factor of safety are related to each other with opposite relationship. The correlation analysis shows the opposite relationship between slope height and factor of safety with an average correlation coefficient of $r = 0.999$ and 0.966 for unreinforced and reinforced embankments, respectively.

*4.2.2. Factor of Safety and Slope Angle.* The second analysis is performed to determine the factor of safety by increasing the side slope from IV : 1H to IV : 3H for different geogrid strengths and height of an embankment. The water table level, slope height, and geogrid strength are kept constant while slope angle varies as IV : 1H, IV : 2H, and IV : 3H. As shown in Figure 5, the factor of safety decreases with an increase in slope angle for constant slope height and geogrid strength. This shows that the stability of an embankment is positively related to the slope angle. The analysis revealed that plastic waste treated clay soil reinforced with geogrid at the interface between foundation soil and fill could be used as embankment fill safely with a side slope up to IV : 2H.

An increase in slope angle resulted in a decrease in the factor of safety as shown in Figure 5. For unreinforced embankment, a strong opposite relationship is observed between the factor of safety and slope angle with an average coefficient of correlation of $r = -0.971$. This indicates that the association between a factor of safety and slope angle is

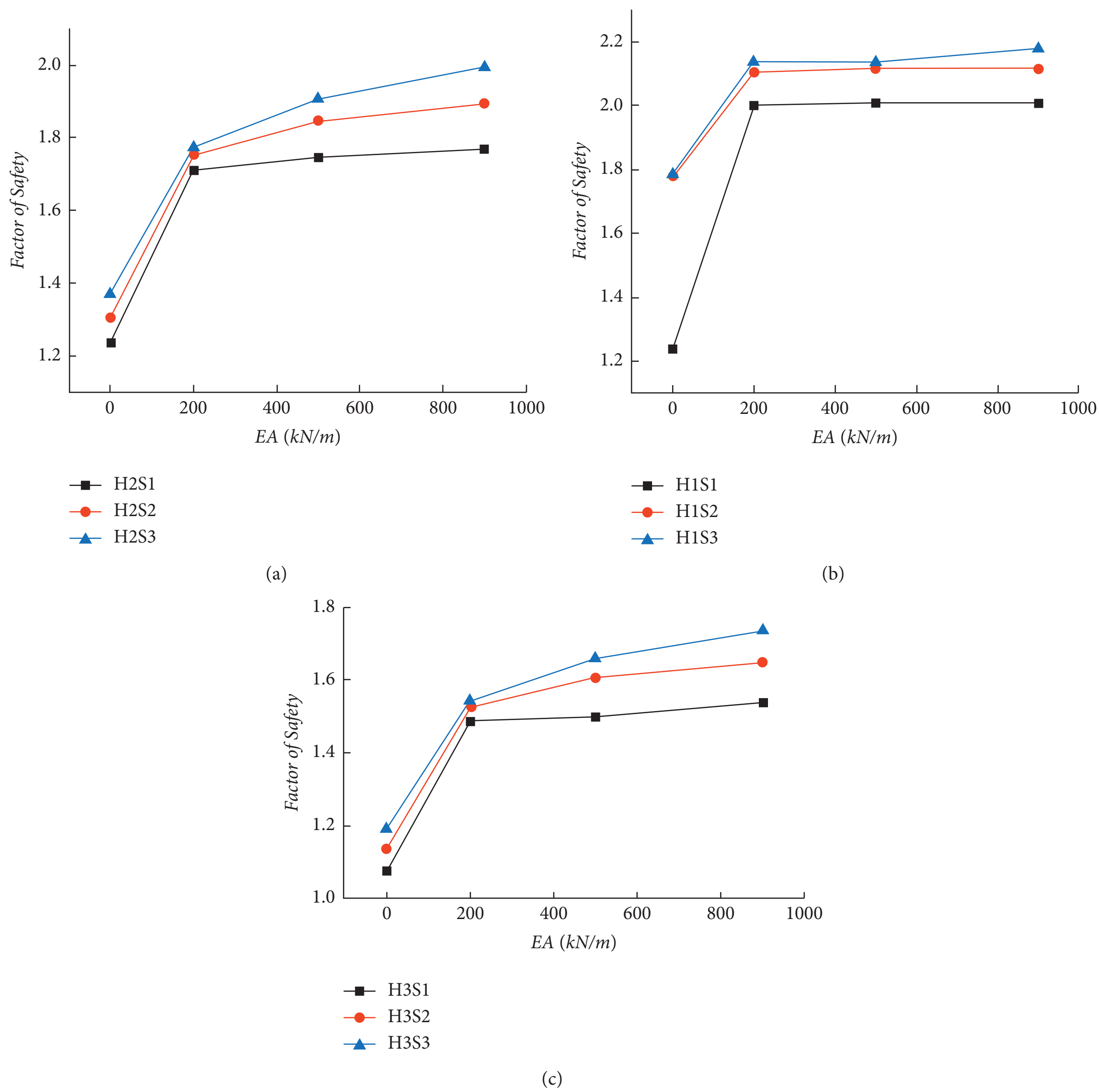



Figure 6: Effects of axial stiffness of geogrids on the factor of safety of the embankment (a) for H1, (b) for H2, and (c) for H3.

significant. The correlation coefficient of −0.971 show a strong negative relationship which indicates that when one variable start decreasing the other variable starts increasing. For reinforced embankments, the slope angle correlated to the factor of safety with an average correlation coefficient of $r = -0.992$, which shows a strong association.

*4.2.3. Factor of Safety and Geogrid Axial Stiffness.* The third analysis is performed on the determination of factors of safety for different geogrid axial stiffness at constant slope height, side slope, and water table level. Geogrid with axial stiffnesses of 200, 500, and 900 kN/m is considered in this study. The geogrid reinforcement is placed at the interface boundary of the foundation soils and treated embankment fill. A significant improvement of a factor of safety of the embankment is observed from the analyses as shown in Figure 6. H and S represent the slope height and slope angles respectively.

The maximum factor of safety improvement is observed for a 1 m high embankment with 1V : 1H side slope orientation with an increase of a factor of safety from 1.22 to 2.04. This shows a 67%, 63%, and 58% increase in factor of safety when geogrid with axial stiffness of 200, 500, and 900 kN/m are used, respectively. The finite element analysis shows that the stability of the embankment is highly affected by the geogrid strength. As shown in Figure 6, variation in geogrid strength resulted in a significant difference in the stability of the embankment. The geogrid EA is positively related to the factor of safety of the embankment with a correlation

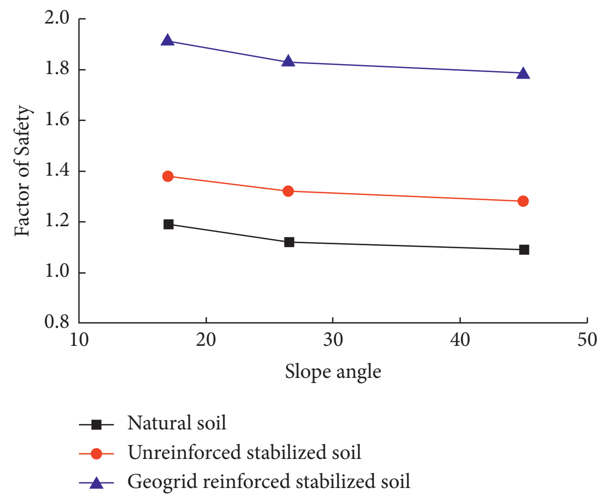



FIGURE 7: Comparison of factor of safety for embankment constructed of natural soil, unreinforced plastic stabilized soil and geogrid reinforced plastic stabilized soil.

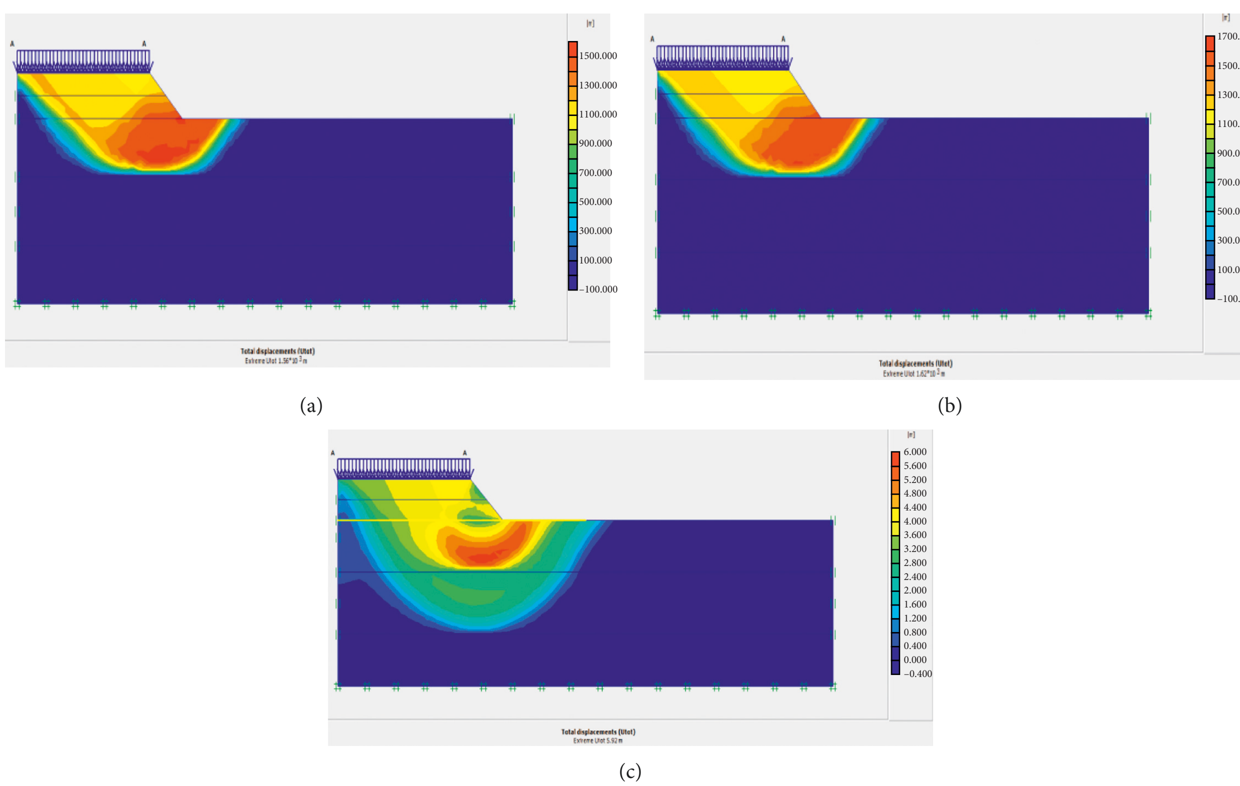
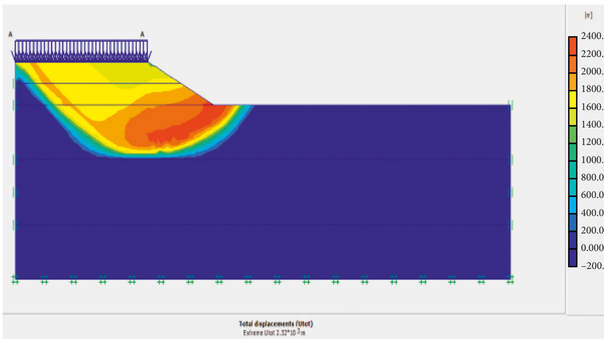



FIGURE 8: Total displacements of H2S1. (a) Natural soil (b) unreinforced stabilized soil. (c) Geogrid reinforced stabilized soil.

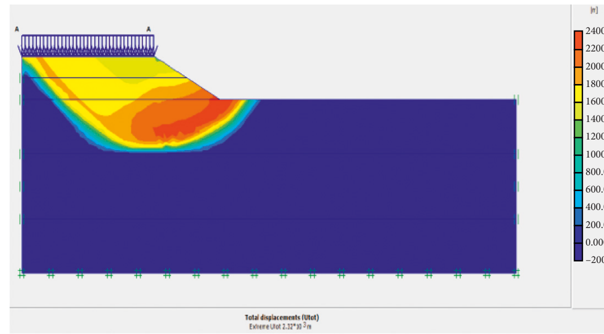
coefficient of $r = 0.899$. This shows that, with an increase in geogrid strength, the factor of safety of the embankment linearly increases.

*4.3. Comparison between Embankment Constructed of Natural Soil, Unreinforced, and Reinforced Plastic Stabilized Soil.* The factor of safety of the embankment constructed from natural soil, unreinforced plastic stabilized soil, and geogrid reinforced plastic stabilized soil were analyzed and the comparison was carried out. The analyses were done by considering the models with H2 and G2 at different slope angles. Therefore, the analyses were done for a single slope height and different slope angles for natural soil, unreinforced plastic stabilized soil and geogrid reinforced plastic stabilized soils as embankment materials.

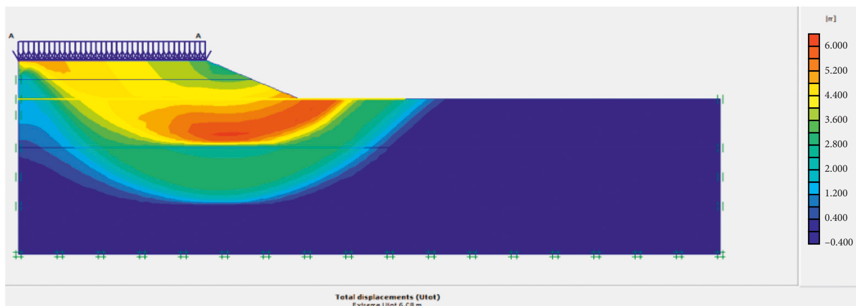
The factor of safety for unreinforced plastic stabilized embankment is greater than that of the embankment constructed of natural soil. The factor of safety for reinforced plastic stabilized soil as embankment material are much




(a)

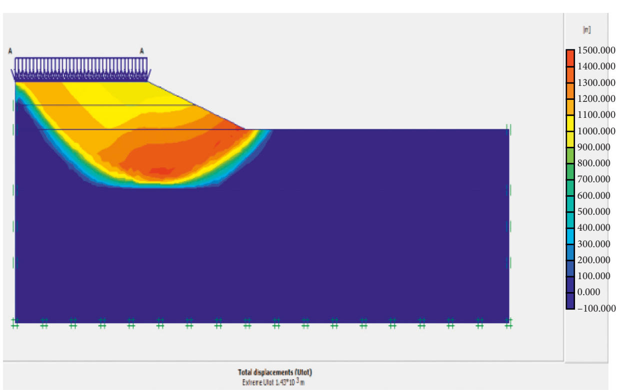



(b)

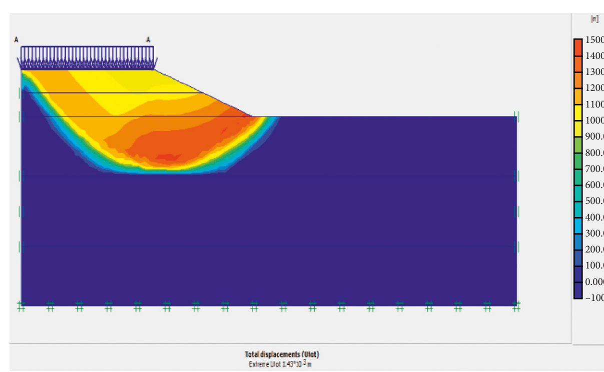



(c)

Figure 9: Total displacements of H2S2. (a) Natural soil (b) unreinforced stabilized soil. (c) Geogrid reinforced stabilized soil.




(a)

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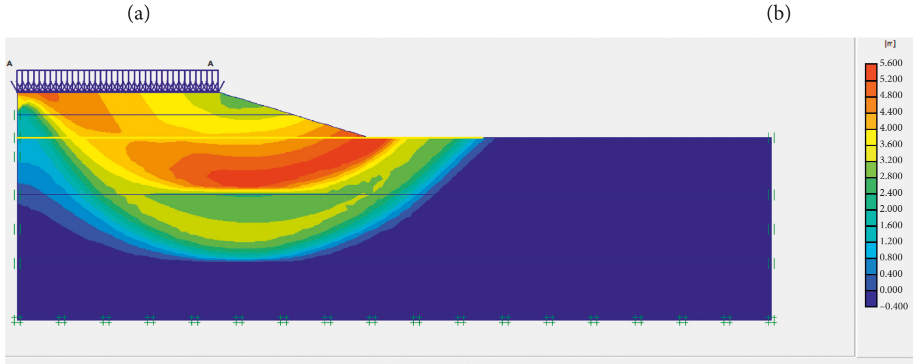


(c)

Figure 10: Total displacements of H2S3. (a) Natural soil (b) unreinforced stabilized soil. (c) Geogrid reinforced stabilized soil.

greater than that of the unreinforced and natural soil as shown in Figure 7.

The study showed that the total displacement of embankment constructed from geogrid reinforced plastic stabilized soil is much less than that of the natural soil and unreinforced stabilized embankment materials as shown in Figures 8–10.

## 5. Conclusion

In this study, the stability of embankment filled with plastic waste treated clay soil is analyzed using the finite element method PLAXIS 2D. Different embankment models with varying slope height, slope angle, and geogrid strength are analyzed. The results obtained from these analysis shows that the factor of safety of an embankment increases with an increase in geogrid strength, decrease in slope angle, and slope height. An increase in slope height and slope angle leads to a drop in the factor of safety. The unreinforced embankments filled with plastic waste treated clay soil at different slope heights and slope angles are seen to be unstable since their factor of safety are less than 1.5. However, the provision of geogrid reinforcement highly improves the factor of safety of embankments.

It is observed that the factor of safety tends to increase with increases in axial stiffness of geotextile reinforcement greater than 500 kN/m. With the use of geogrid reinforcement, plastic waste treated clay soil can be used as embankment fill up to 3 m slope height safely. The study concluded that plastic waste treated clay soil can be used as embankment fill for embankment height less than 3 m and side slope greater than IV : 2H.

## Abbreviations

FS: Factor of safety
H1: Embankment height 1 (1 m)
H2: Embankment height 2 (1 m)
H3: Embankment height 3 (1 m)
S1: Side slope 1 (IV : 1H)
S2: Side slope 2 (IV : 2H)
S3: Side slope 3 (IV : 3H)
G1: Geogrid axial stiffness 1 (200 kN/m)
G2: Geogrid axial stiffness 2 (500 kN/m)
G3: Geogrid axial stiffness 3 (900 kN/m).

## Data Availability

The data used to support the findings of this study are included in the article.

## Conflicts of Interest

The author declares that there are no conflicts of interest.

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