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# Numerical Analysis of Geogrids and Recycled Concrete Aggregate for Stabilizing Road Embankments

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**ABSTRACT**

The amplification of urban development and the extension of road networks necessitate a comprehensive understanding of various soil improvement techniques for civil engineering applications. Soil enhancement methods, typically trusted and practical, are pivotal in addressing geotechnical engineering challenges. This study focuses on the numerical evaluation of the efficacy of geogrids and recycled concrete aggregate (RCA) in the stabilization of road embankments. Critical soil properties such as water absorption, soil erosion, and settlement susceptibility are significantly improved through these methods, promoting sustainable land use, environmental conservation, and infrastructure durability. Literature reveals that the use of geogrids or waste materials like RCA contributes effectively to soil layer enhancement. In this investigation, road embankment models, with and without the aforementioned improvements, were developed and assessed under vehicular load conditions. The findings demonstrated that the incorporation of geogrids or RCA significantly bolsters the stability of road embankments. A noteworthy reduction in vertical settlement, up to 45%, was achieved when geogrids and RCA were concurrently utilized in the embankment. This suggests that these methods, individually or in combination, could provide a viable solution for enhancing the performance and stability of road infrastructures. Further research is proposed to explore the long-term performance of these enhancement methods under various environmental and load conditions.

## 1. INTRODUCTION

The burgeoning urbanization and escalating road traffic worldwide have necessitated the construction of numerous road embankments on soft clay soil, a trend that shows no signs of abating. Road embankments, comprised of compact layers of soil, gravel, or other suitable materials, are integral elements of road infrastructure, providing critical stability and support for roads traversing hilly or uneven terrains. Additionally, they serve as a bulwark against flooding and erosion in low-lying regions and are instrumental in the creation of bridges and overpasses.

However, the establishment of these embankments is not without its challenges. Civil engineers frequently grapple with substantial settlements and slope instability, indicative of the common difficulties encountered during road embankment construction. Rigorous comprehension of site-specific geological and environmental conditions, coupled with an understanding of the materials and techniques utilized in construction, is indispensable for ensuring the safety, durability, and long-term performance of road infrastructure [1].

Instability of road embankments, a prevalent issue, ensues when the supporting soil and rock fail to bear the road's weight, as depicted in Figure 1. A myriad of factors can precipitate this instability, including deficient design, improper construction, and environmental influences such as heavy rainfall, earthquakes, or landslides.

**Figure 1.** Damage to road as a result of landslide (Image posted by VNExpress)

Inadequate drainage, improper soil compaction, and alterations in groundwater levels and soil properties due to construction activities or natural processes further exacerbate the problem. The repercussions of road embankment failure are substantial, potentially leading to road closures, traffic disruptions, and, in the worst case, loss of life. Consequently, regular inspection and maintenance of road embankments are of paramount importance for the prevention of instability and the safeguarding of road users.

Several remedial measures can enhance the stability of road embankments. Adherence to appropriate design and construction practices, including proper soil compaction, drainage, and consideration of environmental factors such as groundwater levels and seismic activity, is imperative. Routine inspections to detect instability signs, such as cracking or settling, are recommended, with prompt repairs to preclude further damage. The planting of vegetation on embankment slopes can stabilize the soil and curtail erosion, while the reinforcement of the embankment with geosynthetics or other materials can bolster its stability [2, 3].

Over the past decades, numerous experimental and numerical studies have been conducted to evaluate the efficacy of these stabilization methods [4-8]. Several reports have demonstrated the utility of terrestrial synthetic materials as reinforcement in road embankments constructed on soft soils [9, 10]. Further, the use of geotextiles and concrete residues for soil stabilization has also been documented [11].

Despite the wealth of literature on the subject, additional parametric studies are needed to delve deeper into the topic and provide practical engineers with more comprehensive guidance. In light of this, the present study aims to numerically investigate the performance of geogrids and recycled concrete aggregate in the stabilization of road embankments.

### 1.1 Road embankment stability using geogrids and geosynthetics

Geogrids and geosynthetics are synthetic materials made from polymers and are designed to be placed in the soil. They provide an additional layer of support to the embankment, which helps to distribute the load more evenly across the soil. This reduces the likelihood of the embankment settling or shifting, which can lead to instability. Basically, geogrids and geosynthetics provide fairly distribution of the load exerted on the soil through various mechanisms including interlocking with soil particles, redistributing horizontal stresses, transferring loads to more strong soil layers, and improving the overall reinforcement of the soil. The utilization of this load distribution mechanism allows the reduction of deformations, enhancement of stability, and improvement of performance in a wide range of engineering structures. A biaxial geogrid is shown in Figure 2.

**Figure 2.** Biaxial geogrid [12]

Additionally, geogrids can improve drainage and prevent soil erosion by creating a barrier between the soil and the surface of the embankment. This can help to prevent water from seeping into the soil and weakening it, which is a common cause of embankment instability. Geogrids can be installed during construction or retrofitted onto existing embankments as a cost-effective solution to improve stability and extend the lifespan of the road. By using geogrids, road embankments can be made more resilient against instability and provide a safer and more reliable transportation network for users.

### 1.2 Road embankment stability using recycled concrete aggregate (RCA)

Recycled concrete aggregate (RCA) is a material that is created from the recycling of concrete waste. Concrete waste is crushed into small pieces and then screened to remove any contaminants, such as metal or wood, as shown in Figure 3. The resulting material is called RCA and can be used in a variety of construction applications, including road and pavement construction, as a replacement for traditional aggregates such as gravel or crushed stone. RCA has several benefits over traditional aggregates, including reduced cost and environmental impact, as well as improved durability and strength.

The application of RCA results in the enhancement of embankment stability and strength through various mechanisms. These include the improvement of compaction, the generation of internal friction, the facilitation of effective drainage, the reduction of lateral pressure, the efficient distribution of loads, and the mitigation of consolidation and settlement. Moreover, the incorporation of RCA promotes sustainability and cost-effectiveness in embankment construction.

**Figure 3.** Recycled aggregates [13]

## 2. RESEARCH METHODOLOGY

PLAXIS2D [14] is a strong geotechnical finite element analysis software that works very well for modeling geogrids to improve the stability of embankments. Its special features make it possible to accurately represent how geogrid behaves, so engineers can accurately simulate how the reinforcement affects embankments. The software makes it easy to simulate real-world situations because it can model how materials behave, define boundary conditions, and do advanced types of analysis. PLAXIS2D helps you understand stress, deformation, and load-displacement data by giving you easy-to-use visualization tools. Engineers can use its parametric study features to find the best geogrid properties and configurations for the best embankment performance. After going through a lot of testing, you can be sure that PLAXIS2D can accurately show how geogrid-reinforced embankments behave. Whether you have a lot of experience with numerical modeling or are just starting out, PLAXIS2D's easy-to-use interface makes analysis quick and accurate. This helps you design safe and stable embankment structures.

### 2.1 Description of the models

The 4m of embankments with slopes as 2:1 as presented in Figure 4 was investigated in this study. The water level was at surface. A nominal surcharge of 5.5 kN/m has been used for modeling the traffic load. A layer of reinforcement is placed between the base of embankment and the soft clay layer.

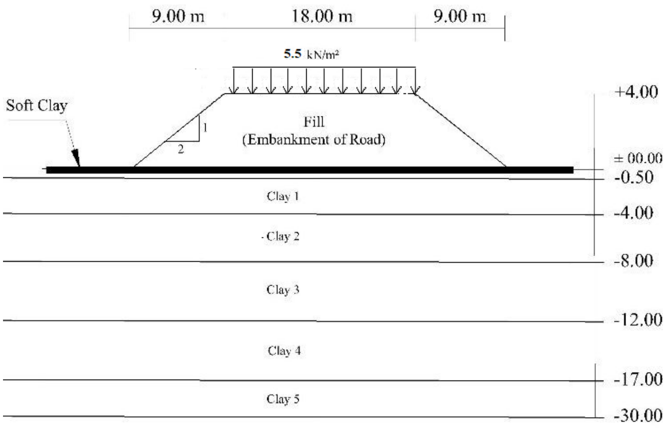


**Figure 4.** Geometrical design

The fill and the entire soil material were modeled as Mohr Coulomb. Table 1 summarizes soil properties used in the PLAXIS modeling.

Five distinct models were built and examined, including an unmitigated embankment serving as a baseline for comparison against embankment models employing various mitigation techniques.

(1) Embankment only without any improvement.
Stages of construction:
Initial phase.
Installation of embankment.
Application of traffic load.

(2) Embankment with geogrid (between the first soil layer and embankment). Table 2 shows the specifications of the geogrid used in the model.
Stages of construction:
Initial Phase.
Installation of embankment
Installation of geogrid. First, the properties of geogrid were defined in the material definition section of PLAXIS2D. Then, using the geogrid element definition, it was modelled and placed in the intended location of the model.
Application of traffic load.

(3) Embankment with geogrids at different levels (embankment + geogrids in the middle).
Stages of construction:
Initial phase.
Installation of half embankment.
Installation of geogrid
Installation of rest of the embankment
Application of traffic load.

(4) Embankment with recycled concrete aggregate.
RCA specifications are listed in Table 1.
Stages of construction:
Initial phase.
Installation of embankment.
Installation of 0.5m of recycled concrete layer. First, the properties of RCA were defined in the material definition section of PLAXIS2D as a new kind of soil body. Then, it was modelled and placed in the intended location of the model. It should be noticed that the 0.5m thickness for RCA is an assumption. More parametric studies with different thicknesses can be done to find the optimum thickness of RCA in stabilizing the embankment.
Application of traffic load.

(5) Embankment with recycled aggregate and geogrids.
Stages of construction:
Initial phase.
Installation of embankment.
Installation of 0.5m recycled concrete layer.
Installation of geogrid on top of the recycled concrete layer.
Application of traffic load.

## 3. RESULTS AND DISCUSSION

Once the numerical analysis of the five constructed models was completed, results were obtained and compared. Figure 5 presents a graphical illustration of total displacement responses on top of the embankment for different models. According to this figure, under traffic load, the embankment without improvement showed a higher value of displacement. It is noticeable that the second and third models (embankment with geogrid) showed almost the same displacement values as that of the case without improvement. It is concluded that one layer of geogrid may not be sufficient to improve the strength of the embankment. More geogrids are needed, such as multilayered geogrids, to enhance the embankment's performance. Although the embankment employing the geogrid exhibited a higher ultimate settlement in comparison to the other methods, this discrepancy can be attributed to the requirement for a greater number of steps to attain stated settlement. The explanation of this phenomenon can potentially be accomplished by considering the incorporation of additional steps. This method enables the gradual application of forces, adjustments in boundary conditions, and enhancements in material properties. Consequently, it assures a thorough examination of the system's response and stability.

While considering models 4 and 5, it was observed that using RCA could significantly decrease the total settlement of the embankment. It confirms the efficiency of using recycled waste materials like crushed concrete in the improvement of embankments against traffic-induced settlements. The mechanical properties of RCA are advantageous, as they possess adequate strength and stiffness, which contribute to their ability to effectively withstand and distribute loads generated by traffic. The irregular shapes of RCA particles enhance the interlocking and compaction of particles within the embankment material, leading to the development of a resilient matrix that can prevent deformation and evenly distribute applied loads.

Figures 6, 7 and 8 demonstrate the total, lateral, and vertical displacements versus the number of loading steps for constructed models. Again, it was seen that the best performance and the lowest settlements was presented in the case where the embankment was reinforced with RCA and geogrids, Simultaneously. It is because of the high compressive strength of the crushed concrete aggregates and high tensile strength of geogrids under pressure applied by the traffic loads. According to Figure 6, total settlement of embankment reinforced with RCA and geogrid is almost 45% less that that of embankment withoy mitigation.

Both geogrids and RCA have benefits for stabilizing embankments, but there are also things to think about with each. Geogrids may have problems with installation, durability, and being able to support vertical loads. In the same way, the effectiveness of RCA can be affected by differences in the material, the presence of possible contaminants, and problems with gradation. To work around these problems and make sure the embankment stabilization works, both solutions need to be carefully planned, tested, and watched.

**Table 1.** Configuration parameters of soil layers

| Name | Material Model | Drainage Type | $\gamma_{sat}$ | $\gamma_{unsat}$ | E (kN/m$^2$) | C (kN/m$^2$) | φ (º) |
|---|---|---|---|---|---|---|---|
| Soft Clay | Mohr-Coulomb | Undrained | 23.5 | 18 | 30000 | 10 | 25 |
| Clay1 | Mohr-Coulomb | Undrained | 17.5 | 16.5 | 2000 | 33 | 1 |
| Clay2 | Mohr-Coulomb | Undrained | 17.5 | 16.5 | 2000 | 12 | 1 |
| Clay3 | Mohr-Coulomb | Undrained | 17.5 | 16.5 | 2000 | 47 | 1 |
| Clay4 | Mohr-Coulomb | Undrained | 17.5 | 16.5 | 2000 | 119 | 1 |
| Clay5 | Mohr-Coulomb | Undrained | 17.5 | 16.5 | 2000 | 164 | 1 |
| Fill | Mohr-Coulomb | Drained | 18 | 16.5 | 50000 | 10 | 28 |
| RCA | Linear elastic | Non-porous | 24 | 18 | 26000 | - | - |

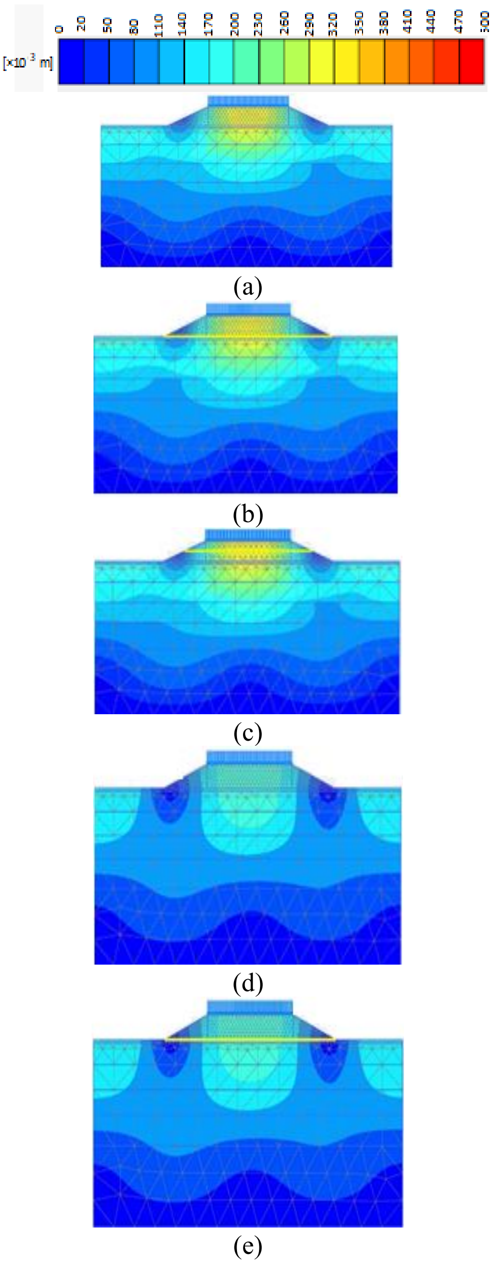


**Figure 5.** Total displacement (a) model 1, (b) model 2, (c) model 3, (d) model 4, (e) model 5

**Table 1.** Geogrid properties

| Specifications | Standard Values |
|---|---|
| Type of mesh | Rectangular apertures |
| Type of polymer | Polypropylene |
| Aperture size mesh | 41 mm |
| Mass per unit area | 250 g/m$^2$ |
| Strength at 2% strain | 7 kN/m |
| Strength at 5% strain | 14 kN/m |
| Peak tensile strength | 20 kN/m |

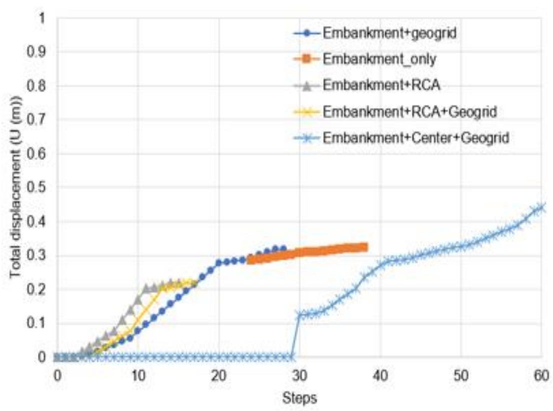


**Figure 6.** Total displacement

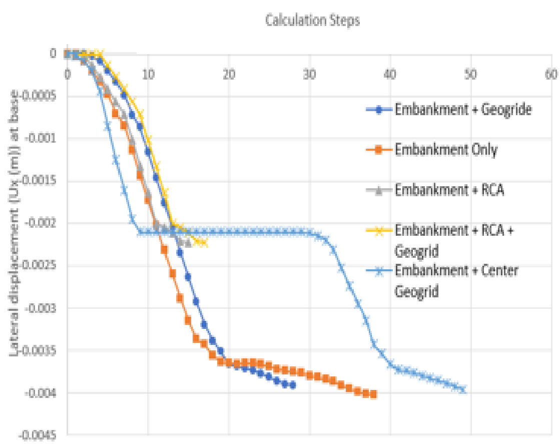


**Figure 7.** Lateral displacement

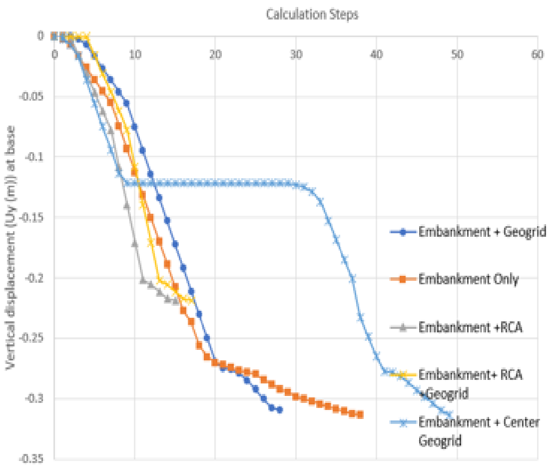


**Figure 8.** Vertical displacement

## 4. CONCLUSIONS

This paper evaluates the effectiveness of using geogrid and recycled concrete aggregate in decreasing the traffic-induced lateral and vertical displacement of embankments. Using a finite element program to analyze the embankment models with and without improvement methods discussed in this study, it was concluded that using geogrid and recycled concrete aggregate can be considered as effective methods to reduce traffic-induced settlements. According to the findings presented in this study, using only geogrids could reduce the total settlement of the embankment up to 5%. Moreover, using geogrid with recycled concrete aggregate could reduce the total settlement up to 45%.

As research in geotechnical engineering moves forward, these new materials help design methods that are flexible and cost-effective. As more projects use geogrids and RCA successfully, regulatory guidelines may make them even more important to future embankment projects. The interaction between performance, sustainability, and regulatory expectations improves geotechnical practices and leads to construction that is stronger, more efficient, and better for the environment.

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## NOMENCLATURE

| | |
|---|---|
| E | Young's Modulus |
| C | Cohesion |
| $\gamma_{sat}$ | Saturated Unit Weight |
| $\gamma_{unsat}$ | Unsaturated Unit Weight |
| φ | Angle of Internal Friction |