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Enhancement of Roadway Embankment Using Geofoam Blocks and Cement Columns: Application of Three-Dimensional Plaxis Program

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Abstract

Enhancement of roadway embankment utilizing several techniques, such as cement columns and applying EPS (expanded polystyrene) Geofoam blocks as subbase materials, helps develop the efficiency of embankment performance under the applied traffic loading for local materials. A PLAXIS 3D (ver.20) finite element program is used for the simulation models of roadway embankments. The results showed that applying the cement column reduced the vertical deformation of the roadway embankment to (50mm) corresponding to approximately (58%) of the reference model. The EPS Geofoam blocks highly lowered the vertical deformation to (20mm) about (83%) of the reference model to those in the cement column. The EPS Geofoam blocks provide a convenient solution for improving the roadway embankment with an (83%) reduction in maximum vertical displacement and sustaining traffic loading on the pavement. The reduction in displacement is well done by utilizing the EPS Geofoam blocks in a granular layer of pavement embankment. The EPS Geofoam blocks acted better in reducing vertical stresses (about 22%) higher than the cement column. This benefits the use of EPS Geofoam blocks in the base layer to enhance roadway embankment against failure.

Keywords: Displacement, Embankment Analysis, Enhancement, Numerical Analysis, Stress, Strain

1. Introduction

Roadway embankments are considered one of the most essential parts of transportation systems and need efficient performance to meet the future growth of traffic demand. When the embankment foundation is soft or weak soil, several problems arise, such as settlement and stability failure due to lack of bearing capacity. Several improvement techniques must be developed and applied to roadway embankments to overcome these problems. The granular base, pavement subbase, and roadway embankment foundation must be upgraded and improved to withstand traffic loading and prevent stability failure. Extensive work and numerical models are required to simulate and evaluate the improvement techniques.

With the growth in traffic demand in major cities, many roadway embankments are foundation materials of soft or weak soil. Several geotechnical issues have appeared, including high displacement, settlement, and stability failure due to a lack of bearing capacity.

Improvement techniques have been increasingly applied to enhance roadway embankments on weak foundation soil. Work has been done on the geotextile-reinforced earth embankment deep-seated failure characteristics [1].

Vashi et al. [2] explored the utilization of geotextile reinforcement for embankments in terms of horizontal and vertical stresses and shear displacements that act on the embankment face. They studied the effect of geotextile reinforcement at the backfill and concluded that the strength of the geotextile (500kN/m) is inefficient in reducing the embankment's deformation.

EPS (Expanded Polystyrene geofoam) blocks have been lightweight for road constructions, such as roadway embankments, railroads, and airfields. They are applied to increase bearing capacity on soft soil and reduce stability failure and settlements [3]. Heavy traffic and vehicular loading induce settlement in the road embankment. The Foundation of soft soil with a high void ratio, high compressibility, and low undrained shear strength has high compressibility [4].

Several works have been conducted through experimental works, numerical modeling, and mathematical techniques to investigate the performance of stone columns-supported embankments to improve the soft soil of embankment foundations. The outcomes prove that stone columns reduce the settlements and stresses on weak foundation soil [5], [6]. Utilizing the bottom ash column as ground reinforcement induced rapid consolidation and increased apparent cohesion compared to the unreinforced case [7], [8]. Applying bottom ash [9] columns under footing provides a gain in load-carrying capacity and reduces settlement [10].

Alkaissi [11] worked on the effect of controlled modulus columns (CMC) for support embankments. The CMC reduces the surface displacement by (12%) and decreases with an increase in the column diameter until it reaches a constant value of (0.5m). The maximum displacement value was observed in the middle of the embankment and then decreased to about (17%) at the embankment foundation. The reinforcement of road embankments with geotextiles reduces the horizontal displacement by about (81%) and vertical displacement by about (32%). Maximum displacements were observed at the toe of the embankment for both vertical and horizontal movement and then reduced gradually to insignificant values for the enforcement layer. Yusof [12] developed an improvement model for soft soil using geotextile embedded with expanded polystyrene to strengthen the soil condition. Two EPS density values indicate various settlement values.

Various research with different effective strategies on embankment piles was employed due to the large differential settlement in embankment pile interaction, which will reduce driver comfort, safety, and vehicle speed [13].

Finite element modeling is an essential technique for exploring the behavior and mechanism of load transfer on embankments with and without geosynthetic reinforcement [14], [15]. Field works were conducted to investigate the bumps/settlements under the EPS geofoam embankment system. Short-term measured settlement data was analyzed with the hyperbolic model to predict the long-term. A finite element model is used in this work to estimate settlements [16]. Optimizing the thermal characteristics of the surrounding soil utilizing ground improvement offers a solution to offset these effects. Also, increasing the radius and thermal conductivity of the improved soil zone has beneficial impacts on the thermal performance of the Ground Source Heat Pumps GSHP [17]. A finite element model using the GEO5 program is used to work the effect of reinforcement by geotextile or geogrid to improve the stability of the embankment and provide more uniform settlements [18]. Finite element analyses were conducted to model pile-supported embankments. Also, a comparison and verification have been made. The field monitoring results and finite element model agreed well [19].

The objective of this work is to investigate the improvement of roadway embankments utilizing adopted methods and include the following points:

1. Develop a three-dimensional finite element model using PLAXIS (ver.20) to simulate a roadway embankment with EPS geofoam blocks and cement column-supported embankment.
2. Estimate the displacement, strains, and stresses of the roadway embankment and foundation soil system.
3. The placement efficiency of EPS as an alternative for the granular pavement layer.
4. The effect of the cement columns model was compared with a reference model to depict their impact on the enhancement of roadway embankments under traffic loading.

2. Methodology

2.1. Developed Model using the Finite Element Method

The modeling of road embankments with various improvement techniques, cement columns, and application of EPS Geofoam blocks as granular layers have been analyzed and investigated using finite element software PLAXIS 3D (ver.20). In this research, three basic models were analyzed; first, the performance of road embankment (Asphalt layer (50mm); base layer(120mm) and foundation layer (4000 mm)) was analyzed without any improvement techniques (reference model), see Fig. 1. The second model of road embankment was analyzed using cement columns (cement columns model-1) as shown in Fig. 2, and the third model was analyzed by using Expanded Polystyrene (EPS) geofoam blocks as granular layers (EPS Geofoam blocks in model-2) with a height of (0.12) m and side slope of 1:2, see Fig. 1. The traffic moving a load of standard axel load of 18 kips (18 kN) and contact pressure of (0.6MPa) over a rectangular area of the tire contact was adopted [16]. And simulated by PLAXIS ver.20, the finite element modeling of the roadway embankment system with cement columns is presented in Fig. 3. The dimensions of the foundation soil using the PLAXIS model program are (40*4*5) m in the x, y, and z directions, respectively, 15 noded triangular are used with a 3D finite element plane strain model. Column-supported embankments (cement columns) were modeled with a (0.8) m diameter and spacing a (1.2) m. The PLAXIS program allocates material properties and sophisticated characteristics of different models adopted in this research. Tables 1 and 2 illustrate the required parameters for constitutive models to assign each layer of the roadway embankment system.

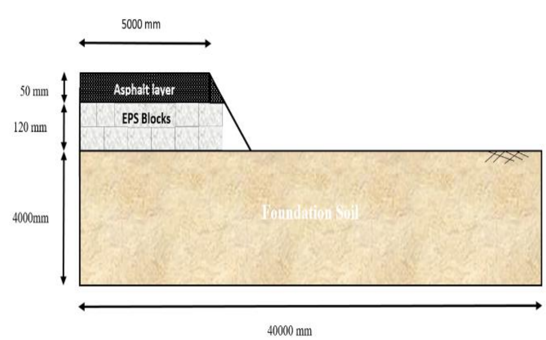


Figure 1: Schematic diagram of Roadway Embankment with EPS Geofoam Blocks.

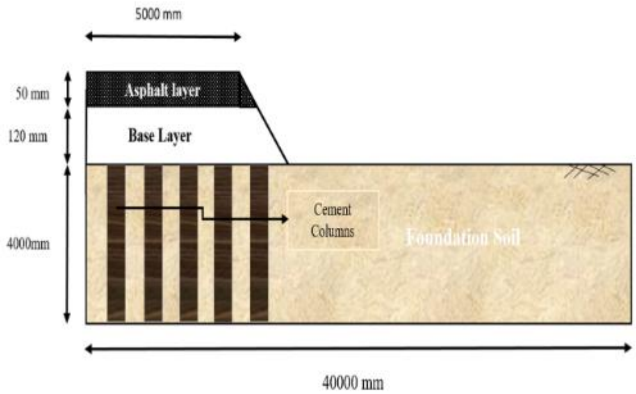


Figure 2: Schematic diagram of Roadway Embankment with Cement Columns.

Table 1: The input of Roadway Embankment Model Materials Parameters [20]-[23].

Model	Asphalt Layer Linear Elastic Model Non-Porous	Base Layer Mohr-Coulomb	Subgrade Layer Mohr-Coulomb
Elastic Modulus (kPa)	$75000*10^3$	1853	1947
Poisson Ratio	0.35	0.30	0.35
Cohesion (kN/m^2)	-	42	15
Friction angle (Φ^0)	-	67	11
Undrained Shear Strength (kPa)	-	-	127.68
Dry Density (kN/m^3)	22	22	13.56
Saturated Density (kN/m^3)	-	23	19.93

Table 2: The input of EPS and Cement Columns Model Parameters [20], [22].

Model	Cement Columns Linear Elastic Model	EPS Geofoam Blocks Linear Elastic Model
Elastic Modulus (kPa)	$100*10^3$	$10*10^3$
Poisson Ratio	0.15	0.1
Cohesion (kN/m^2)	-	-
Friction angle (Φ^0)	-	-
Undrained Shear Strength (kPa)	500	
Dry Density (kN/m^3)	15	18
Saturated Density (kN/m^3)	-	-

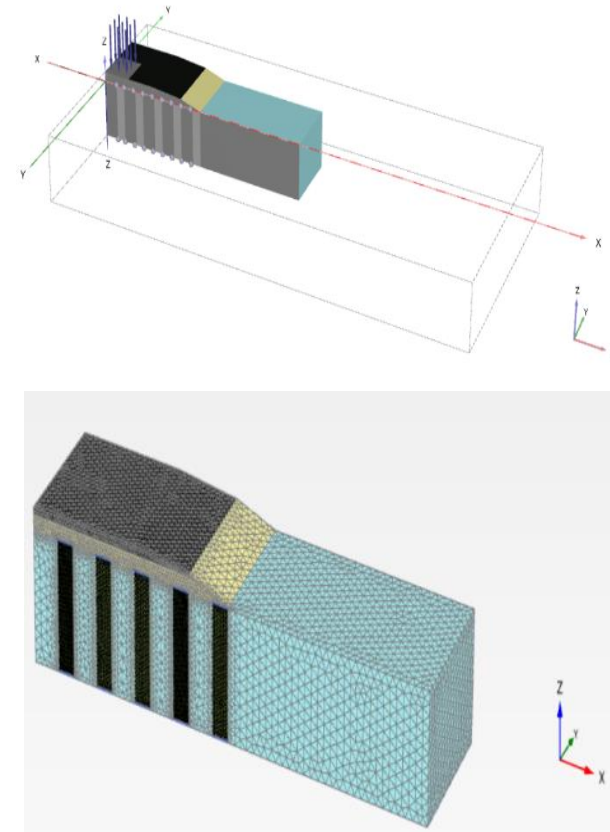


Figure 3: Finite Element Mesh Roadway Embankment with Cement Columns.

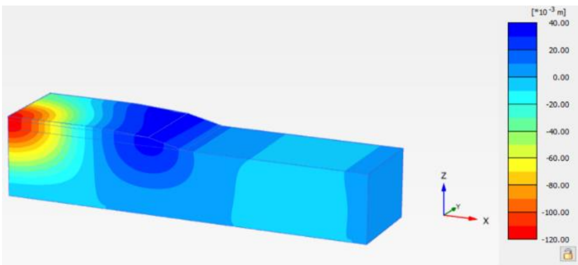
3. Results and Discussions

In general, the roadway embankment is made of heavy materials built over soft foundation soil, and this causes deformation and insatiability of the embankment. Enhancement of roadway embankment utilizing several techniques, such as cement columns and the application of EPS Geofoam blocks as subbase materials, helps develop the efficiency of embankment performance under the applied traffic loading by reducing settlements with time and increasing load-carrying capacity. The output results of different improvement models (cement columns and EPS Geofoam blocks) are applied using the 3D PLAXIS (V.20) program and explained in the following paragraphs, including deformation, stresses, and strains.

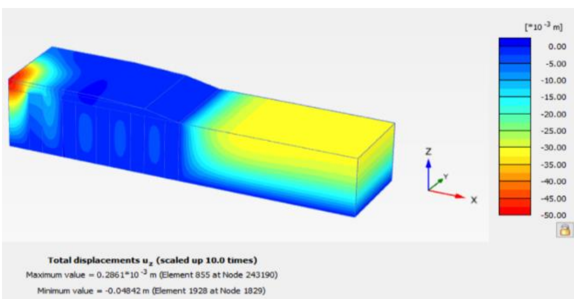
3.1 Displacement Analysis Results

The displacement results were determined for different improvement models (cement column and EPS Geofoam blocks) and compared with a reference model to depict their effects on enhancing roadway embankment under traffic loading. The deformation results of roadway embankment with and without improvement models are shown in Fig. 4. The critical values of vertical deformations were under the traffic loading with the red color of the reference model with a value of (120 mm). The enhancement of the cement column in mode 1 reduced the vertical deformation to (50mm) corresponding to approximately (58%) of the reference model. Furthermore, the EPS Geofoam blocks in model 2 highly lowered the vertical deformation to (20mm) about (83%) of the reference model to those in the cement column in model 1.

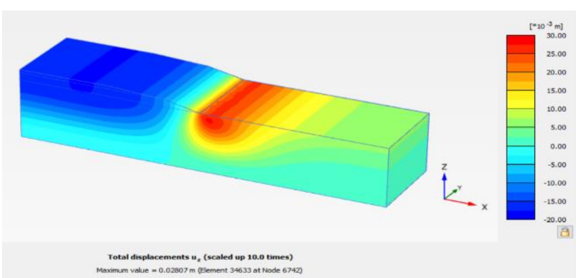
The EPS Geofoam blocks provide a convenient solution to improve the roadway embankment with an (83%) reduction in maximum vertical displacement and sustain the traffic loading on pavement, so their material does not deteriorate with time. The placement of EPS as an alternative for the granular subbase layer strengthens the embankment and reduces the potential risk of failure. Fig. 5 shows the displacement variation with depth below the roadway embankment. For all models, a high value was depicted on the pavement surface under the tire pressure, and then the depth decreased. The reduction in displacement is well done by utilizing the EPS Geofoam blocks in model 2.



a) Reference Model.



b) Cement Column Model 1.



c) EPS Geofoam blocks Model-2.

Figure 4. Vertical Displacement Distribution within Roadway Embankment for Different Models.

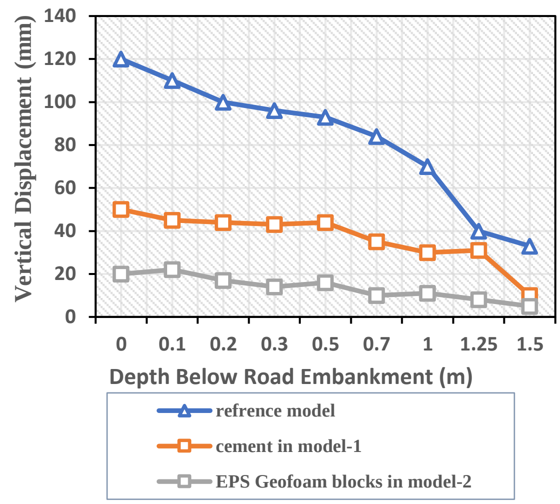
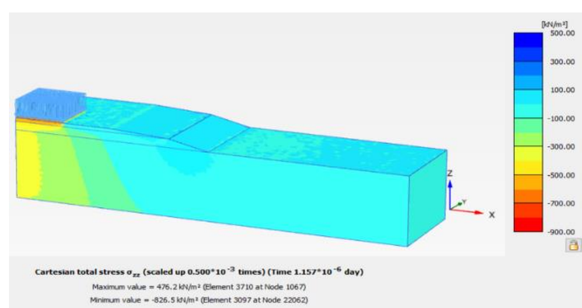


Figure 5. Variation of Vertical Displacement for Different Models with Depth below Roadway Embankment.

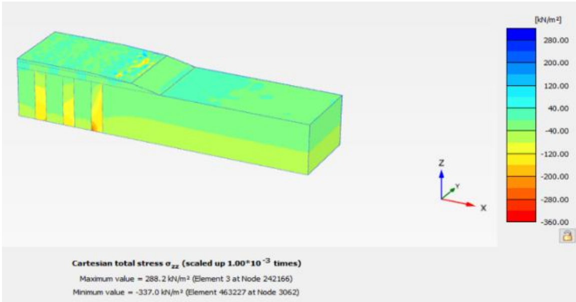
3.2 Stress and Strain Results Analysis

The beneficial effects of using different techniques for roadway embankment improvement are investigated in terms of stress and strain results. The models (cement column and EPS Geofoam blocks) with a reference model were analyzed using PLAXIS 3D (version 20). The output results regarding stress distribution are presented in Fig. 6 and Fig. 7 for the worked models of embankment enhancement. There was a reduction in vertical stresses of the reference model to about 56% below the asphalt pavement layer pavement layer and 67% below the base course. The vertical stress was reduced to about (60%) for the cement column in model 1 model 1 and (82%) for EPS Geofoam blocks in model 2 and model 2, respectively. In general, it's clear from the stress distribution results that the entire road embankment load is transmitted well by inserting the cement column and EPS. The EPS Geofoam blocks in Model 2 reduced vertical stresses (about 22%) better than the cement column. This benefits the use of EPS Geofoam blocks in the base layer to enhance roadway embankment against failure.

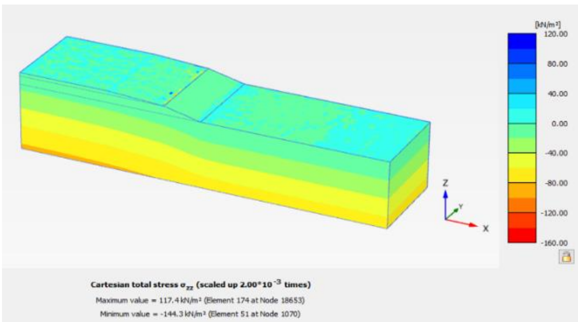
Regarding the strains, the results of the vertical strain are presented in Figs. 8 and 9 for the cement column in model-1 and EPS Geofoam blocks in model-2, respectively. There is a noticeable reduction in the maximum vertical compressive strains at the top of the pavement and maximum tensile strain at the bottom of the foundation layers.



a) Reference Model.



b) Cement Column Model-1.



c) EPS Geofoam blocks Model-2

Figure 6: Vertical Stresses Distribution within Roadway Embankment for Different Models.

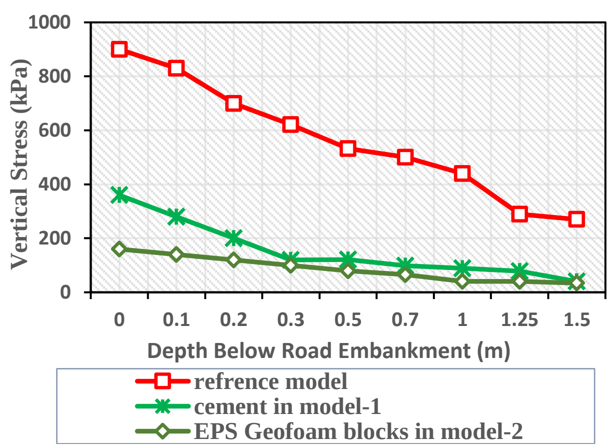


Figure 7. Variation of Vertical Stresses for Different Models with Depth below Roadway Embankment.

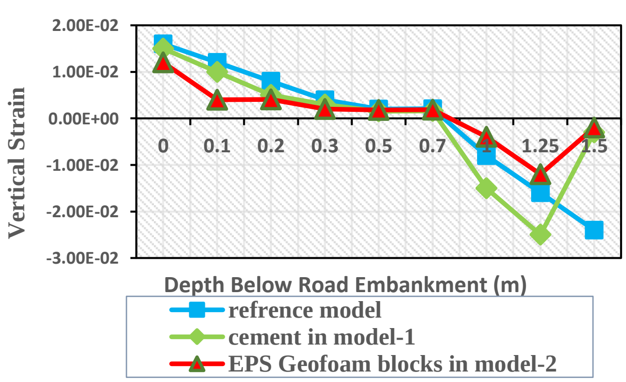
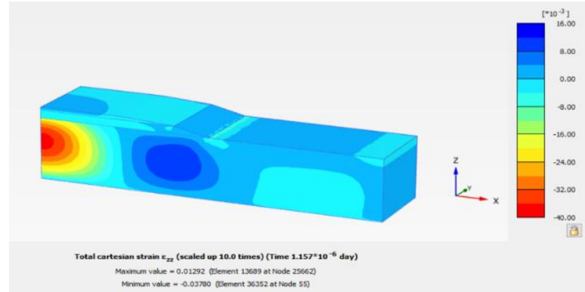
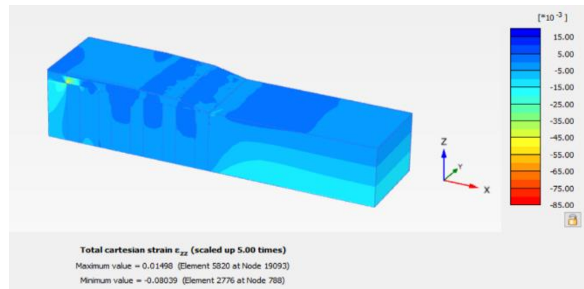


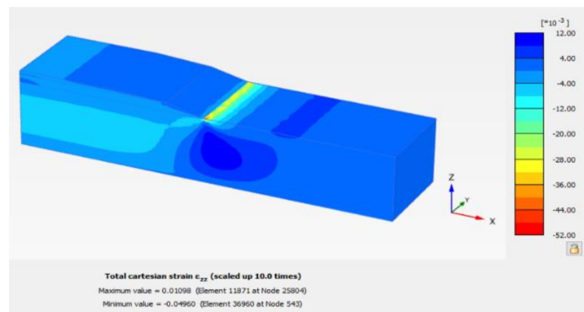
Figure 8. Variation of Strains for Different Models with Depth below Roadway Embankment.



a) Reference Model.



b) Cement Column Model-1.



c)EPS Geofoam blocks Model-2

Figure 9: Strains Distribution within Roadway Embankment for Different Models.

5. Conclusions

It is based on the finite element analysis using PLAXIS 3D (ver.20) for the simulation models of roadway embankments constructed with cement columns and GPS geofoam blocks. The enhancement of the cement column reduced the vertical deformation of the roadway embankment to (50mm) corresponding to approximately (58%) of the reference model. The EPS Geofoam blocks highly lowered the vertical deformation to (20mm) about (83%) of the reference model to those in the cement column. The EPS Geofoam blocks provide a convenient solution for improving the roadway embankment with an (83%) reduction in maximum vertical displacement and sustaining traffic loading on the pavement.

The placement of EPS as an alternative for the granular subbase layer strengthens the embankment and reduces the potential risk of failure. The reduction in displacement is well done by utilizing the EPS Geofoam blocks in a granular layer of pavement embankment. There was a reduction in vertical stresses of the reference model to about 56% below the asphalt pavement layer and 67% below the base course. The vertical stress was reduced to about (60%) for the cement column and

(82%) for EPS Geofoam blocks. The EPS Geofoam blocks acted better in reducing vertical stresses (about 22%) higher than the cement column. This benefits the use of EPS Geofoam blocks in the base layer to enhance roadway embankment against failure. There is a noticeable reduction in the maximum vertical compressive strains at the top of the pavement and maximum tensile strain at the bottom of the foundation layers.

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Conflict of interest

There is no conflict of interest.

Author Contribution Statement

The author developed the model using the finite element program and analyzed and discussed the obtained results.

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