Numerical Simulation of Triaxial Test to Study the Effect of Reinforcement in Enhancing the Shear Behaviour of Black Cotton Soil

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Abstract. Black cotton soil is a problematic soil in the field of construction due to its poor shear behavior. The main objective of this study is to analyze the shear parameters of reinforced black cotton soil numerically using SIGMA/W in the Geo Studio tool. The study has been carried out to investigate the shear parameters of considered soil for different layers of reinforcement. The necessary boundary conditions have been applied for the numerical model. The numerical analysis has been performed considering various stresses and forces such as deviatoric stress, vertical stress, confining stress, and backpressure. The result in terms of effective stress, major principal stress, minor principal stress, total stress, and pore water pressure is obtained. The results obtained from numerical simulation are compared with those of the experimental studies of black cotton soil. This study shows that the results are within the marginal limits.

Keywords: SIGMA/W; Geo Studio; Black cotton soil; Numerical simulation; Planar reinforcement.

1 Introduction

Black cotton soil is highly compressible and poses problems in the field of construction due to its poor shear behavior and high swelling and shrinking properties. Soil reinforcements can be used to improve the shear parameters of soil. It is necessary to analyze the effect of reinforcement on the shear parameters of black cotton soil in order to know the effectiveness of the reinforcements. Soil reinforcements can be introduced in two different ways, namely planar and randomly distributed fibers. In planar reinforced soils, the fibers are laid layer by layer. Reinforcement layers are placed in the same orientation (i.e., the layers of reinforcement are parallel to each other. The reinforcements used for planar reinforced soils are geo-grids, geotextiles, geo-cells, etc. Randomly distributed reinforced soil has discrete fibers distributed randomly in the soil mass. The mixing of reinforcement with the soil is done until they form a homogeneous mixture. Reinforcements used for preparing randomly distributed reinforced soil are polypropylene fiber, Recron fibers, basalt fibers, etc.

Triaxial testing involves applying constant lateral pressure to soil samples while raising the vertical pressure to identify the stress-strain characteristics of the soils. The shear strength parameters are obtained by a triaxial test. Controlling drainage, measuring pore water pressures, stress, and strain, increasing loads, and observing deflections up until sample failure are all achievable during the experiment. [12]

Geo-grid is a polymeric, mesh-like geosynthetic planar reinforcement product formed by intersecting elements, called ribs which are joined at the junctions. These can be used to enhance the various engineering properties of soil. The improvement in the soil properties is due to the friction developed at the soil–reinforcement interface. The openings or apertures of the geo-grid provide interlocking with the surrounding soil particle. [6]

The effect of planar soil reinforcement on shear behavior can be numerically simulated in the SIGMA/W window of the Geo Studio tool. Geo Studio is a modeling software for earth engineers and geo-scientists. It is capable of doing detailed analysis and has a wide range of applications to various geo-engineering and earth science challenges.It has different windows namely SLOPE/W, SEEP/W+SEEP3D, SIGMA/W, QUAKE/W, TEMP/W+TEMP3D, AIR/W, CTRAN/W, BUILD3D. Different windows are used for different purposes.

Slope and deformation analysis utilizes the SIGMA/W window. For modelling stress and deformation in soil, rock, and structures, it is a potent finite element software program. With sigma/W, we can examine a wide range of issues, including complex consolidation challenges, slope stability issues for soil and rock slopes, soil structure interaction issues, and more. 1-D, 2-D and 3-D models can be analysed using the Geo Stodio software. [5]

Several reinforced soil investigations have been conducted in the past, and some of them were studied. Nader Hataf et al (2018) [1] investigated the improvement in soil bearing capacity with the usage of geobags. During the study, physical models and 3D finite element computer code analyses were generated. The simulation findings show that an external force caused a tensile force to be generated in the bags, which resulted in soil confinement and enhanced soils' compressive strength. The introduction of geobags reduced foundation settlement, as demonstrated by the load-settlement curves. The bearing capacity of the foundation increased as the quantity of geobags increased, and the positioning of geobags underneath the foundation is crucial for improving the soil. Madhu Sudan Negi et al (2019) [2] studied the effects of geotextile reinforcement used for subgrade. On the geotextile reinforced soil, the standard laboratory California bearing ratio (CBR) test was carried out. In this investigation, two types of subgrade soil—clayey and sandy—as well as two different geotextile materials—woven and non-woven—were used. Samples with one, two and three layers of geotextile reinforcements were tested. Investigation on the effects of geotextile type, positioning, and number of geotextile layers on the subgrade's strength were carried out. The addition of woven geotextile reinforcement to the subgrade resulted in an increase in CBR value. Additionally, it was found that woven geotextile excelled non-woven geotextile in terms of performance. The experimentally determined CBR values were also back analyzed using the finite-element program ABACUS, and it is concluded that they are in fairly good agreement with the experimental findings.

Chao Xu et al (2020) [3] investigated the reinforcing principles of geosynthetic-reinforced soil (GRS) under a plane strain environment. This proved that as reinforcement spacing reduced and stiffness was increased, the modulus of the GRS mass increased. The application of closely spaced geosynthetic reinforcement had a more noticeable restraining impact on the vertical settlement and could prevent the vertical settlements along the height of the GRS mass.

Ningyu Yang et al (2021) [4] analyzed the effects of fiber stiffness and friction coefficient on the shear behavior of fiber-reinforced soils. This shown that the inclusion of fibres with high stiffness (more than the threshold) leads to a rise in the peak strength and dilatancy of the mixes, whereas the addition of fibres with large friction coefficients enhances the residual strength of the samples.

The main objective of this study is to analyze the shear parameters of reinforced black cotton soil numerically using SIGMA/W window in the Geo Studio tool. Triaxial simulation has been carried out numerically to analyse the shear parameters of the soil.

2 Methodology

Two dimensional models of soil with zero to three layers of reinforcements were prepared in the SIGMA/W window of the Geo Studio tool and triaxial analysis was carried out on the models.

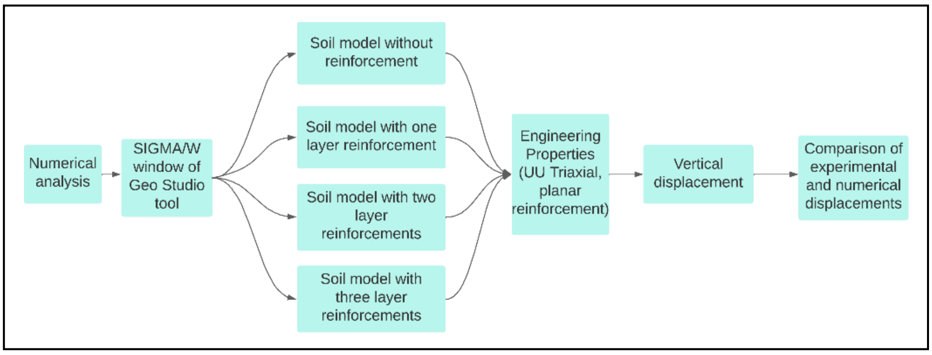

Fig. 1. Numerical analysis process

To prepare the model, initially, a blank page or window is opened in the SIGMA/W window of the Geo Studio software, and the X and Y axes are plotted. A model is drawn to a scale of 1:235.3. This scale is selected for the convenience of plotting the model. Horizontal bars have been used as reinforcement. Four models with different reinforcement conditions, i.e. models with zero, one, two and three layers of reinforcements are plotted. Once the model is drawn, the material properties, have to be defined for both the soil and the reinforcements. The input parameters considered for the analysis were the soil and reinforcement properties, lateral pressure and deviatoric pressure. Soil properties were – black cotton soil with void ratio, unit weight, undrained activated pore water pressure and effective poisson's ratio of 0.7, 19.7 kN/m^2, 150 kPa and 0.334 respectively. A high plastic material was used for the soil.

Properties of the reinforcement were – elastic modulus, cross-sectional area, pre axial force and spacing of 2.28 x 10^5 kPa, 53139 m^2, 200 kN and 0.05 m respectively. In case of model with no reinforcement, only the properties of the soil were defined. The next step was to draw the mesh properties. The model region was selected and the mesh was changed to quads and triangles with ratio of default size as 0.5. Then, boundary conditions were defined. For the simulation, the lateral pressure at X stress was taken as -150 kPa on the right side of the specimen and 150 kPa on the left side of the specimen. The negative sign is used so that the pressure is applied towards the specimen. The deviatoric pressure at Y stress is taken as -200 kPa. The boundary conditions and material properties were then assigned to the model. The model was then analysed for one-day analysis. The results were obtained. The output parameter considered for the analysis was the vertical displacement or deformation of the sample. The displacements obtained through numerical simulation and experimental analysis were compared.

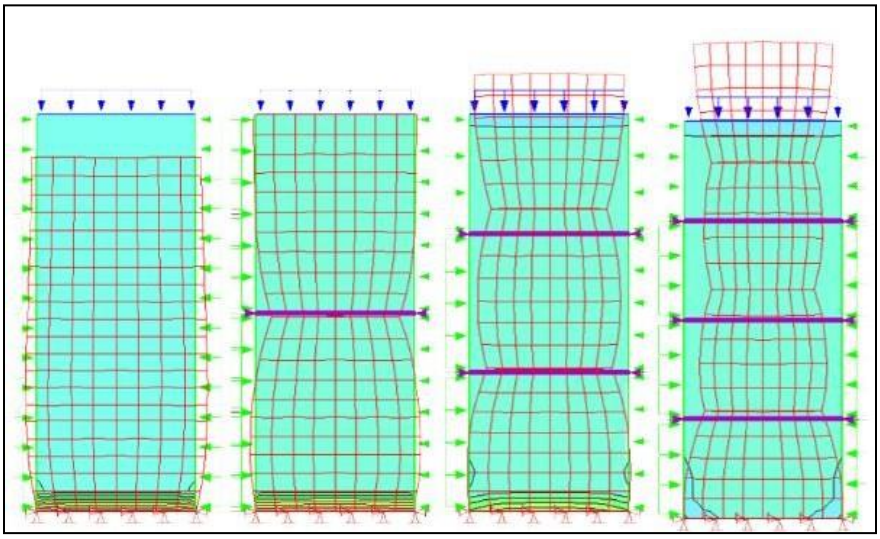

Fig. 2. Numerical models prepared in Geo Studio

3 Numerical results

The results were obtained in the form of the deformations or displacements along the length of the sample. The vertical displacement v/s elevation for each model has been obtained. The displacement figures obtained after numerical analysis of the black cotton soil model with zero, one, two and three layers of reinforcement are shown in fig. 2 to fig. 5. Since the models were geometrically symmetrical, the displacement figures obtained for both left and right side of the specimen were same. Hence, only figures of one side have been shown. (Here, left side refers to left side of the soil model)

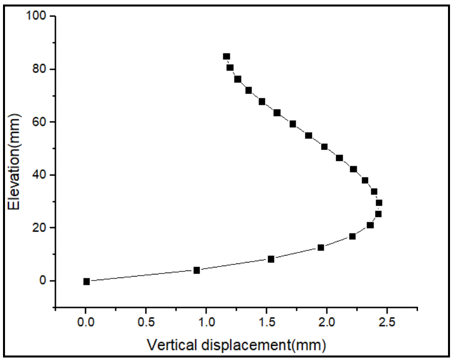

Fig. 3. Without reinforcement (left side)

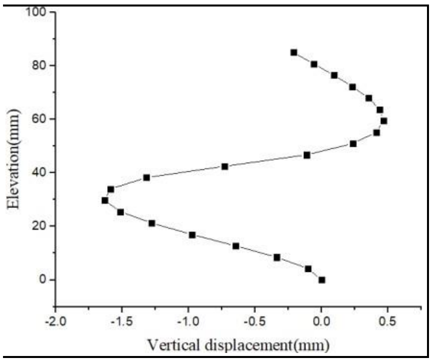

Fig. 4. One layer reinforcement (left side)

Fig. 5. Two-layer reinforcement (left side)

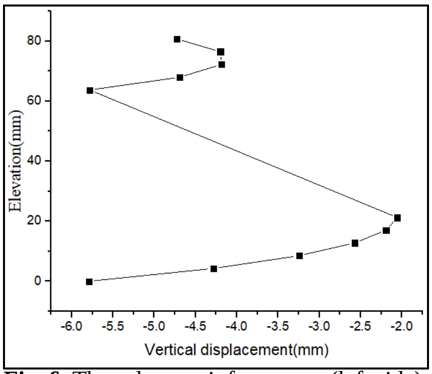

Fig. 6. Three-layer reinforcement (left side)

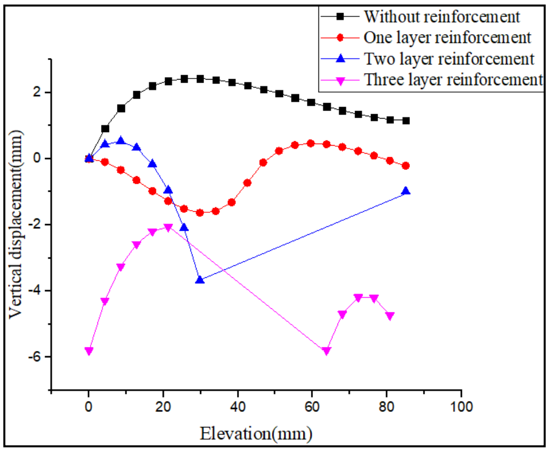

Fig. 7. Comparison of vertical displacements obtained in numerical simulation

The figures shown in Fig. 3 to Fig. 6 shows the deformations in the soil samples with zero to three layers of reinforcements respectively along the length of the sample. From the figures, it is observed that the displacements reduced with the increase in the number of layers of reinforcement. The comparison of the displacements obtained in all the samples is shown in Fig. 7. It can be noted from Fig. 6 that the displacement in the sample without reinforcement is highest and it goes on decreasing as the number of layers of reinforcement increases.

The interlocking property of the soil reinforcement improves the shear parameters of the soil. Improvement in shear parameters of soil reduces the deformation caused in the soil model. Hence, the decrease in the vertical displacement of the soil model due to the increase in number of layers of soil reinforcement can be attributed to the improvement in shear parameters of the soil due to inclusion of soil reinforcement.

4 Comparison of displacements obtained from experimental analysis and numerical simulation

The numerical displacements obtained in representative samples with zero, one, two and three layers of reinforcements are compared with the displacements obtained during the experimental analysis of soil model with zero, one, two and three layers of reinforcement respectively. Comparison figures comparing the displacements obtained in numerical simulation and experimental analysis were plotted for each soil model taking vertical displacement on x-axis and elevation on y-axis. The comparison figures plotted are shown in the 8 to 11.

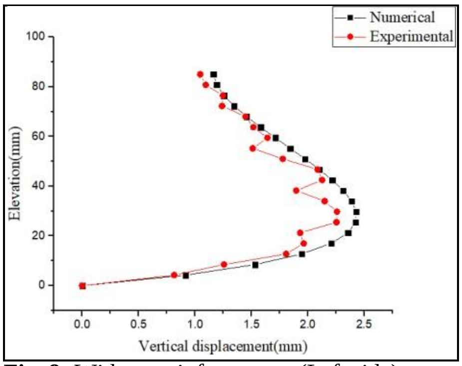

Fig. 8: Without reinforcement (Left side)

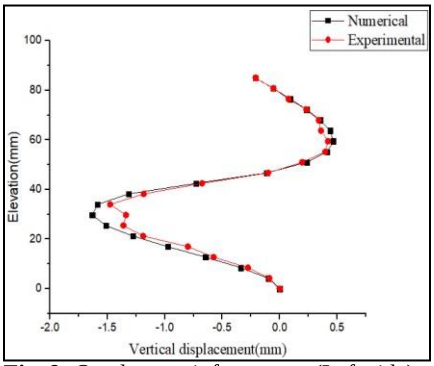

Fig. 9: One layer reinforcement (Left side)

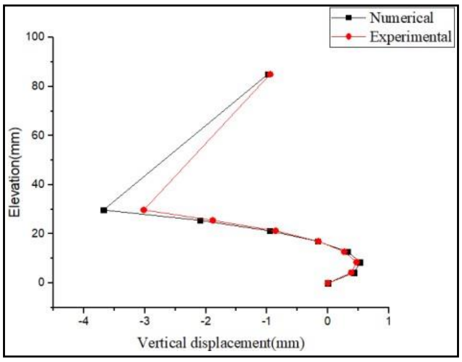

Fig. 10: Two-layer reinforcement (Left side)

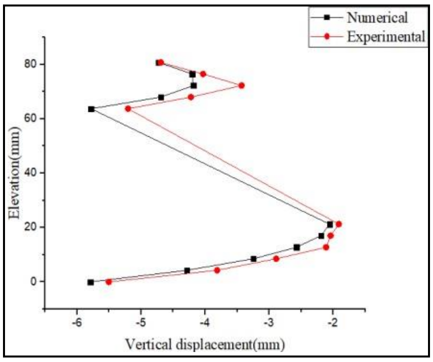

Fig. 11: Two-layer reinforcement (Left side)

From the figures 8 to 11, it can be observed that the displacements obtained through both numerical simulation and experimental analysis are almost the same through the length of the sample. Hence, the experimental results are validated through numerical simulation. The displacement figures obtained for the left and right side of the sample were same due to the symmetry of the soil model.

5 Conclusions

The main objective of the study was to study the effect of planar reinforcement on the shear behavior of the black cotton soil. The effect of number of layers of reinforcement is also intended to be studied. Numerical simulation was carried out in the SIGMA/W window of the Geo Studio software for this purpose.

The results showed that with the increase in number of layers of reinforcement, the deformation of the soil sample decreased. This study shows that soil reinforcements are useful in improving the shear behavior of soils. Increasing the number of layers of planar reinforcements can increase the effectiveness of soil reinforcements. The displacements of soil models with zero to three layer reinforcements obtained through numerical simulation correlate with those obtained through experimental analysis. Therefore, numerical results are validated using the experimental analysis results. Hence, soil reinforcements can be used in areas with weaker soils to improve the properties of soils.

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