Proceedings of Indian Geotechnical Conference 2020
December 17-19, 2020, Andhra University, Visakhapatnam
Visakhapatnam Chapter

Numerical Analysis of Bearing Capacity and Settlement Reduction of Bamboo Reinforced Sand Beds

Ajesh Sankar M.[1], K.S. Akhil[2], N. Sankar[3] and S. Chandrakaran[4]

[1] M-Tech Student. Dept of Civil Engineering, NIT Calicut, Kerala 673601,
E-mail: ajeshsankarm@gmail.com
[2] Research Scholar, Department of Civil Engineering, NIT Calicut, Kerala, 673601,
E-mail: ksakhil1992@gmail.com
[3] Professor, Department of Civil Engineering, NIT Calicut, Kerala, 673601
E-mail: sankar@nitc.ac.in
[4] Professor, Department of Civil Engineering, NIT Calicut, Kerala, 673601
E-mail: chandra@nitc.ac.in

Abstract Reinforcing soil with cheap and locally available materials is common nowadays. Use of sustainable and readily available substances as reinforcing materials has been prevalent and trending. Bamboo is one of the most effective naturally available materials for soil reinforcement due to its excellent mechanical and engineering properties. Numerical modelling techniques are often used in geotechnical engineering to deal with problems involving complex geometries.
This paper aims to present the results of numerical investigations carried out on bamboo reinforced sand beds using PLAXIS 2D software. Bamboo mats with a rectangular pattern with a thickness of 0.5mm were used. Improvement in bearing capacity and reduction in the settlement were analysed using the software, and it was observed that bearing strength of sand beds increased as the number of reinforcing layers increased.

Keywords: Bamboo mat, Numerical Modelling, PLAXIS 2D

1 Introduction

1.1 Bamboo reinforced soils

Rapid population growth and industrialization demand more and more ideal land to meet the demand. This results in an acute shortage of ideal land for construction. So, the development in the soft ground has almost become unavoidable for civil engineers. In such cases, the soil needs to be improved to increase its mass density and thus the shear strength and bearing capacity. Soil reinforcement techniques have been used to improve the bearing capacity of foundation soil.

Reinforcing soil with locally available materials is quite common and cost-effective. The use of sustainable and naturally accessible substances as reinforcing materials has become popular nowadays. Bamboo is one of the most abundantly available natural material for reinforcing soil because of its excellent mechanical and engineering properties. Several researchers reported (Akhil et al., 2019; Sara et al., 2016; Hegde & Sitharam, 2015; Waruwu and Susanti, 2015; Azaduzzaman and Islam, 2014) that the use of bamboo reinforced soil bed gave improved results in bearing capacity and settlement reduction compared with soil without any reinforcements. Small scale laboratory model experiments on soil reinforced with bamboo coated with bitumen yielded about 24% of settlement reduction (Sara et al., 2016). Green or dry state of bamboo require different preservation techniques to be adopted (Hegde and Sitharam, 2015). Steeping, diffusion, and sap displacement are the commonly adopted methods for treating bamboo obtained in fresh condition. Soaking, pressure impregnation, hot and cold processes, etc are used to treat dry bamboo. In soaking, the air-dried bamboo grids immersed in the preservative solution (Copper-Chrome-Arsenic) for a certain period. Chemical composition test was carried out to ascertain the effectiveness of the preservation method adopted (Hegde & Sitharam, 2015). They reported that the treatment of bamboo reduces the tensile strength by 15%. However,the tensile strength is more for treated bamboo than geotextiles and geogrids. The surface roughness was found reduced to 20% by treatment. Boucherie-Mourisco principle includes a preservative solution of borax with water into bamboo with air pressure (Warywu and Susanti, 2015).

Several researchers (Ahammed et al., 2016, Balakumar et al., 2017, Makkar et al., 2019) reported that to simulate the behaviour of foundation soil “Mohr-Coulomb model” is the most appropriate model since it assumes the soil as elastoplastic. Mohr-Coulomb model requires five parameters namely, Young’s modulus(E), Poisson’s ratio(υ), cohesion(C), angle of friction(φ), and angle of dilatancy(ψ). Young’s modulus and Poisson’s ratio to present the elastic behaviour of soil. Cohesion and angle of internal friction define the failure criteria. Angle of dilatancy describes the flow rule. Ahmed et al., 2016 studied the effect of first geogrid reinforcement depth, the spacing between the reinforcement and its extension relative to the footing length on the mobilized bearing capacity. The laboratory results were simulated, and results were validated using the commercial finite element package (PLAXIS v8.2). The authors reported the comparison between experimental and model studies through bearing capacity ratio (BCR).

Akhil et al., 2019 conducted an experimental study to understand the performance of sand beds reinforced with bamboo mats in improving the bearing capacity and settlement characteristics. They reported that when the number of layers was increased, bearing capacity and settlement reduction were also increased. In the present investigation, an attempt has been made to simulate the bamboo mat reinforced soil foundation numerically.

2 Numerical Modelling

Numerical modelling technics are powerful tools that have been used to study the behaviour of various structures under a variety of loading conditions. Numerical models are particularly useful in situations where prototype is huge to be tested in the laboratory.

Plate load tests were conducted to study the effect of bamboo reinforcements on sand beds, and the properties of the sand bed are shown in Fig 1.

Property	Value
Effective size (D_{10})	0.265
D_{30}	0.46
D_{60}	0.70
Coefficient of uniformity (C_u)	2.66
Coefficient of curvature (C_c)	1.13
Specific gravity, G	2.65
Maximum dry density, kN/m^3	16.3
Minimum dry density, kN/m^3	14.4
Angle of internal friction (ϕ) at relative density of 60%, degrees	39.5
Classification of soil as per Unified Soil Classification System (USCS)	SP (Poorly graded sand)

Fig. 1. Basic properties of sand bed (after Akhil et al., 2019)

Test tank of 750 mm × 750 mm × 750 mm size and steel plate of thickness 25 mm representing the model footing was used. The same dimensions and experimental setup were used for the modelling. However, because of the symmetry and to reduce the computation time and effort, only a quarter portion of the test tank was modelled. The soil was modelled as elastoplastic Mohr-Coulomb model and the reinforcement as a linear-elastic model. The boundary conditions were fixed such that the horizontal boundaries which represent the vertical walls of the test tank were restrained in the horizontal direction while the bottom boundary was restrained in both vertical and horizontal directions. Table 1 shows the soil properties assigned in material data set of PLAXIS 2D.

The shear strength parameters (C and φ) calculated by direct shear test and reported by Akhil et al. (2019) was used in the present study. Young's modulus of sand bed modelled was directly taken from the load – settlement response of the plate load test conducted on unreinforced sand beds. Latha & Somwanshy, 2009 and Makkar et al., 2019 also used the same procedure to determine the elastic modulus of sand. Ghazavi & Lavason (2008) showed that the best results of the numerical analysis were achieved when the angle of dilatancy (ψ) was considered as two-third(2/3) of the angle of internal friction(φ). A typical value for the angle of dilatancy for dense sand is 15^0. The value of ψ used in this study is 28^0.

Table 1. Soil Properties for Modelling

Material	Symbol	Assigned value
Material Model	-	Mohr-Coulomb
Drainage type	-	Drained
Unsaturated unit weight	$\gamma_{unsat,}$	15.44 kN/m^3
Saturated unit weight	γ_{sat}	19.42 kN/m^3
Young's Modulus	E	3500 kPa
Poisson's Ratio	υ	0.3
Cohesion	C	1 kPa
Angle of internal friction	Φ	39.5^0
Dilation angle	Ψ	28^0

Tensile tests on bamboo strips were conducted by several researchers (Hegde and Sitharam, 2015, Akhil K.S. et al., 2019) showed that the tensile strength of bamboo was about nine times more than that of the geogrid and geocell materials (Hegde and Sitharam, 2015). a mean value of 205 MPa as the tensile strength and a mean secant modulus of 6350 MPa (Akhil. et al. 2019) was used to determine the axial stiffness of the reinforcement material for numerical modelling.

Depth to first reinforcement layer was kept as 0.3 times width of footing, the width of the bamboo mat was kept three times the width of footing, and subsequent layers was kept at 0.3 times width of footing each. All these parameters were reported as optimum parameters for reinforcement placing in the referred journal paper (Akhil et al., 2019).

A uniformly distributed load was applied on top of the footing. As mentioned earlier, the horizontal and vertical boundaries were fixed.

A non-dimensional parameter was introduced to evaluate the degree of improvement of bearing capacity.

$$\boldsymbol{IF = \frac{BC}{BCu}} \qquad (1)$$

Where IF = Improvement Factor

BC = Bearing Capacity of bamboo reinforced sand

BCu = Bearing Capacity of unreinforced sand

3 Results and Discussions

The load-settlement curve obtained from numerical modelling of unreinforced sand is shown in Fig 2. A maximum bearing pressure of 361.1 kPa and a maximum settlement of 40.87 mm were obtained.

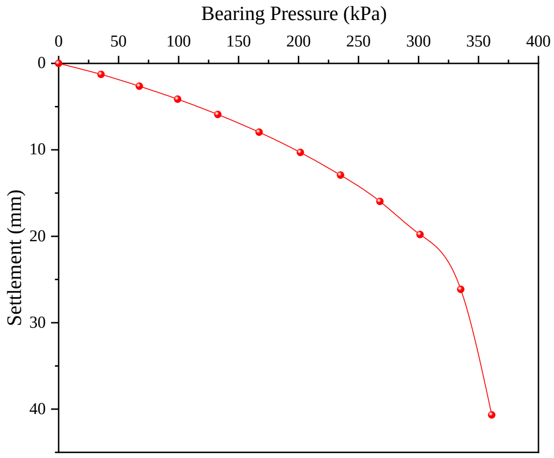


Fig. 2. Load settlement curve for unreinforced sand

With the increase in the number of layers, the applied pressure is distributed over a more significant depth, thereby contributing to higher bearing capacity and settlement reduction. The trend observed in the current study is shown in Fig 3. When the number of layers increases the bearing capacity also increases. Beyond a certain depth, the inclusion of reinforcements has no significant effects in bearing capacity. When N=4 and N=5 the load-settlement curves are almost the same. Considering the economic aspects, three layers of reinforcement are sufficient for optimum performance. Fig 4 shows the improvement achieved for different number of layers.

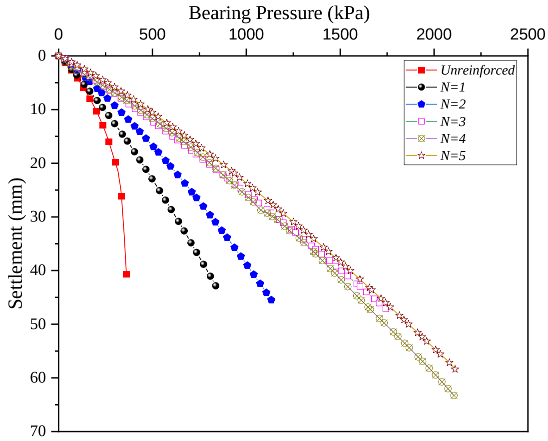


Fig.3. Load settlement curve for different number of layers

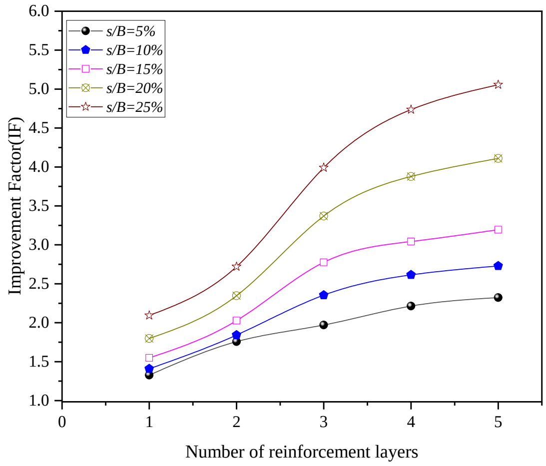
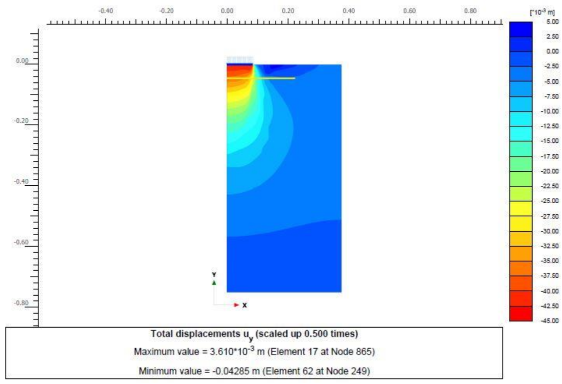
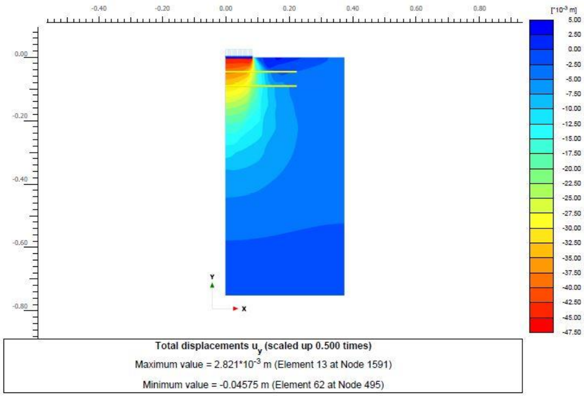


Fig. 4. Improvement factors for different number of layers of reinforcement

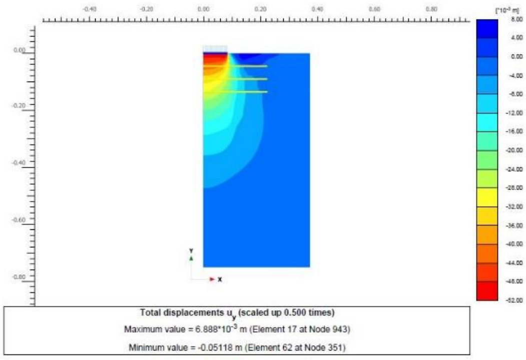
Figure 5 (a to e) shows the vertical displacement contours for different layers of bamboo reinforcement it is observed that settlement is more for 4 number of layers compared with 5 number of layers. Considering the economic aspects, three layers of reinforcement are sufficient for optimum performance.



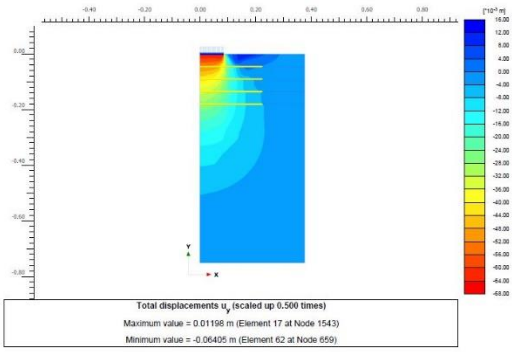
(a) N=1


Total displacements u_y (scaled up 0.500 times)
Maximum value = $2.821*10^{-3}$ m (Element 13 at Node 1591)
Minimum value = -0.04575 m (Element 62 at Node 495)

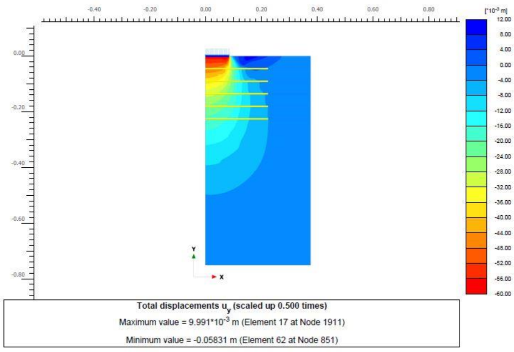
(b) N=2


Total displacements u_y (scaled up 0.500 times)
Maximum value = $6.888*10^{-3}$ m (Element 17 at Node 943)
Minimum value = -0.05118 m (Element 62 at Node 351)

(c) N=3


Total displacements u_y (scaled up 0.500 times)
Maximum value = 0.01198 m (Element 17 at Node 1543)
Minimum value = -0.06405 m (Element 62 at Node 659)

(d) N=4



(e) N=5

Fig.5. Vertical Displacement Contours for different layers of bamboo reinforcement

4 Conclusions

Numerical analysis were carried out to understand the behaviour of bamboo mat reinforced soil systems using PLAXIS 2D. From the numerical study, the following conclusions have been made:

1. Bearing capacity of the soil was increased when reinforced with bamboo grids of rectangular pattern
2. When number of layers is more, the bearing capacity was also found to be more. There is no significant increase in bearing pressure from layer 4 to 5. So by considering the economic aspects we can say that optimum results were obtained at 4 layers of reinforcement.

References

1. Akhil K.S, Sankar N., and Chandrakaran S. "Behaviour of model footing on bamboo mat-reinforced sand beds" Soils and Foundations 59, 1324–1335 (2019).
2. Hegde A. and Sitharam T.G. "Three-dimensional numerical analysis of geocell-reinforced soft clay beds by considering the actual geometry of geocell pockets." Canadian Geotechnical Journal, 52(9): 1396-1407 (2015).
3. Sara C.S. and Shyla J.A. "Experimental investigation on soil reinforced with bitumen coated bamboo" International Research Journal of Engineering and Technology 3(9) 66-68 (2016).
4. Waruwu A. and Susanti R. D. "Behavior of Soil Peat with Reinforcement of Bamboo Grid." IOSR Journal of Engineering 5(11) 29-36 (2015).
5. Asaduzzaman Md. and Islam M.I. "Soil Improvement By Using Bamboo Reinforcement" American Journal of Engineering Research 3(8) 362-368 (2014).
6. Balakumar V., Huang M., Erwin O. and Balasubramaniam A. S. "Critical and Comparative Study on 2D and 3D Analyses of Raft and Piled Raft Foundations", SEAGS 50th Anniversary Symposium Proceedings 14, 15-26 (2017).

7. Makkar F. M. , Sreya M. V., Chandrakaran S. and N. Sankar ”3-Dimensional Numerical Modelling of Sand Bed Reinforced with 3D Geogrids of Triangular Form”, Australian Geomechanics, 54(2), 99-110 (2019).
8. Latha, G.M. and Somwanshi, A. “Bearing capacity of square footings on geosynthetic reinforced sand”, Geotextiles and Geomembranes, 27 (4), 281-294 (2009).
9. Ghazavi M. and Lavasan A.M. “Interference effect of shallow foundations constructed on sand reinforced with geosynthetics”, Geotextiles and Geomembranes 26, 404-415 (2008).