Centrifuge model studies on geogrid reinforced embankments

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ABSTRACT: The increasing population and the industrial growth demand for the utilization of areas with even soft clay deposits. Construction of embankments on soft soils pose several threats like slope failure and increased settlements. Basal reinforced embankments prove to be one of the ground improvement techniques to enhance the stability of the foundation soil and reduce the settlements in soft soils. The objective of the paper is to study the performance of embankments with and without geosynthetic reinforcement tested in a large beam centrifuge test facility available at IIT Bombay. The paper presents result of centrifuge model tests on embankments constructed inflight at 40g. The surface settlements and geogrid movements were monitored. The analysis and interpretation of centrifuge test results help in understanding the importance of basal reinforcement in improving the stability of slopes.

Keywords: Geosynthetic reinforcement, Embankments, Soft Soil, Centrifuge, Settlement

1 INTRODUCTION

With the increasing population in the recent decades it has become necessary to utilize even the soft soils for construction. Building embankments on weak soil can result in slope failures, excessive settlement and bearing capacity problems. Several ground improvement measures are being adopted to tackle these problems. These include excavation and replacement, use of lightweight fills, preloading and staged construction, vacuum preloading, preloading with vertical drains, use of geosynthetic reinforcement, piled rafts, geosynthetic reinforced piled embankments etc. For an embankment on soft foundation soil, reinforcement is provided at the base of the embankment to improve lateral stability, slope stability and to reduce differential settlements by distributing the load uniformly. The geosynthetic reinforcement has been used extensively in the past few decades in geotechnical structures due to its low cost and increased tolerance to the ground movement.

Centrifuge modelling technique is used by geotechnical engineers to simulate identical stress conditions in the model as that of the prototype. This can be achieved by subjecting the model which is scaled down to 1/N times that of prototype to an acceleration of N times. Many researchers constructed embankment in 1g and it was loaded in the centrifuge and accelerated in stages over a period of time. This technique was used by Bassett (1973,1974), Endicott (1971b), Mandal and Joshi 1996, Bujang et al. 1993, Barchard 1999, Aslam 2008. However, this method could not simulate the same stress history on the model foundation soil and its equivalent prototype (Almeida 1984). Beasley (1973) developed inflight embankment construction to simulate similar stress conditions at the end of embankment construction. This method has been used by Sharma and Bolton 2001, Almeida 1984 and is being adopted in this paper. Though this gives more realistic values it is not being used widely for the embankment construction in centrifuges.

In this paper settlement responses of geosynthetic reinforced and unreinforced embankments constructed inflight on soft foundation soil are presented.

2 SCALING CONSIDERATIONS

Centrifuge model studies are of utmost importance in understanding the behavior of most geotechnical structures due to its ability to simulate in situ stress conditions. In order to model the embankments with and without geosynthetic reinforcement, certain scaling laws need to be established so as to get an identical response for the model and prototype.

Table 1. Summary of scaling factors for modelling geosynthetic reinforced embankments in a centrifuge

Parameters	Prototype	Model
Soil		
Cohesion, c (kN/m^2)	1	1
Angle of internal friction, φ (°)	1	1
Unit weight of soil, γ (kN/m^3)	1	N
Rate of construction	1	$1/N^2$
Geogrid Reinforcement		
Length a, b, t (m)	1	1/N
Cross sectional area of rib, A_l or A_t (m^2)	1	$1/N^2$
Percentage Open Area, f (%)	1	1
Tensile load, T (kN/m)	1	1/N
Geogrid strain, ε (%)	1	1
Secant Stiffness, J_g (kN/m)	1	1/N
Pull-out force, F (kN)	1	$1/N^2$
Pull-out stress, τ_b (kN/m^2)	1	1
Soil-geogrid friction angle, φ_{sg} (°)	1	1
Soil-geogrid interface stiffness, J_{sg} (kN/m)	1	N

3 MATERIALS PROPERTIES

3.1 *Model soil*

In the present study, the model embankment soil was fine sand taken from the Indian state of Goa which is classified as SP in Unified Soil Classification System (USCS). The maximum and minimum unit weights of the sand were 16.61 kN/m^3 and 14.1 kN/m^3 respectively. The effective and average particle size of the sand was 0.14 mm and 0.21 mm respectively. The bottom hard soil layer was placed at a relative density of 85% and geogrid reinforcement was placed on a fill which was placed at a relative density of 45%. However the embankment was constructed inflight at a relative density of 67%. The peak angle of internal frictions at relative densities of 45%, 67% and 85%, determined through direct shear tests on sand are 32°, 35° and 41° respectively.

The foundation soil used was commercially available Kaolin. The liquid limit, plastic limit and specific gravity of the soil were found to be 45.5%, 21% and 2.59 respectively. The soil can be classified as CL as per USCS.

3.2 *Model geogrid reinforcement*

A model geogrid which satisfied the scaling considerations of Viswanadham and König (2004) and Rajesh and Viswanadham (2012) was considered for the tests. The scaling of frictional bond behavior and tensile load-strain behavior of the geogrid are considered to be the two basic requirements for modeling geogrid. The scaling of frictional bond behavior was ensured by scaling of rib cross sectional area and grid opening size and by maintaining identical percentage open area for both model and prototype geogrids. The model geogrid was selected such that it has a tensile load and secant stiffness 1/N times than that of the prototype geogrid. The properties of the model geogrid used here were reported by

Balakrishnan and Viswanadham (2016) as geogrid G1. The model geogrid with ultimate tensile load of 11 kN/m and ultimate tensile strain of 15% was used for the tests.

4 CENTRIFUGE MODEL TESTS ON BASAL REINFORCED EMBANKMENTS

The tests were conducted on a 4.5 m radius large beam centrifuge facility at IIT Bombay. The specifications of the centrifuge are given in Chandrasekaran (2001).

4.1 *Prototype details*

The tests were performed at an acceleration of 40g. The prototype dimensions were chosen to be 6 m high embankment on top of soft foundation soil of 6 m depth. The base width of the embankment is 35 m with a slope angle of about 33.7°. Crest width of the embankment is about 16.8 m. Due to the symmetry of the system only half the model is constructed.

4.2 *Details of tests set up and tests preparation*

The schematic cross section of geogrid reinforced embankments is as shown in the Figure 1. The model is prepared and tested in the strong box of internal dimensions 760 mm in length, 200 mm in breadth and 410 mm in height. A thick transparent Perspex glass sheet on the front allowed viewing the model during flight. The front and rear walls were coated with petroleum grease and 100 mm width polythene sheet strips were placed with an overlap on the walls to reduce the boundary friction effects (Viswanadham and Mahajan, 2007).

Firstly, a 20 mm thick base sand drainage layer was placed at the bottom, moist compacted to maximum dry density and optimum moisture content to represent a hard foundation strata. The container is now filled with soft foundation soil layer to a height of 150 mm. A surcharge of 4 kPa was placed overnight. After levelling the top foundation soil surface, L shaped movable plastic markers were placed to study the movement of the foundation soil during the tests. Black artificial seeding were applied on the clay surface layer to get an improved image based deformation measurement using image analysis software. A dry sand layer of 5 mm thickness was placed on top of the foundation soil surface to place the geogrid layer. A geogrid anchorage system was developed such that it allows for vertical movement of the geogrid but restricts the horizontal movement at the center of the embankment which was taken to be its axis of symmetry. The geogrid layer was anchored at one end to the anchorage system and at the rear end its fixity was ensured using earthen bund. L shaped markers were placed on the geogrid surface also, to understand the movement of geogrid layers during tests. Another 5 mm thick dry sand layer was placed on top of the geogrid reinforcement. A geogrid layer is sandwiched between 10 mm thick dry sand layer since geogrid mobilize tension mainly by the passive resistance from the soil confined between the apertures. Two numbers of vertical Linear Variable Differential Transformers (LVDTs) were placed at 30 mm and 50 mm from the expected toe of the embankment constructed inflight.

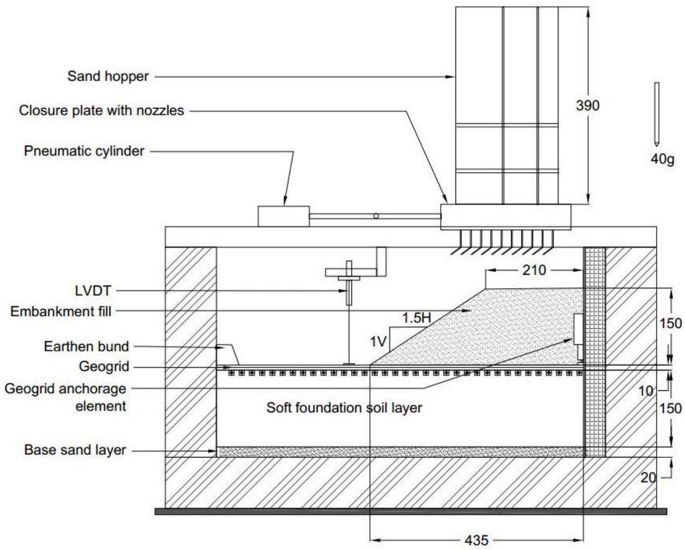


Figure 1: Cross Sectional View of the experimental set up (All dimensions in mm)

4.3 *Test program*

The embankment was constructed inflight using inflight sand hopper at a constant acceleration of 40 g. The method of construction was similar to that developed by Beasley (1973) which consists of pouring sand from a hopper mounted on top of the strong box while the centrifuge was running at a constant acceleration.
The sand was poured when the holes at the bottom of the sand hopper matched with the holes in the closure plate, the movement of which was controlled by means of a pneumatic cylinder. The front elevation images were captured using the digital camera mounted with the strong box and was triggered by accessing central processing unit through a computer in the control room.
In the present study, the results of two centrifuge tests carried out on unreinforced and reinforced embankments are presented. All the models were tested at 40 g. The embankment was constructed inflight to simulate similar stress conditions in the model and the prototype.

5 TEST RESULTS AND ANALYSIS

To understand the soil movement, digital image analysis was performed using ImageJ software. Displacement was obtained by tracing the movement of markers in different images taken during different time intervals during the tests. Figure 2 shows the deformation profiles plotted for different time intervals during the tests on unreinforced embankments. The settlement increased as the construction progressed and the slope failed at the end of the construction (3.7 days). The comparison of deformation profiles for both the tests at the end of the embankment construction was shown in Figure 3. Both the vertical displacements and horizontal displacements are normalized using depth of the clay layer, d. For unreinforced embankments, the foundation soil underwent a base failure of slopes whereas for basal reinforcement the horizontal load was taken care of by the tensile strength of the reinforcement. Hence the slope proved to be stable without the reinforcement.

It can be seen that slip surface developed at 10.76 m from the toe of the embankment for unreinforced soil. The formation of slip surface was observed after 1.19 days of embankment construction. Maximum displacement in unreinforced embankment was observed to be 1.1 m with a heaving of 0.8 m. However, geogrid reinforcement proved to be an effective means to stabilize the slope. Though it reduced heaving and vertical settlement to a considerable amount (by 38 % and 26 % respectively) settlements need to be further reduced for which other ground improvement techniques need to be dependent upon.

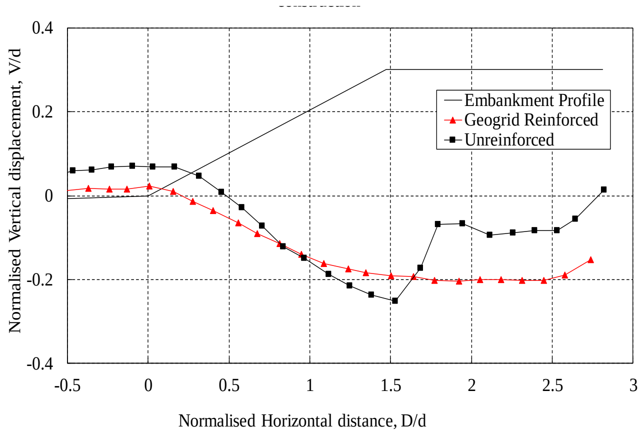


Figure 2: Comparison of surface deformation profiles at the end of embankment construction

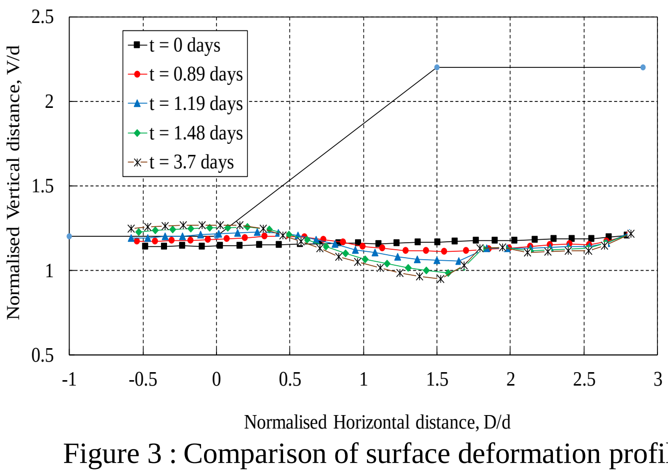
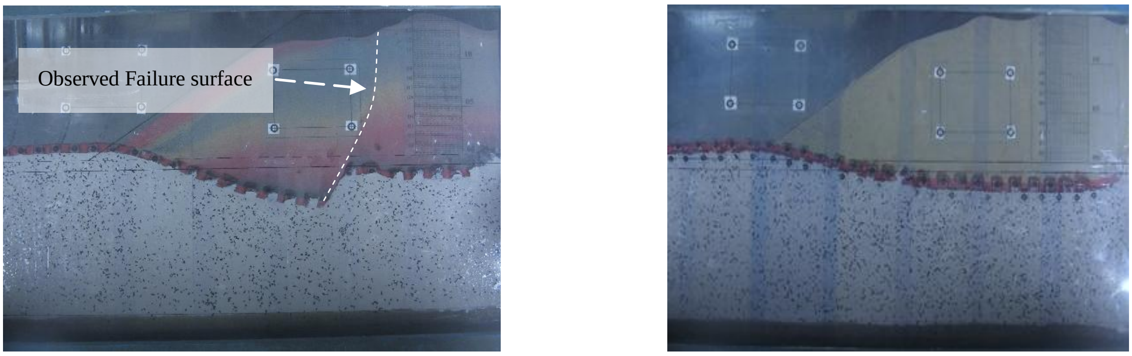


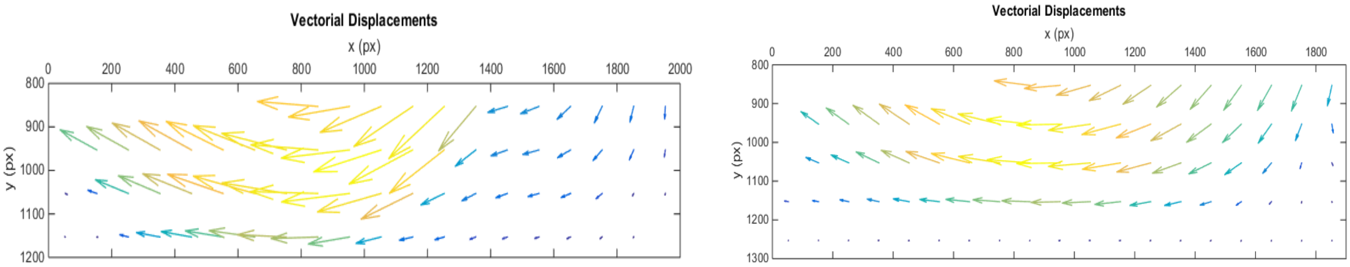
Figure 3 : Comparison of surface deformation profiles at different elapsed times during construction for unreinforced embankments



a) Unreinforced b) Geogrid reinforced

Figure 4: Comparison of front elevations of the model at 40g

The displacement vectors were obtained using non-contact based improved image analysis technique namely GeoPIV-RG software (White et al. (2003). It is based on Particle Image Velocimetry technique (PIV) which was developed initially to track the movement of the seeded particles through fluid medium through image acquisition and post processing (Mishra et al. 2016). However, most of the researchers (White et al. 2003, Stanier and White 2013, Take 2015) have used the software to determine the deformation pattern in the soil. It is a MATLAB based software and in the present study black seeding on the clay surface has been used to track the deformation pattern in the foundation soil. From Figure 5, it can be seen that lateral displacement is more pronounced in unreinforced embankments.



a) Unreinforced Embankment b) Geogrid Reinforced Embankment

Figure 5: Vectorial representation of lateral deformations in the foundation soil

6 CONCLUSIONS

Based on the analysis and interpretation of the results, the following conclusions can be drawn:

a) Without the basal reinforcement, base failure of the soft foundation soil was observed. The effectiveness of geogrid reinforcement in stabilizing the slope of the embankment was shown. This can be attributed to the tension membrane effect of geogrid reinforcement. Hence base reinforcement proves to be an effective ground improvement technique providing stability to the slopes. Rapid construction of embankment may have resulted in excessive deformation of the foundation soil.
b) Image based analysis technique proves to be an important tool in understanding the movement of soil at every stage. Its use in geotechnical engineering is being wide spread and can be adopted for numerous applications.
c) Though basal reinforcement reduced the displacement and provided stability to the embankment, other ground improvement techniques are to be used to further reduce the displacements.

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