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NUMERICAL ANALYSIS OF GEOMAT REINFORCED VERTICAL EARTH EMBANKMENTS USING PLAXIS SOFTWARE

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Abstract: The design procedure of reinforced earth retaining structures considers the safety against tensile failure and pull out failure as the internal stability criteria. However, evaluation of the lateral deformation also needs to be considered as an important criterion to satisfy serviceability limit states. It is imperative that the designer limits the lateral deformation of reinforced earth walls under service loads. In a reported number of previous studies, extensive laboratory experiments have been carried out to investigate the lateral deformation characteristic of embankments reinforced with coir mats. For this purpose, ordinary coir mats and those coated with polyethylene to improve their durability under acidic and alkaline environments have been used. The above studies, also investigated the effect of wetting on the lateral deformation as well. In this study, numerical analyses of the above laboratory experiments are carried out using Plaxis 2D software to determine lateral deformation characteristics and the results are compared with the experimental results. The analyses was carried for uncoated and coated geomats used to reinforce a vertical embankment prepared to 95% of maximum dry density and that subjected to soaked conditions which simulates exposure to rainy weather.

The results show that the variations of lateral deformation obtained from the numerical analyses under various conditions are similar to those observed in the experimental studies. However, quantitatively, the lateral deformation obtained from the numerical analyses show less value in magnitude than those observed in the experimental work.

Keywords: Geomats, Vertical embankment, Lateral deformation, Plaxis

1. Introduction

In civil engineering applications, embankments are constructed to support road or railway running through low lying areas, in canal excavations, dams and also in maintaining two different elevations as in retaining structures. These embankments are mainly built using compacted reinforced or unreinforced soil and with or without a rock fill, or even using mass concrete. Selection of material not only depends on the side slope of the embankment, the geometry and its dimensions but also the sub-grade soil type.

In case of vertical embankments a supporting structure needs to be provided to withstand lateral earth pressures. However, use of polymer geo-reinforcement to support the embankment internally would eliminate the need for an external structure. Instead, it is also possible to use geomats made of coir as the reinforcing material (as a cost effective solution to stabilise the vertical face of an embankment making use of its engineering properties, taking care of the durability considerations of coir mats against degradation by coating with a polymer (eg. Polythene). Retaining structures are usually designed to take care of ultimate limit states (ULS) (Chai and Zhu, 2002). However, it is also important to ensure that serviceability limit states are also satisfied, an essential requirement for its satisfactory functionality.

Jayaprakas et.al (2012) carried out laboratory model studies to compare the performance of the coated and uncoated Geomat reinforced vertical embankments.

In this research, a numerical analysis is carried out to investigate the deformability of Geomat reinforced vertical embankments. The methodology involved validation of the numerical model against experimental records from past studies.

2. Literature review

Reinforcing the soil is the common method used to improve the stability of an embankment so that external supporting system is not required. When reinforcements are placed at a designed vertical spacing, each of reinforcement will carry the force transferred by the soil within its tributary area which can be calculated using Rankine's active earth pressure theory. It is also possible to use coir geomats as the reinforcing material as a cost effective solution to stabilize the vertical face of an embankment making use of its engineering properties as described in Kurukulasuriya et.al, (2011), where they had conducted an experimental study to investigate the suitability of coir geomats in an internally stabilized vertical embankment construction. They constructed an embankment of 500 mm in height, 605 mm in width, and 700 mm in length with five layers of reinforcement and then the embankment was loaded under dry and wet conditions.

Based on the laboratory experimental model study, they concluded that the lateral displacement in both reinforced embankments increased with the applied pressure and decreased with depth and whether the loading is applied under natural moisture content of the fill or under soaked conditions and from the results, coir geomat reinforced vertical wall showed less lateral deformation than the geotextile reinforced wall, at the same fraction of the allowable surcharge pressure corresponding to each material.

Jayaprakas et al, (2012) had conducted a research that investigates the suitability of coated coir geomat as a reinforcement considering lateral displacements. The suitability of durability improved coir geomat, made by coating coir geomat with waste plastic material as reinforcement material, for satisfying lateral displacement was determined by laboratory model tests. For this study, they used the same soil and experimental setup used in a study by Kurukulasuriya et.al, (2011) which made it possible to carryout comparative studies on the suitability of durability improved coated coir geomat.

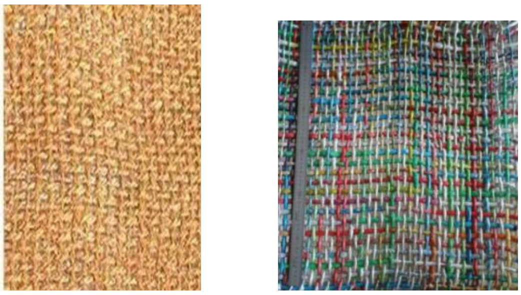
Based on the laboratory experimental model study, they came to a conclusion that whether the loading is applied under dry or wet conditions, the durability improved coated coir geomat reinforced vertical wall showed similar lateral deformation to that of uncoated coir geomat reinforced wall. Therefore, the improvement of the durability by coating a waste polymer material did not affect the lateral deformation characteristics of a coir geomat reinforced vertical wall.

Chai et al, (2002) had conducted numerical analyses and concluded that only when the embankment approaches failure, the reinforcement has noticeable effect on the lateral displacement of the soil.

3. Methodology

3.1 Experimental Data collection

Material properties (Table 1) required for the numerical analyses and experimental results needed for comparison and validation were derived using the material data from the past studies of Kurukulasuriya et.al., (2011) and Jayaprakas et.al.(2012). The uncoated and coated geomat materials used in the above studies are shown in Figure 1. It is noted that the coated geomat has been produced using the uncoated geomat maintaining the same spacing of the ribs (coir ropes) in both directions. The shear strength properties and unit weight of the soil wall fill were based on the direct shear and compaction test results as reported and the Elastic properties were assumed to represent a typical value corresponding to the soil type. A relatively high value of coefficient of permeability was assigned to simulate drained conditions. The value of EA that should be assigned as a material parameter for the geomat in Plaxis software was evaluated based on the Young's modulus (E) value obtained from the wide-width tensile strength tests carried out on uncoated and coated geomats and the crosssectional area of ribs of the geomat per unit length.



(a) (b)

Fig 1. Experimental study materials (a) uncoated geomat, (b) coated geomat

Table1: Material properties from the past studies

Material		Parameter	Value
Silty Sand		c′	5 kPa
		ϕ′	31°
		γ_{sat}	20 kN/m³
		γ_{unsat}	17 kN/m³
		E	20 MPa
		ν	0.4
		k	25 m/day
Geomat	Uncoated	EA	5.2 kN/m
	Coated		7.4 kN/m

3.2 Numerical Analysis

The same embankment geometry and boundary conditions applicable to past experimental studies were used to construct the geometry model for the numerical analyses. For this study, Mohr-Coulomb model was used as the material model and the use of uncoated and coated geomats in a vertical embankment were analysed under dry and wet conditions where the values of material unit weight and interface shear strength between soil and geomat were considered to be affected by the degree of saturation of the embankment as given in Table 2.

Table 2: Parameters used in Plaxis software for analysis under dry and wet conditions

Parameter	Dry condition	Wet Condition
γ_{sat} (kN/m³)	-	20.0
γ_{unsat} (kN/m³)	17.0	20.0
Interface strength Ratio, R	1.00	0.65

The experimental set up of the vertical embankment was modelled using Plaxis software as shown in Figure 2 with geomat reinforcement placed at same vertical spacing as that in the experimental set up. In the experimental setup, a thin geotextile was placed between adjacent layers of geomats at the front face to improve local stability at the front face. This preventive measure was not considered in the numerical analysis. Figure 3 shows the generated 15 noded triangular finite element mesh.

Fig 2: Generated Material model with boundary conditions

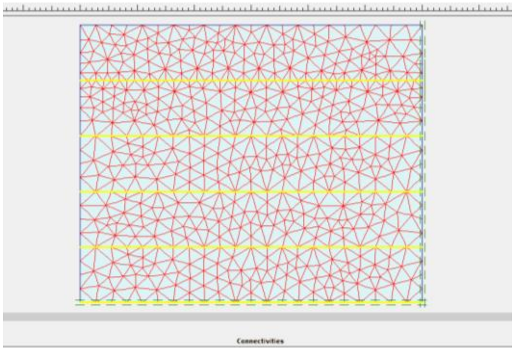


Fig 3: Generated mesh of vertical embankment

A gradually increasing surcharge load was applied at the surface of the model and the vertical deformations and lateral deformations at the same locations as those measured experimentally were evaluated under each load.

4. Results

4.1 Comparison of numerical and experimental results

Lateral and vertical deformations obtained experimentally and numerically under different loading were plotted as described below.

4.1.1. Uncoated geomat under dry condition

Figures 4 shows the experimentally and numerically obtained profiles of the vertical face of the vertical embankment after deformation depicting the extent of the lateral deformation when the top surface was subjected to three different values of surcharge pressure.

Comparison of horizontal displacement with depth shows that the variations of experimentally and numerically obtained profiles is similar at early stages of loading. However, comparison of vertical displacement with depth (Figure 5) shows similar variation for both experimental and numerical analyses. But, quantitatively, the displacements obtained from the numerical analyses show less value in magnitude than those observed in the experimental work. It should be noted that the numerical analysis only computes the elastic compression based on the assumed Young's modulus value, whereas under the experimental loading conditions, the embankment has been subjected to plastic deformations under high surcharge pressures.

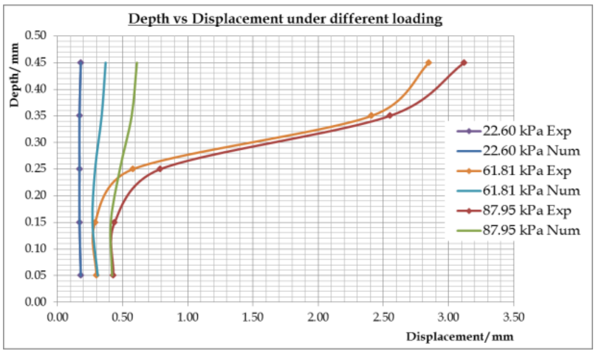


Fig 4: Comparison of lateral displacement with depth for uncoated geomat under dry condition

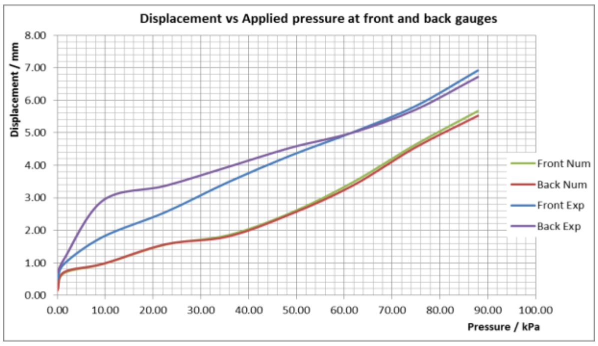


Fig 5: Comparison of vertical displacement with depth for uncoated geomat under dry condition

4.1.2. Coated geomat under dry condition

Similar comparison of experimental and numerical results of lateral and vertical deformations of vertical embankment reinforced with coated geomats is given in Figures 6 and 7 respectively.

Comparison of horizontal displacement with depth (Figure 6) shows relatively similar variations. However, comparison of vertical displacement with depth (Figure 7) shows that some tilting has occurred in the physical experiment which has resulted in giving different variations for front and back vertical deformation. Quantitatively, the average vertical displacement in the experimental set up appears to be similar to that obtained from the numerical analysis.

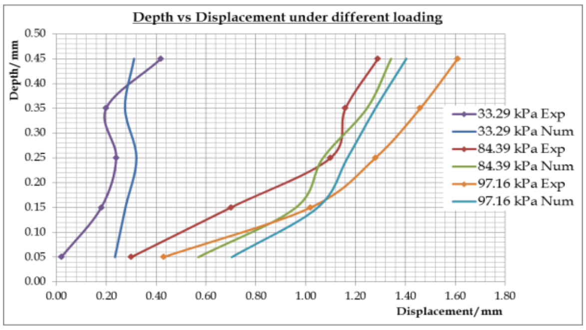


Fig 6: Comparison of lateral deformation for coated geomat under dry condition

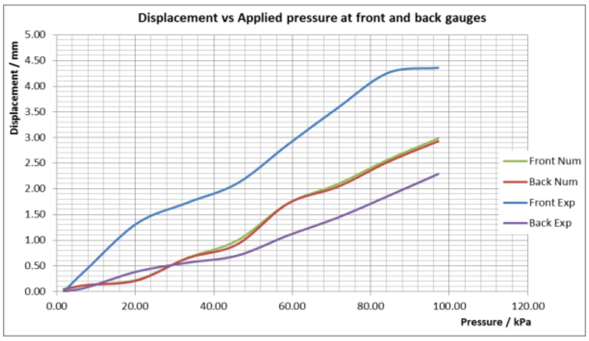


Fig 7: Comparison of vertical displacement with depth for coated geomat under dry condition

4.1.3 Uncoated geomat under wet condition

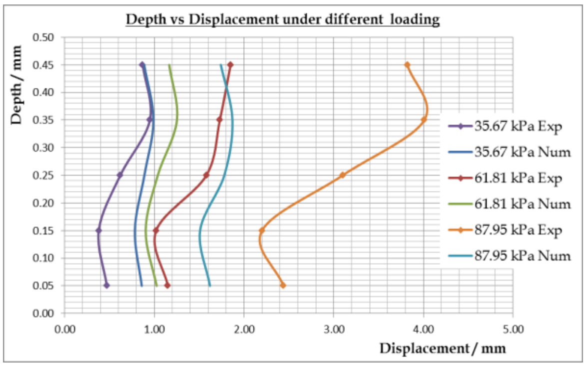


Fig 8: Comparison of lateral deformation for uncoated geomat under wet condition

The experimental and numerical results of lateral and vertical deformation characteristics for uncoated geomat reinforced vertical embankment under wet conditions is shown in Figures 8 and 9 respectively.

Comparison of horizontal displacement with depth (Figure 8) shows that the variation is similar for experimental and numerical analyses and comparison of vertical displacement with depth (Figure 9) also show similar variation for both experimental and numerical analysis.

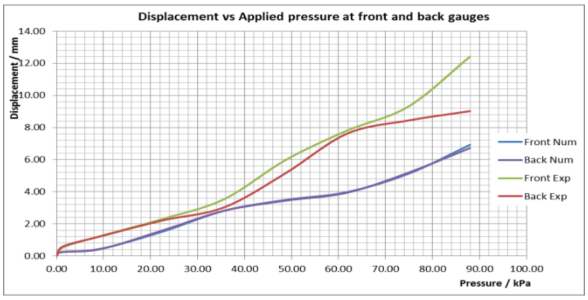


Fig 9: Comparison of vertical displacement with depth for uncoated geomat

However, quantitatively, the lateral displacements obtained from the numerical analyses show slightly less value in magnitude than those observed in the experimental work except that under the highest surcharge pressure. It appears that the degree of saturation is not uniform along the depth in the experimental study resulting in softening of soil at the upper layers as evidenced by the accompanying greater vertical deformation as well. However, in the Plaxis analysis, uniform saturation is assumed.

4.1.4 Coated geomat under wet condition

Comparison of horizontal displacement with depth (Figure 10) shows that the variation is similar to each other. However, the comparison of vertical displacement with depth (Figure 11) for both experimental and numerical analysis show greater deformation in the experiment than that in the numerical analysis.

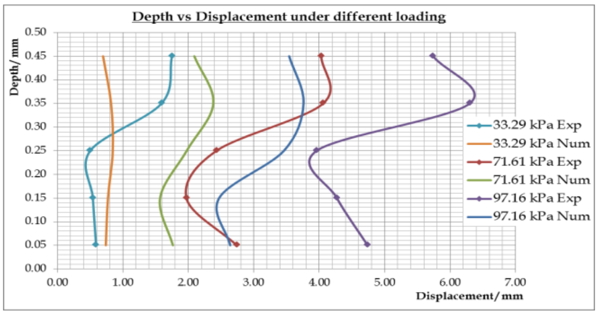


Fig 10: Comparison of results for coated geomat under wet condition

This may have been caused due to loosening of soil near the top surface during the soaking stage.

However, quantitatively, the lateral displacement obtained from the numerical analyses show less value in magnitude than those observed in the experimental work. This difference could be partly associated with the fact that the geomat is modelled as a membrane. However, in the experiment, the geomat behaves as a mesh with apertures in between.

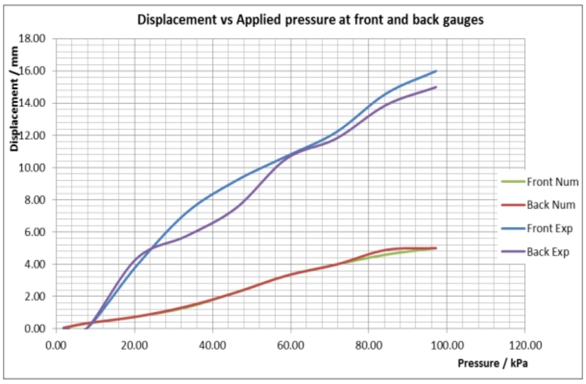


Fig 11: Comparison of vertical displacement with depth for coated geomat

4.2 Development of plastic zone

The Plastic points option available in the Plaxis software shows the stress points that are in a plastic state, displayed in a plot of the undeformed geometry. Plastic points can be shown in the 2D mesh or in the elements around a cross section. The plastic stress points are indicated by small symbols that can have different shapes and colours, depending on the type of plasticity that has occurred where a red square indicates that the stresses lie on the surface of the Coulomb failure envelope and a white cube indicates that the tension cut-off criterion has been reached.

The Mohr-Coulomb plastic points are particularly useful to check the failure plane. In this numerical analysis a surcharge pressure of 100 kPa was applied and the plot of plastic points in the undeformed geometry was extracted.

Figure 12 shows the plot of plastic points that are on the Mohr-Coulomb failure surface defined by the shear strength parameters, under an applied surcharge pressure of 100 kPa. The development of plastic points appear to show a failure surface similar to that is developed in a slope failure. However, this kind of a failure mechanism may not be possible in the experimental set up as the loading was carried out through a rigid steel plate. However, in the experimental set up, a greater vertical deformation observed at the front gives an indication that yielding may have taken place towards the front as indicated in the numerical analysis.

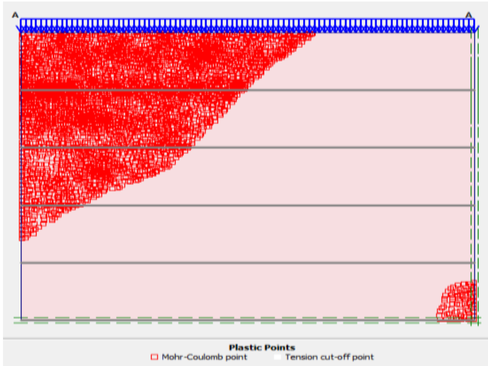


Fig 12: Plot of plastic points in the undeformed geometry under a surcharge pressure of 100 kPa

5. Conclusions

A numerical analysis was carried out to investigate the comparability of the lateral and vertical deformation characteristics of a coated and uncoated geomat reinforced vertical embankment under dry and wet conditions with the results of an experimental investigation.

The comparison of experimental and numerical results indicated that variations of the lateral and vertical deformations obtained from numerical analyses were similar to those of experimental work.

However, quantitatively the deformations obtained from the numerical analyses show lesser values in magnitude than those observed in the experimental work.

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