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NUMERICAL ANALYSIS OF SAND- FIBRE MIXED GRANULAR PILES

N.K.Samadhiya, Professor, Department of Civil Engg., IIT Roorkee, Roorkee – 247 667, nksamfce@iitr.ernet.in
Partha Basu, Research Officer (SM), River Research Institute, West Bengal, partha_gt@rediffmail.com
S.L. Baite, Former PG Student, Department of Civil Engg., IIT Roorkee, Roorkee – 247 667, lalbawi_iitr@gmail.com

ABSTRACT: Ground improvement technique is a methodology to treat and improve the foundation performance on poor ground so that the ground properties are improved and the effects of heterogeneity are reduced. Stone column or granular pile is one of the techniques of ground improvement. The installation stiffens the soil, reduces settlement, improves load carrying capacity and accelerates consolidation. Further, the addition of random fibers in the granular pile/ column matrix increases the stiffness. The response of granular pile due to random sand-fiber mix has been studied in detail by [5] by carrying out extensive short term model tests in the laboratory by varying fiber content, fiber length and depth of fibers in the granular piles. A considerable improvement in the performance of granular piles in terms of load carrying capacity, stiffness and reduction in bulging of the granular pile on addition of random fiber mixed and sand pad thickness has been reported by [5].The present work deals with the development and analysis of a numerical model of sand fiber mixed granular pile and thereby comparing the results with the experimental investigation results [5].

INTRODUCTION

The increasing infrastructure growth in urban and metropolitan areas has resulted in a dramatic rise in land prices and lack of suitable sites for development. As a result, construction is now carried out on sites which, due to poor ground conditions, would not previously have been considered economical to develop. In order to make these sites suitable for construction various ground improvement techniques, such as vibro-floatation, dynamic compaction, stone columns, compaction piles, compaction grouting, drainage techniques etc. are available which may be employed depending upon soil conditions and nature of projects. Ground improvement using granular piles is gaining importance now-a-days. The principle of granular pile reinforcement involves the replacement 10 to 35 percent of the weak soil with coarse granular material such as stone, gravel or sand in the form of column. The granular piles are usually extended to bedrock or a hard layer. Many investigators have now attempted to investigate the behavior of granular piles reinforced with fibres or geogrids through experimental or numerical approaches e.g. [1-6]. A detailed parametric study has been conducted by [5] with random fiber to observe the effect of fiber content, fiber length and fiber depth in granular pile (GP) on load carrying capacity of GP. Short term load tests have been conducted as per the procedure given in Federal Highway Administration (U.S. Department of Transportation, Report No. FHWA/RD-83/026) [7]. Every increment of load has been maintained for 15 minutes, which is not enough for achieving completely drained condition. The tests may, therefore, be considered as un-drained tests. Conclusively, based on the study on randomly oriented fiber in granular pile, he has recommended that for optimum conditions, 0.5% fiber content (for facilitating proper mixing), 0.6d fiber length and 3.0d fiber depth is the best combination for randomly fiber mixed granular pile to improve its load carrying capacity. Here d= diameter of the granular pile. The objective of the present work is to analytically validate the experimentally investigated work [5].

NUMERICAL MODELLING AND SIMULATION

Description of Developed *FLAC^{3D}* Model

FLAC^{3D} (Fast Lagrangian Analysis of Continua in three dimensions), an explicit finite difference computer program to study the mechanical behaviour of study the mechanical behaviour of a continuous three dimensional medium, has been employed in the study. The clay-bed, random fiber mixed GP and the sand-pad have been modeled using the elastic perfectly plastic Mohr-Coulomb model predefined in the *FLAC^{3D}* program. The material used in the model can yield and flow. Because of the symmetry of the system, quarter symmetry model has been taken for the simulation. A cubical soil grid with appropriate dimensions has been used to construct one fourth of the 3D model. The geometry of the model can be manipulated as per requirement to simulate the sand-clay-fibre interaction system.

Broadly, two different models have been generated with sizes 0.2625m×0.2625m×0.6m and 0.2625m×0.2625m×0.4m for single granular piles (GP) of 75 mm and 50 mm respectively (Figs. 1 and 2). Three types of zone models, namely cylindrical mesh (cylinder) for granular pile, cylindrical shell mesh (cshell) for loaded area and radially graded mesh around cylindrical-shaped tunnel (radcylinder) for clay bed, have been used for grid generation. The advantage of using the grouping command has been utilized for better grouping of the model such as clay bed, granular piles with or without fibres, which aid in assigning the material properties. Appropriate boundary conditions were applied to the various models to simulate the conditions of experimental study [5]. The force due to gravity of the earth is initially applied in the form of acceleration due to gravity i.e., 10 m/s^2. The developed model is first brought to its initial equilibrium condition. The loading is applied by giving a constant velocity of 2.0x 10^{-6} m/step on the grid points through the circular footing for single granular pile resting on the granular pile.

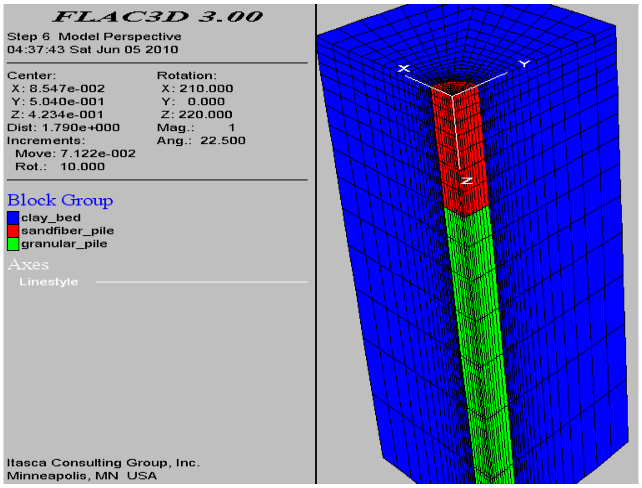

Fig. 1 Typical model for 75 mm single GP (size 0.2625m×0.2625m×0.6m)

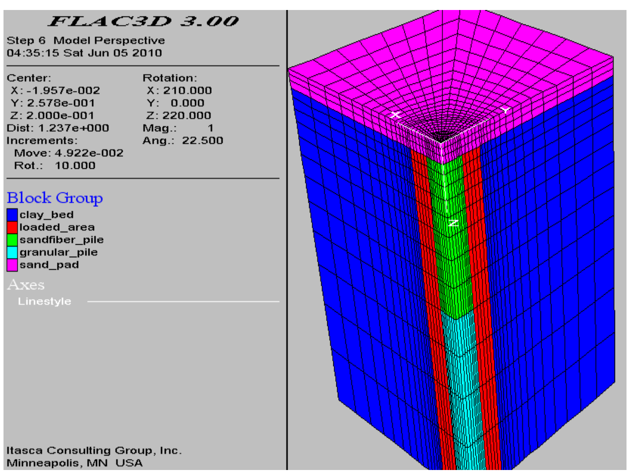

Fig. 2 Typical model for 50 mm single GP (size 0.2625m×0.2625m×0.4m)

Material Properties

The shear strength parameters and Young's modulus, E, have been obtained by conducting triaxial tests in laboratory. The Poisson's ratio ha been assumed as 0.3. The material properties used in the modeling are tabulated as under:

Numerical Study Programme

The numerical investigation has been carried out in the sequence given in Table 2. A total number of 17 different models have been developed depending upon the variation in fibre content, fibre length and fibre depth.

RESULTS AND DISCUSSION

Random Fiber Mixed Granular Pile (d = 75 mm)

The present numerical model test results of load-settlement behavior of GP with fiber content variation along with the experimental findings [5] have been shown in Fig. 3. The plot shows that the increase in fiber content increases the load capacity of GP. The values don't exactly match each other; nevertheless the values of numerical study approaches towards the experimental study. This numerical finding supports the experimental study [5]. It may be seen from Fig. 3 that the curves have become steeper which is an indication of increase in the stiffness of GP. These effects are more visible with fibre content more than 1.0%.

Both the plot of experimental and present numerical study of load-settlement behavior of GP with varying fiber length for F_c = 0.5% and F_d = 8.0d has been shown in Fig. 4. It may be noted that increase in fiber length improves the load carrying capacity of GP in comparison with the unreinforced one.

The experimental and numerical load-settlement behavior of GP with varying fiber depth has been presented in Fig. 5. The load carrying capacity of GP increases with F_d variation up to 3.0d. The reason attributing to this result being the stiffness of GP.

Random Fiber Mixed Granular Pile (d = 50 mm)

The load-settlement curves of GP with varying F_c for both present numerical study and experimental study [5] have been presented in Fig. 6. The figure shows that the numerical models show lesser load capacity than the experimental models. This discrepancy may be due to the material properties adopted for numerical modeling on one side, and on the other side the equipment or human error during the execution of experimental study. The experimental approach [5] concluded that the trends of curves and trend of improvement for both 50 mm and 75 mm diameter random fiber mixed GP have been found to be similar.

Table 1 Material properties

Serial No.	Fiber Details			Shear Strength Parameters		Young's Modulus, E (MPa)	Density, γ_{dry} (kN/m^3)
	F_c (%)	F_{rd} (mm)	F_l (mm)	c_s (kPa)	ϕ_s (^{o})		
1	*Only clay bed*			16.00	0.00	0.25	14.90
2	0.0	0.2	30	15.55	34.47	6.70	18.00
3	0.3	0.2	30	24.84	39.27	7.50	18.00
4	0.5	0.2	30	29.59	40.91	9.70	18.00
5	1.0	0.2	30	43.00	42.76	10.50	18.00
6	1.5	0.2	30	54.88	45.56	12.50	18.00
7	2.0	0.2	30	77.92	46.30	13.90	18.00
8	0.5	0.2	15	20.13	41.00	10.50	18.00

F_{rd} = Fiber diameter F_c = Fiber content F_l = Fiber length

Table 2 Numerical study programme on granular pile

Model No.	GP Specification		D (mm)	Fiber Details			
	d (mm)	L (mm)		F_c (%)	F_{rd} (mm)	F_l (mm)	F_d (mm)
Granular Pile Diameter d = 75 mm and footing diameter = 75 mm *Only Clay Bed*							
MT 00	0	0	75	0	0	0	0
Varying Fibre Content							
MT 01	75	600	75	0	0	0	0
MT 02	75	600	75	0.3	0.2	30	600
MT 03	75	600	75	0.5	0.2	30	600
MT 04	75	600	75	1.0	0.2	30	600
MT 05	75	600	75	1.5	0.2	30	600
MT 06	75	600	75	2.0	0.2	30	600
Varying Fibre Length							
MT 07	75	600	75	0.5	0.2	15	600
MT 08	75	600	75	0.5	0.2	30	600
Varying Fibre Depth							
MT 11	75	600	75	0.5	0.2	30	75
MT 12	75	600	75	0.5	0.2	30	150
MT 13	75	600	75	0.5	0.2	30	225
MT 14	75	600	75	0.5	0.2	30	300
MT 15	75	600	75	0.5	0.2	30	450
Granular Pile Diameter d = 50 mm and footing diameter = 50 mm *Varying Fibre Content*							
MT 22	50	400	50	0	0	0	0
MT 23	50	400	50	0.5	0.2	30	400
MT 24	50	400	50	1.0	0.2	30	400

Note: d = Granular pile (GP) diameter, D = Footing diameter, F_{rd} = Fiber diameter, F_d = Fiber depth in the GP, F_c = Fiber content in the GP, F_l = Fiber length in the GP, L = Granular pile length

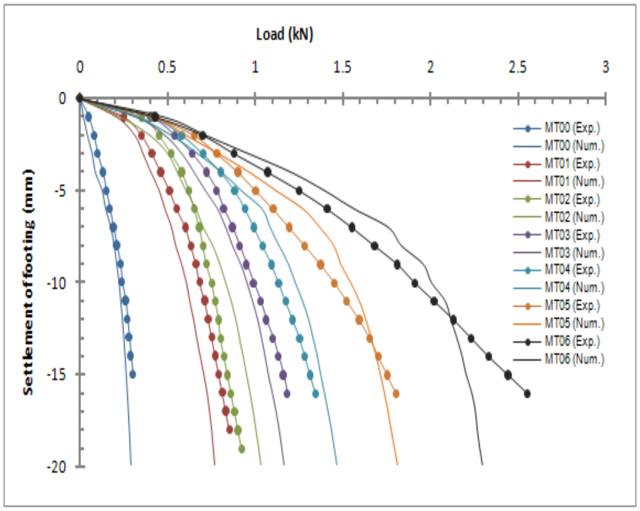

Fig. 3 Comparison between experimental [5] and present numerical model study of load-settlement curve for GP with varying fiber content

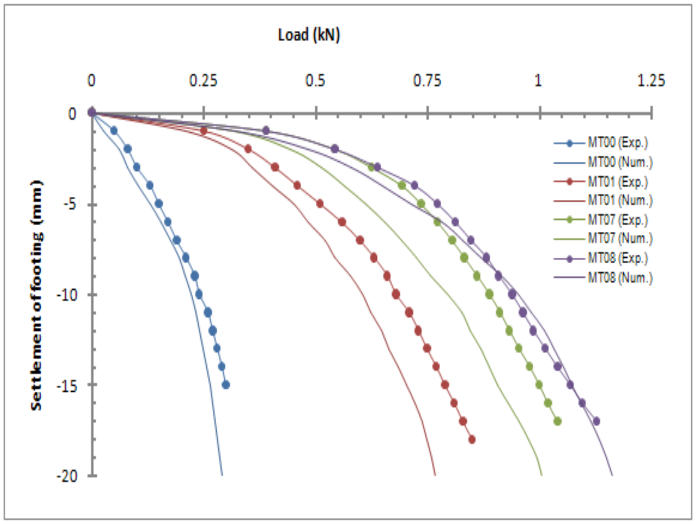

Fig. 4 Comparison between experimental [5] and present numerical model study of load-settlement curve for GP with varying fiber length

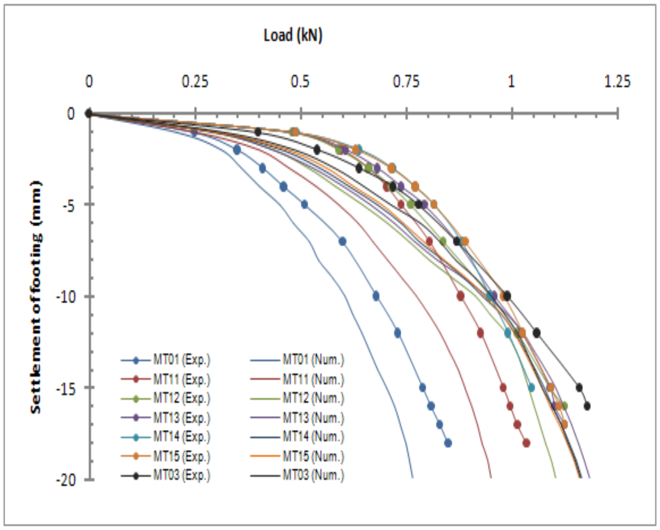

Fig. 5 Comparison between experimental [5] and present numerical model study of load-settlement curve for GP with varying fiber depth

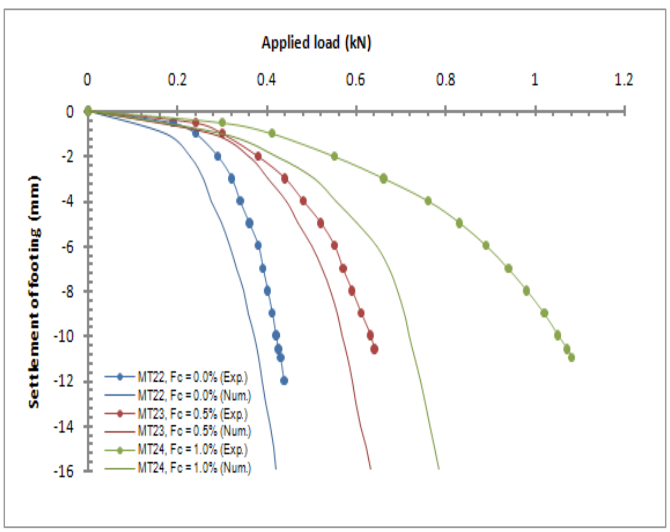

Fig. 6 Comparison between experimental [5] and present numerical model study of load-settlement curve for GP with varying fiber content

CONCLUSIONS

The aim of the present analytical study has been to develop and analyze a suitable *FLAC*^{3D} model to simulate a randomly fiber mixed granular pile. The results obtained have been compared with the experimental findings of [5]. The major conclusions of the present study are summarized as under:

i) The load carrying capacity of 75 mm diameter GP increases with increase in the percent fiber content, fiber length and the fiber depth in the GP. For F_c =0.5% and F_l = 0.4d, the optimum fiber depth has been found to be 3.0d.

ii) The load carrying capacity of 50 mm diameter GP also increases with increasing percent fiber content. The same conclusions have been drawn by [5] though the load capacity of 50 mm diameter GP from present study exhibit lower value than that from the experimentally obtained one.

The above conclusions have been drawn based on the findings from the numerical model tests. Hence though with limitations in selection of material properties and the model itself, the present numerical model study authenticate the experimental study [5].

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