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ANALYSIS OF EMBANKMENTS REINFORCED WITH GEOTEXTILE

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Abstract: Embankments play a vital role in the transportation infrastructure, serving as essential components of roads, railways, and airports. The stability and deformation behavior of embankments are influenced by various factors, including soil type, embankment height, and traffic loads. Geotextile reinforcement has emerged as a promising solution to enhance the stability and deformation characteristics of embankments. This research paper presents a comprehensive analysis of an embankment that has been reinforced with geotextile under different loading conditions, utilizing the PLAXIS 2D software. The primary objectives of the analysis are to evaluate the stability and deformation characteristics of the embankment and the geotextile reinforcement system.

Furthermore, the study aims to determine the optimal geotextile properties, investigate the impact of various design parameters on the embankment's performance, compare the performance of the geotextile-reinforced embankment with a conventional embankment, and identify the optimal geotextile placement for maximum stability and minimum deformation in embankments. The analysis involved conducting numerical simulations using the PLAXIS 2D software, which is widely recognized for its ability to model soil-structure interaction. The geotextile reinforcement was incorporated into the embankment design by introducing appropriate material properties and boundary conditions in the numerical model. A range of loading scenarios, including static and dynamic loads, were applied to investigate the embankment's response.

The findings of the analysis reveal the significant improvements in stability and deformation characteristics achieved through geotextile reinforcement. The optimal geotextile properties were determined based on the specific soil conditions and project requirements. Additionally, the study highlighted the influence of various design parameters, such as embankment height, on the performance of the reinforced embankment. Comparative analysis between the geotextile-reinforced embankment and a conventional embankment demonstrated the superior performance of the former in terms of stability and deformation behavior. The geotextile reinforcement system exhibited enhanced load-bearing capacity, reduced settlement, and improved overall performance. Furthermore, the study identified the optimal geotextile placement for maximum stability and minimum deformation in embankments. The findings suggest that proper placement of geotextile layers within the embankment can significantly enhance its performance.

Keywords: Embankments, Geotextiles, PLAXIS 2D, Stability, Reinforcement, Displacement

I. INTRODUCTION

Embankments play a crucial role in various applications, including raising ground levels, constructing roads, protecting infrastructure from floods, and retaining slopes [1]. The stability of embankments is a significant concern, and their performance is influenced by factors such as soil type, embankment height and thickness, and applied loads [2]. To enhance the strength and stability of embankments, geotextiles have emerged as a well-established technique. Geotextiles are permeable fabrics composed of synthetic materials that are employed to improve soil properties [3]. These materials act as reinforcement by separating different soil layers and providing tensile strength to the structure. Geotextiles find applications in embankment reinforcement, slope stabilization, erosion control, and ground improvement [4].

The utilization of geotextiles in embankment construction offers numerous advantages, including cost-effectiveness, ease of installation, and reduced construction time [5]. The behavior of geotextile-reinforced embankments is influenced by several factors, including soil type, geotextile properties, and loading conditions. Finite element analysis software, such as PLAXIS 2D, has proven to be an effective tool for analyzing the behavior of such embankments [6]. This software enables the modeling of embankment and geotextile layers, providing valuable insights into stress distribution and displacement patterns. The results obtained from such analyses can be utilized to optimize geotextile layer design, thereby enhancing the overall performance and longevity of the embankment [7].

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II. LITERATURE REVIEW

Geotextile reinforcement has proven to be an effective technique in enhancing the stability of embankments constructed on soft ground and minimizing plastic deformation in the underlying foundation soil. Bergado et al. conducted a comprehensive study in 2002, employing both field data and finite element analysis (FEM) to evaluate the efficacy of geotextile-reinforced embankments [8]. The investigation involved the construction of three full-scale instrumented test embankments, with and without geotextile reinforcement, to analyze critical embankment height and geotextile strain under undrained conditions. The stability assessments of the embankments and the failure mechanism analysis were carried out using Bishop's streamlined approach, while FEM undrained analyses were conducted to examine the failure process of each embankment.

In one embankment, multiple layers of low-strength, nonwoven, needle-punched geotextile, referred to as the MGE embankment, were employed for reinforcement. Conversely, the other embankment was reinforced with a single layer of high-strength composite nonwoven/woven geotextile known as the HE embankment. A nearby control embankment, the CE embankment, remained unreinforced [8]. PLAXIS software was utilized to successfully carry out a finite element study, focusing on the stability and deformations of the geotextile-reinforced embankments. Vashi et al. (2019) further employed the restricted equilibrium approach for the design and analysis of the reinforced construction [9]. This approach involved considering the force applied to the top of the wall to compute the horizontal pressure resisted by the reinforcement. The results obtained from these studies indicated that the utilization of geotextile reinforcement considerably reduced the vertical settlement of the backfill material. The maximum vertical settlement of the unreinforced soil mass ranged between 2.4% and 4% of the embankment height. Factors such as soil-reinforcement interaction, the lower stiffness of the reinforcing material, and vertical spacing were identified as crucial contributors to the reduction in vertical settlement. It was observed that stiffer and more spaced-apart geotextiles did not significantly contribute to the decrease in vertical settlement, as the rigid embankment body and high fill modulus were the dominant factors [8][9].

Overall, geotextile reinforcement has proven to be a highly effective technique for enhancing embankment stability on soft ground and limiting plastic deformation in the underlying foundation soil. The application of finite element analysis, such as the one conducted using PLAXIS software, has played a crucial role in assessing the effectiveness of geotextile reinforcement. The findings underscore the significance of factors such as soil-reinforcement interaction, stiffness, and vertical spacing in determining the success of geotextile reinforcement techniques [8][9].

III. MODEL DESCRIPTION

In the research paper titled "Analysis of Geotextile Reinforced Road Embankment Using PLAXIS 2D," authored by Paravita Sri Wulandari and Daniel Tjandra [6], a comprehensive model of a fill embankment for road construction is presented. The primary focus of this study was to examine the stability and strength characteristics of the embankment, with a particular emphasis on the utilization of geotextile as the main reinforcing element. The chosen slope ratio for the embankment was 2H:1V, a commonly employed ratio that ensures stability and minimizes the risk of slope failures. To simulate the real-life traffic load, a nominal surcharge of 6.13 kN/m was applied to the embankment.

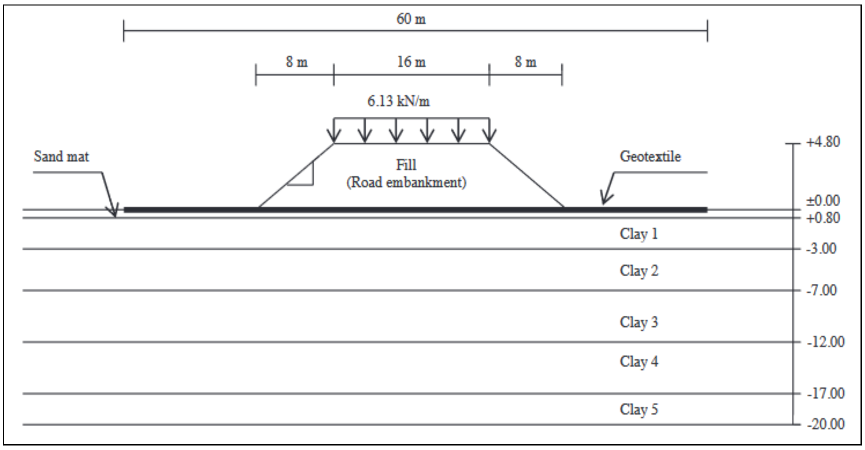

Fig 1. Geometry Model

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The analysis was conducted using the PLAXIS 2D finite element method, a widely recognized geotechnical engineering software capable of simulating and analyzing soil-structure interaction problems. The researchers employed the Mohr-Coulomb model, a well-established constitutive model in geotechnical engineering, to accurately represent the shear strength of the soil layers based on their cohesion and internal friction angle. The fill embankment in the model consisted of five layers of clay and a sand mat layer, with each layer's key parameters such as thickness, Young's modulus, Poisson's ratio, cohesion, and internal friction angle meticulously documented. Notably, the geotextile used in this study exhibited a primary strength of 100 kN/m, providing essential reinforcement to the embankment structure.

Material	γ_{unsat} (kN/m³)	γ_{sat} (kN/m³)	E_{ref} (kN/m²)	c (kN/m²)	ϕ (°)	Ψ (°)
Fill	18	18	50000	1	33	3
Sand Mat	18	23	30000	1	33	3
Clay 1	16.6	17.31	2000	33.02	1	0
Clay 2	16.6	17.31	2000	12.01	1	0
Clay 3	16.6	17.31	2000	47.07	1	0
Clay 4	16.6	17.31	2000	118.66	1	0
Clay 5	16.6	17.31	2000	163.45	1	0

Table 1. Soil Parameters

This research paper provides a comprehensive and detailed analysis, offering valuable insights into the design and construction of geotextile-reinforced road embankments using the PLAXIS 2D software.

IV. METHODOLOGY

The research project is aimed at studying the effectiveness of geotextile-reinforced embankments and its relation to real-world applications. The research is divided into two parts with each part focusing on specific aspects of the study. To accurately simulate the behavior of the reinforced embankment, the researchers utilized the PLAXIS 2D software and conducted a series of numerical simulations. The results of the simulations were used to evaluate the stability and deformation characteristics of the geotextile-reinforced road embankment under the applied loading conditions. This will enable the researchers to determine the most effective geotextile placement and embankment material for maximum stability and minimum deformation in geotextile-reinforced embankments.

Part A involves analyzing eleven cases of geotextile placement to measure the maximum change in the Maximum Displacement Value. The starting value used for the calculation is 0.3475 m, and each case's percentage change is recorded to assess the effectiveness of geotextile placement. The results will be used to determine the optimal geotextile placement for maximum stability and minimum deformation in embankments.

Part B focuses on studying the effect of different embankment materials on displacement under varying loads. Four different cases are considered, including embankments with clay material, fill material, clay above and fill below, and fill above and clay below. The displacement is studied under three different loads, i.e., 6.13 KN/m, 10 KN/m, and 20 KN/m, using PLAXIS 2D software. Both with and without geotextile placement are considered in each case. The results will be used to determine the optimal embankment material, position and the load capacity for geotextile-reinforced embankments.

4.1 Literature Review :

A comprehensive literature review was conducted to gather information on the effect of different embankment materials on displacement. The aim was to understand the factors that influence the behavior of embankment structures under different loading conditions. The literature review was based on peer-reviewed journal articles, books, and conference proceedings related to the subject matter.

4.2 Design of Embankment Models :

Embankment models were designed using PLAXIS 2D software. The models were designed to have a height of 10m with a slope of 1:2. The soil layers were defined with their respective properties, including cohesion, angle of internal friction, and unit weight. The dimensions of the embankment models were kept constant, and only the materials were varied for the four different cases.

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4.3 Validation of the Software :

Our primary objective was to verify the accuracy of our software model based on the research paper titled "Analysis of geotextile reinforced road embankment using PLAXIS 2D" by Paravita Sri Wulandari and Daniel Tjandra, published in "Procedia Engineering 125(2015) 358-362". Although the research paper considered multiple tensile strength values for the geotextile, we focused on validating the software using a single tensile strength value of 100KN/m, while all other properties were detailed in the model description section [6]. Upon running the simulation in our software, we obtained a maximum displacement value of 0.3475m, whereas the referenced research paper reported an actual value of 0.336m. This resulted in a difference of 0.0115m, corresponding to a percentage change of 3.42% between the two values.
Since the percentage difference between our simulated software value and the value reported in the research paper is 3.42% (which falls below the 10% threshold), we have successfully validated our software in accordance with the findings presented in the research paper by Paravita Sri Wulandari and Daniel Tjandra.

4.4 Numerical Simulations :

The researchers conducted numerical simulations using PLAXIS 2D software to analyze the embankment models. Three different loads were applied to the models: 6.13 KN/m, 10 KN/m, and 20 KN/m. The purpose of these simulations was to observe and record the displacement exhibited by the embankment structures under each load. To ensure accuracy, the mesh used in the models was fine enough to capture the intricate behavior of both the geotextile and the soil layers.

4.5 Analysis of Results :

Following the numerical simulations, the researchers analyzed the displacement results obtained. The primary objective was to examine the impact of different embankment materials on displacement. This analysis involved computing the displacement, stress, and strain fields within the soil and the geotextile. By examining these factors, the researchers gained valuable insights into the behavior and performance of the embankment structures. Furthermore, the stability of the embankments was evaluated by checking the factor of safety against various failure modes. This allowed for a comprehensive assessment of the embankments' structural integrity.

4.6 Comparison of Results :

In order to understand the specific effect of geotextile on displacement, a comparison was made between the results obtained for cases without geotextile and those with geotextile. The comparison focused on the maximum displacement recorded for each load. By contrasting these values, the researchers could quantitatively determine the influence of geotextile on the embankment's displacement behavior.

Additionally, the researchers analyzed the effect of geotextile on the factor of safety, further elucidating the role of geotextile in enhancing embankment stability. This comprehensive comparison provided clear insights into the benefits of utilizing geotextile as a reinforcement material in embankment structures. The methodology employed in this study relied on well-established procedures for examining embankment structures through numerical simulations.

To achieve this, the researchers utilized PLAXIS 2D software, a widely recognized tool for creating precise models that accurately depicted the behavior of both the geotextile and the soil layers involved. By analyzing the results obtained from these simulations, valuable insights were gained into the impact of various embankment materials on displacement, as well as the pivotal role played by geotextile in enhancing the stability of such structures. These significant findings hold considerable potential for guiding the design and construction of embankment projects, particularly those that incorporate geotextile as a reinforcing material.

V. RESULTS AND DISCUSSION

CASE A

After validating the software, we proceeded with the main objective of this research project, which is to investigate the effect of different placement cases of geotextiles on the maximum displacement value in a test embankment.

In order to establish a reference point, we first analyzed the maximum displacement value without the use of any geotextile, which was found to be **0.3475 m** at element 20 and node 2070.

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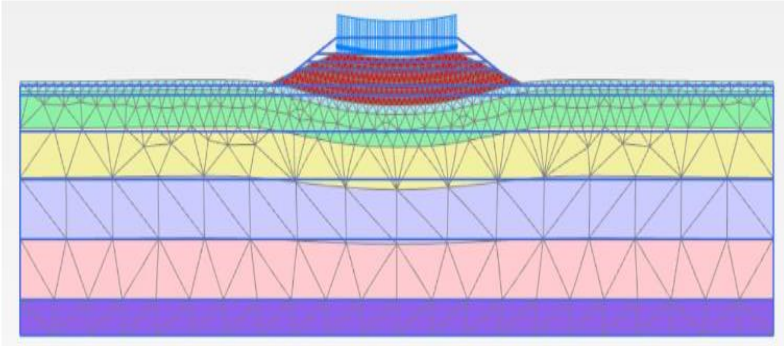

Fig 2. Reference Case (No Geotextile was used)
Maximum Displacement = 0.3475m

We then proceeded to analyze 11 different cases of geotextile placement, using a geotextile with a tensile strength of **1000 KN/m**. The cases varied in terms of the number and placement of geotextiles within the embankment structure. Our aim was to identify the best combination of geotextile placement that could reduce the displacement of the embankment for a prolonged period of time.

CASE NO.	NO. OF GEOTEXTILES USED	POSITION OF GEOTEXTILES
CASE 1	ONE	On the base of Embankment
CASE 2	ONE	Below First Layer of Soil
CASE 3	ONE	Below Second Layer Of Soil
CASE 4	TWO	One on the base of Embankment ; One in the middle of Embankment
CASE 5	TWO	One on the base of Embankment ; One below the layer of sand mat
CASE 6	TWO	One in the middle of Embankment ; One below the layer of sand mat
CASE 7	THREE	One in the middle of Embankment ; One below the layer of sand mat ; One on the base of Embankment
CASE 8	THREE	Two in the Embankment at equal distance ; One on the base of the Embankment
CASE 9	THREE	One below the sand mat ; One below the soil layer 1 ; One on the base of the Embankment
CASE 10	THREE	One below the sand mat ; One below the soil layer 1 ; One between the Embankment
CASE 11	THREE	Two in the Embankment at equal distance ; One below the sand mat layer

Table 2. Description of All Possible Cases analyzed

We compiled the percentage change in the maximum displacement value for each of the 11 cases analyzed, which showed that Case 9, where three geotextiles were used, with one below the sand mat, one below the soil layer 1, and one on the base of the embankment, resulted in the highest percentage change of **6.88%**.

Case	Max. Displacement(m)	Reference Value(m)	Value Change(m)	Percentage Change(%)
Case 1	0.3427	0.3475	0.0048	1.38%
Case 2	0.3410	0.3475	0.0065	1.87%
Case 3	0.3352	0.3475	0.0123	3.54%
Case 4	0.3406	0.3475	0.0069	1.99%
Case 5	0.3346	0.3475	0.0129	3.71%
Case 6	0.3396	0.3475	0.0079	2.27%
Case 7	0.3343	0.3475	0.0132	3.80%
Case 8	0.3391	0.3475	0.0084	2.42%
Case 9	0.3236	0.3475	0.0239	6.88%
Case 10	0.3271	0.3475	0.0204	5.87%
Case 11	0.3380	0.3475	0.0095	2.73%

Table 3. Percentage Change Across Different Cases

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Case 10, where three geotextiles were used, with one below the sand mat, one below the soil layer 1, and one between the embankment, resulted in the second-highest percentage change of **5.87%**. The least percentage change was observed in Case 1, where only one geotextile was used and it was placed at the base of the embankment between the fill and sand mat layer, resulting in a percentage change of **1.38%**.

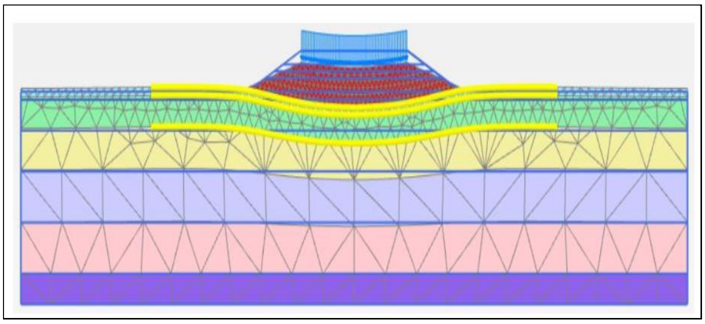

Fig 3 (CASE 9). Three Geotextiles (One below the sand mat, One below the soil layer 1 and One on the base of Embankment)

Based on these findings, we selected **Case 9** for further analysis as it exhibited the highest reduction in displacement. Our subsequent research work will involve investigating the performance of Case 9 in more detail to determine the long-term effectiveness of this geotextile placement strategy. We will employ various geotechnical techniques, including laboratory tests and numerical simulations, to better understand the underlying mechanisms behind the observed reduction in embankment displacement.

CASE B

The primary objective of CASE B was to investigate the impact of different embankment materials on the displacement under varying loads. The study considered four cases, namely embankment with (i) Clay material, (ii) Fill material, (iii) Clay above and fill below and (iv) Fill above and clay below. Each case was analyzed with and without the use of geotextile using PLAXIS 2D software. The displacement behavior of the embankment was studied under three different loads, namely **6.13 KN/m**, **10 KN/m**, and **20 KN/m**. We have analyzed a total of 24 cases, including four different cases with three different loads. For each case, the displacement values have been obtained with and without geotextile.

Without Geotex	Load		
Material Case	6.13 kN/m	10 kN/m	20 kN/m
Clay	0.3434m	0.3708m	0.4783m
Fill	0.3473m	0.3805m	0.5842m
Both (F↑,C↓)	0.3522m	0.3807m	0.5050m
Both (C↑,F↓)	0.3348m	0.3662m	0.5183m

Table 4. Maximum Displacement Values without Geotextile

With Geotextile	Load		
Material Case	6.13 kN/m	10 kN/m	20 kN/m
Clay	0.3365m	0.3619m	0.4514m
Fill	0.3332m	0.3600m	0.4712m
Both (F↑,C↓)	0.3438m	0.3691m	0.4639m
Both (C↑,F↓)	0.3259m	0.3520m	0.4522m

Table 5. Maximum Displacement Values with Geotextile

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After calculating the percentage difference before and after Geotextile (shown in the table below), the results show that the use of geotextile significantly reduces the displacement values in embankments. This is because geotextiles help in distributing the load uniformly, thereby reducing the displacement.

Percentage Diff	Load		
Material Case	6.13 kN/m	10 kN/m	20 kN/m
Clay	2.00%	2.40%	5.62%
Fill	4.05%	5.38%	19.30%
Both (F↑,C↓)	2.38%	3.04%	8.13%
Both (C↑,F↓)	2.65%	3.87%	12.75%

Table 6. Percentage Difference before and after using Geotextile

Our findings indicate that the choice of embankment material plays a crucial role in determining the embankment stability. The clay material exhibits the lowest displacement values, followed by the clay above and fill below case. However, the fill material shows the highest displacement values among all the cases. This suggests that clay material is more stable compared to fill material.

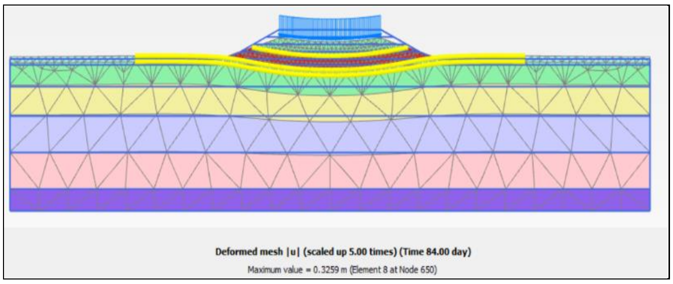

Fig 4. Most Stable Case (Clay is in the upper layer and Fill is in the lower layer of the embankment)

Furthermore, our analysis shows that the embankment stability can be significantly improved by using geotextile. The results also reveal that the case where Clay is in the upper layer and Fill is in the lower layer exhibits better stability compared to other cases.

VI. CONCLUSION

The results of our research project provide valuable insights into the effectiveness of geotextile-reinforced embankments and their real-world applications. Through a series of numerical simulations using PLAXIS 2D software, we investigated the impact of geotextile placement and embankment materials on the stability and deformation characteristics of embankments.

In Case A, where we focused on geotextile placement, we analyzed 11 different cases to determine the optimal combination that reduces embankment displacement. Our findings revealed that Case 9, which involved the use of three geotextiles positioned below the sand mat, below soil layer 1, and at the base of the embankment, exhibited the highest percentage change in the maximum displacement value. This indicates that the selected geotextile placement strategy effectively reduced embankment displacement. Further research will be conducted to assess the long-term effectiveness of this strategy through laboratory tests and numerical simulations.

In Case B, we studied the effect of different embankment materials on displacement under varying loads. Our analysis considered four cases, including embankments with clay material, fill material, clay above and fill below, and fill above and clay below. The results demonstrated that the choice of embankment material significantly influenced embankment stability, with clay material exhibiting the lowest displacement values and fill material showing the highest displacement values.

Additionally, the case with clay in the upper layer and fill in the lower layer demonstrated improved stability compared to other cases. Furthermore, the incorporation of geotextile consistently reduced displacement values, emphasizing its

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role in enhancing embankment stability. This finding suggests that careful selection of embankment material and its layering can enhance the overall stability and reduce deformation.

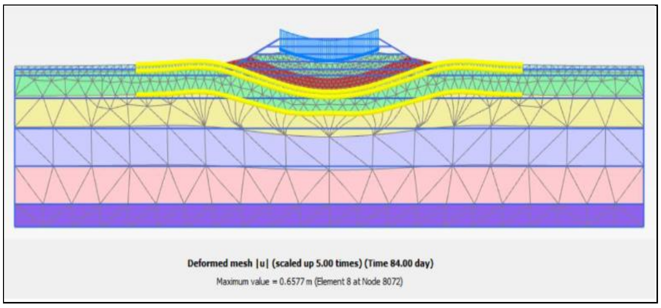

Fig 5. Most Efficient Model for using Geotextile to reinforce Embankments (Derived after drawing conclusions from CASE A and CASE B)

The findings of this research contribute to the understanding of geotextile-reinforced embankments and their practical applications. By identifying the optimal geotextile placement and embankment material, engineers can design and construct road embankments with improved stability and reduced deformation. The results emphasize the importance of considering geotextile reinforcement and suitable embankment materials in geotechnical engineering practices.

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