Model study on the behaviour of Railway embankment reinforced with Geocell and Geogrid

Anju Abraham
Department of Civil Engineering
Saintgits College of Engineering
Kottayam, India

Sindhu A R
Department of Civil Engineering
Saintgits College of Engineering
Kottayam, India

Abstract— **Construction of high embankments has become inevitable with the development of railway transportation. The present study investigates the effect of geocell and geogrid layers on controlling the stability and settlement of high railway embankments using laboratory model tests. Five series of embankments with 25cm height were constructed, at a scale of 1:50 and then uniformly loaded on the crest in a loading chamber of dimensions 90 x 90 x 60 cm. The embankments of the first series were constructed without reinforcing layers followed by second to fifth series with one to four layers of reinforcement respectively. The load-settlement results were compared and failure mechanism is studied. When compared to the unreinforced case, there is a significant increase in bearing capacity and decrease in settlement with definite increase in geocell and geogrid layers. But increasing the number of geosynthetic layers beyond the third layer does not make much difference in bearing capacity and settlement. The overall study showed that geocell produces a higher improvement in bearing capacity of 7% and reduction in settlement of 12% than geogrid.**

Keywords—embankment, geocell, bearing capacity, settlement

I. INTRODUCTION

Railway transportation network has shown a huge development during the recent years due to which designers have started shortening the routes length and travel time. Railways were made to pass through areas with many difficult terrains, and therefore, construction of structures such as high embankments has become inevitable. Controlling the stability and settlement of embankments under different loading conditions, is always a challenging issue for the designers [1]. Ground improvement techniques like vibro stone columns are used to strengthen embankment bases in soft soils generally. The recent trend these days is to use geosynthetic reinforcements to enhance the stability of embankments. Incorporating reinforcement inclusions within soil is an effective way to improve the engineering properties of soil. A geocell is a geosynthetic product with a three-dimensional, polymeric, honey-comb like structure of cells interconnected at joints. Geocell reinforced bases provide more lateral and vertical confinement, tensioned membrane effect and wider stress distribution [5]. The present study aims to find the effect of geocell and geogrid layers on high railway embankments. The major factors considered are sliding control in embankment and decreasing the crest settlement. Geocell provides all round confinement to the materials hence it prevents the lateral spreading of soil on application of load. So the use of geocell reinforcement increases the strength and stiffness property of the soft soil [4]. The utilization of polymeric reinforcement like geogrid has increased over the years. Providing them as foundation reinforcement to improve load bearing capacity has gathered a lot of attention. In the past two decades, some laboratory and field research projects have been conducted to investigate the performance of the geocell-supported embankments on soft subgrades. Geocell reinforcement is now successfully utilized for different geotechnical structures like slope stability, retaining wall, embankment etc.

A review on the literature suggests that geosynthetics have been abundantly used in road and railway projects during the recent years. Most of these projects are based on placing geosynthetic layers as reinforcement in superstructure layers of roads and railways [1]. An extensive range of studies have been carried out on geogrid inclusion on footing or on the bearing capacity of geogrid-reinforced slope using laboratory model tests. This include unreinforced models and reinforced cases tested by varying parameters such as geogrid length, number of geogrid layers, vertical spacing and depth to topmost layer of geogrid [9]. Based on the studies already carried out, using geosynthetics in railway embankments can be justified in two ways. First, during embankment construction, in case where the borrow area with good quality materials is scarce, geosynthetics can be used to construct slopes with better stability. Secondly, embankment reinforcement will be important for increasing the running speed or axle load on existing railway tracks [1].

II. MATERIALS

A. Soil

River sand is collected from Kottayam, Kerala as shown in fig. 1. The sand is classified as well graded (SW) according to the Indian Standard Classification System. The grain size distribution of this soil is shown in fig. 2. Table 1 shows the properties of the sand used for the study. Sand is used as subgrade and embankment material.

Fig. 1. River sand

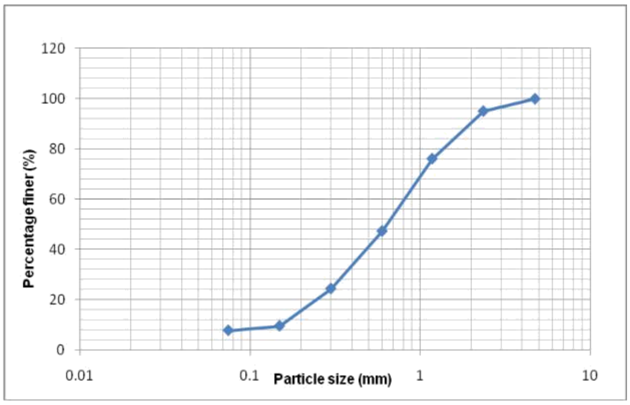

Fig. 2. Grain size distribution curve of soil

Table 1. Properties of sand

Property	Value
Specific gravity of soil	2.59
Relative density	53%
Uniformity coefficient	6.2
Curvature coefficient	1.9
Angle of internal friction	32°
Cohesion	0.02kg/cm^2
Optimum moisture content	9.15%
Maximum dry density	1.56g/cm^3

B. Geocell

Geocells used in this study is of 40mm cell depth and is collected from Strata Geosystems, Mumbai as shown in fig. 3. They provide all around confinement to the soil thus increasing the load carrying capacity of soil. The material properties and cell properties of geocells are shown in table 2.

Fig. 3. Geocell

Table 2. Material properties of Geocells

Property	Value
Polymer density (g/cc)	0.935-0.965
Environmental stress crack resistance (hrs)	>5000
Carbon black content (%)	Min 2.0
Nominal sheet thickness (mm)	1.52
Material	Compound of various polyethylene and additives
Cell depth (mm)	40
Seam peel strength (N)	1065 per 50mm

C. Geogrid

Biaxial geogrids of 41mm aperture size is used in this study and is collected from Strata Geosystems, Mumbai as shown in figure 4. The properties of the geogrid used are shown in table 3.

Fig. 3. Geogrid

Table 3. Specifications of Geogrid

Property	Type or value
Standard colour	Black
Polymer type	Polypropylene
Aperture size	41mm
Mass per unit area	250g/m^2
Peak tensile strength	20kN/m
Standard colour	Black

III. METHODOLOGY

A loading chamber of fixed dimensions is to be modelled for the application of load on the embankment. Four series of embankments should also be modelled after sufficient scaling.

A. Subgrade preparation

Considering the height of the loading chamber, the embankment is constructed with a height of 0.2m over a 0.25m thick subgrade in the chamber. Well graded (SW) sand with uniformity coefficient (C_u) of 6.2 and curvature coefficient (C_c) of 1.9 has been used as subgrade material. Inorder to make the subgrade, the soil was compacted with optimum moisture in 5cm layers using sufficient roller weights up to a height of 0.2m from the base of the chamber.

B. Embankment modelling

In this study, a 10m height embankment with a crest width of 4.8m and side slope of 1:1.5 is selected as the reference embankment. Thereafter on the basis of the method proposed by Wood (Geotechnical modelling, 2004), the scaling law was applied on the aforementioned embankment with a scale of 1:50 for the laboratory test programme. A side slope of 1:1 is selected for laboratory model. The well graded (SW) sand with uniformity coefficient (C_u) of 6.2 and curvature coefficient (C_c) of 1.9 was adopted as the embankment material. The maximum dry density of this soil has been obtained equal to 1.56g/cm^3 in the optimum moisture 9.15%. The dimensions of the actual embankment and the laboratory model are given in table 3. Fig. 4. shows the schematic diagram of the model embankment.

Table 3. Dimensions of the actual embankment and the laboratory model

Parameter	Real embankment	Laboratory embankment
Embankment length (m)	48.0	0.90
Embankment height (m)	12.0	0.25
Embankment crest width (m)	4.8	0.096
Subgrade depth (m)	12.0	0.25
Width of bed sides (m)	2.0	0.20

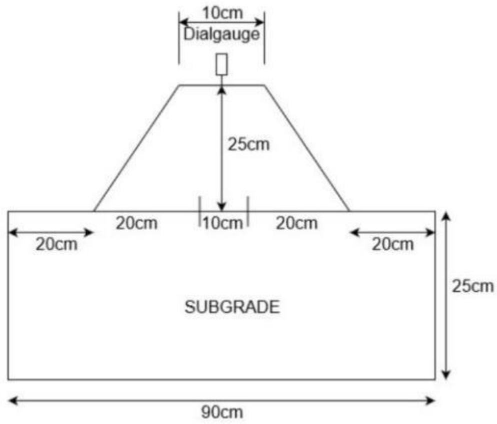

Fig. 4. Schematic diagram of the model embankment

C. *Laboratory test procedure*

Model study was conducted in a tank of dimensions 0.9mx0.9mx0.5m which is modelled based on the scaled dimensions of model embankment and subgrade. Four series of embankments are to be constructed and uniformly loaded in the crest. EM0 embankment denotes an embankment without geocell layers and EM1GC to EM4GC embankments infer the embankments with one to four geocell layers respectively. Similarly EM1GG to EM4GG refer the embankments with one to four layers of geogrid respectively. The embankments of first series are constructed without reinforcing layers. Second to fifth series are reinforced with one to four layers of reinforcement each at a spacing of 2cm respectively. Firstly, the subgrade is prepared by filling soil in the chamber in step by step manner after compacting each 5cm layers using sufficient weight. Inorder to make the embankment model, a mould of same dimensions as that of the embankment is used. It is then modelled by filling sand and compacting at optimum moisture in 5cm layers using sufficient weights. Loading frame arrangement is used to apply load in the vertical direction using a rotating arm connected to a screw. Proving ring is connected to the screw and it rests on the top of a loading plate to transfer the load uniformly. For monitoring the settlement of embankment crest, dial gauges are to be kept at the centre. Load was given continuously by rotating arm and displacement was noted for each load increment. The diagram of the loading frame arrangement is as shown in fig. 5.

Fig. 5. Loading frame arrangement

IV. RESULTS AND DISCUSSION

A. *Geocell*

- Load-settlement results

With regard to the laboratory tests, EMO embankment failed under the vertical load of 1.78kN corresponding to the uniform vertical stress of 43.9kN/m^2. The embankment settlement at failure load was equal to 8.6mm. EM1GC embankment failed under the vertical load of 2.13kN corresponding to the uniform vertical stress of 48.35kN/m^2. The crest settlement under this load was recorded as 7.48mm. EM2GC embankment failed under the vertical load of 2.4kN or the vertical stress of 53.14kN/m^2. In addition, the recorded crest settlement under this load was about 5.5mm. For the embankment EM3GC and EM4GC, the failure load were respectively 2.45kN and 2.48kN corresponding to a vertical stresses of 55.7kN/m^2 and 56.2kN/m^2. Similarly the crest settlement under these loads were respectively 4.3mm and 4.0mm. The comparison of load-settlement diagrams of EM0, EM1GC, EM2GC, EM3GC and EM4GC is shown in fig. 6. Moreover, table 5 depicts the percentage increase in bearing capacity and decrease in settlement upon adding geocell layers to the lab models.

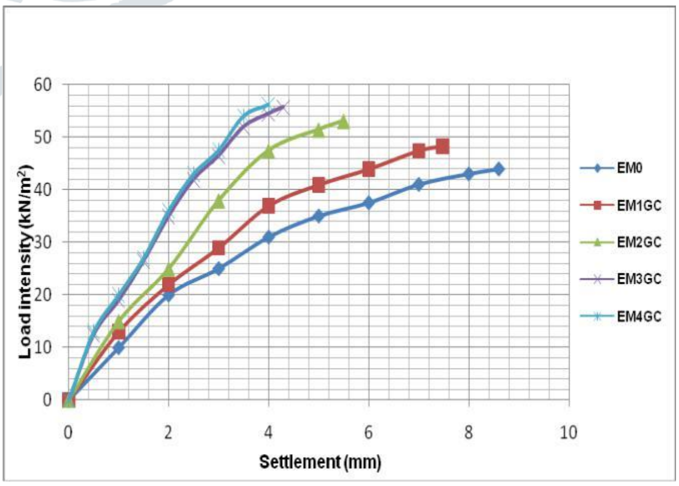

Fig. 6. Comparison of load intensity-settlement diagrams of laboratory embankments of EM0, EM1GC, EM2GC, EM3GC and EM4GC.

By adding the geocell layers from one to four layers, the load capacity has increased by 10.1, 21, 27 and 28% respectively and the crest settlement has reduced by 13, 36, 50 and 53.4%. The increase in bearing capacity and decrease in settlement diminish with the increase in geocell layers, that is, after the third layer. So it is inferred that more geocell layers do not affect these parameters.

- Failure mechanism of laboratory models

In unreinforced embankment, the sliding surface covers more than half portion of the embankment and some fractures are observed in the lower part of the embankment. Upon positioning the geocell layers in the embankment, the sliding surface gradually moves towards the upper part of reinforced area and at the interface between reinforcing layers and soil. In embankments reinforced with three and four layers of geocell, the failure is identified as in the form of cracks only in the upper part of the embankment. The geocell layers prevent the extension of sliding surface to deepen in to the soil. Fig. 7 shows the failure pattern of embankment models.

Fig. 7. Failure mechanism of laboratory embankments. a. EM0 b. EM1GC c. EM2GC d.EM3GC e. EM4GC

B. Geogrid

- Load-settlement results

EM1GG embankment failed under the vertical load of 2.07kN corresponding to the uniform vertical stress of 40.81kN/m^2. The crest settlement under this load was recorded as 7.73mm. EM2GG embankment failed under the vertical load of 2.24kN or the vertical stress of 50.8kN/m^2. In addition, the recorded crest settlement under this load was about 6.3mm. For the embankment EM3GG and EM4GG, the failure load were respectively 2.33kN and 2.35kN corresponding to a vertical stresses of 52.89kN/m^2 and 53.16kN/m^2. Similarly the crest settlement under these loads were respectively 5.3mm and 5.15mm. The comparison of load-settlement diagrams of EM0, EM1GG, EM2GG, EM3GG and EM4GG is shown in fig. 8. By adding the geogird layers from one to four layers, the load capacity has increased by 7, 14,20.5 and 21.1% respectively and the crest settlement has reduced by 10.1, 27.7, 38.3 and 40.1%. The increase in bearing capacity and decrease in settlement diminish with the increase in geocell layers, that is, after the third layer. So it is inferred that more geocell layers do not affect these parameters.

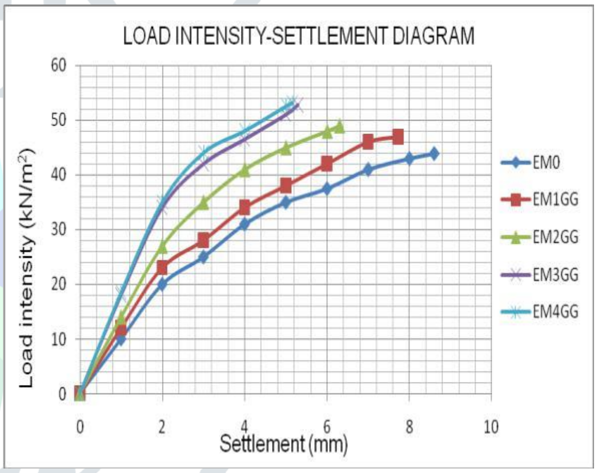

Fig. 8. Comparison of load intensity-settlement diagrams of laboratory embankments of EM0, EM1GG, EM2GG, EM3GG and EM4GG.

- Failure mechanism of laboratory models

In unreinforced embankment, the sliding surface covers more than half portion of the embankment. On positioning the geogrid layers in the embankment, the sliding surface gradually moves towards the upper part of reinforced area and at the interface between reinforcing layers and soil. When reinforced with three and four layers of geocell, failure is identified as in the form of cracks only in the upper part. Figure 9 shows the failure pattern of laboratory embankments reinforced with geogrids.

Fig. 9. Failure mechanism of laboratory embankments. a. EM0 b. EM1GG c. EM2GG d.EM3GG e. EM4GG

V. CONCLUSION

In this paper, the effect of geocell and geogrid layers on the bearing capacity and settlement of railway embankments is studied. The inclusion of geocell and geogrid layers produces a comparative increase in bearing capacity and decrease in settlement. As compared to the unreinforced case, there was an increase in failure load of 27% and decrease in settlement of 50% when three layers of geocells are used. Whereas in case reduction in settlement of 12% than geogrid. In unreinforced embankment, the sliding surface covers more than half part of the embankment. Upon positioning the geocell layers in the embankment, the sliding surface of geogrids, the increase in load capacity was 20% and reduction in settlement was 38% compared to unreinforced case. From the results, it is inferred that gradually moves towards the upper part of reinforced area and at the interface between reinforcing layers and soil. In embankments reinforced with three and four layers of geocell and geogrid, the failure is identified as in the form of cracks only in the upper part of the embankment. Geocell and geogrid layers prevent the extension of sliding surface to deepen in to the soil.

REFERENCES

[1] Esmaeili, M.,Naderi, B., Kalantar, H.,Khodaverdian, A., “Investigating the effect of geogrid on stabilization of high railway embankments,” Journal of Soils and Foundations, vol. 58, pp. 319-332, April 2018.

[2] Esmaeili, M.,Khajehei, H., “Mechanical behaviour of embankments overlying on loose subgrade stabilized by deep mixed columns,” Journal of Rock mechanics and Geotechnical Engineering, vol. 8, pp.651-659, October 2016.

[3] Esmaeili, M., Arbabi, B., “Railway embankments stabilization by tied back-to-back system,” Computers and Geotechnics, vol. 67, pp.110-120, February 2015.

[4] Priyadarshee,A.,Dhane, G., “Application of Geocells in Reinforcement of Soil: A Review,” Journal of Civil Engineering and Environmental Technology, vol. 1, pp.60-64, August 2014.

[5] Sitharam, T, G., Hedge,A., “Design and Construction of geocell foundation to support the embankment on settled red mud” Journal ofGeotextiles and Geomembranes, vol. 41, pp.55-63, August 2013.

[6] Nazir, A, K and Sawwaf, E, M., “Cyclic settlement behavior of strip footings resting on reinforced layered sand slope,” Journal of Advanced Research, vol. 3, pp.315-324, November 2011.

[7] Choudhary, A, K., Jha, J, N., Gill, K, S., “Laboratory investigation of bearing capacity behaviour of strip footing on reinforced fly ash slope,” Journal ofGeotextiles and Geomembranes, vol. 28, pp. 393-402, September 2009.

[8] Zhang, L., Zhao,M., “Bearing capacity of geocell reinforcement in embankment engineering,” Journal of Geotextiles and Geomembranes, vol. 28, pp. 475-482, December 2007.

[9] Alamshahi, S., Hataf, N., “Bearing capacity of strip footings on sand slopes reinforced with geogrid and grid anchors” Journal of Geotextiles and Geomembranes, vol. 27, pp. 217-226, June 2009.

[10] Abusharar,S,W., Zheng, J, J., Chen, B, G., Yin, J, H., “A simplified method for analysis of a piled embankment reinforced with geosynthetics,” Journal of Geotextiles and Geomembranes, vol. 27, pp. 39-52, February 2009.

[11] Alamshahi, S., Hataf, N., “Bearing capacity of strip footings on sand slopes reinforced with geogrid and grid anchors” Journal of Geotextiles and Geomembranes, vol. 27, pp. 217-226, June 2009.

[12] Zhou, H., Wen, X., “Model studies on geogrid or geocell- reinforced sand cushion on soft soil,” *Journal of Geotextiles and Geomembranes*, vol. 26, pp. 231-238, December 2007.

[13] Sawwaf, E, “Behaviour of strip footing on geogrid reinforced sand over a soft clay slope,” Journal of Geotextiles and Geomembranes, vol. 25, pp. 50-60, September 2006.

[14] Yoo, C., “Laboratory investigation of bearing capacity behaviour of strip footing on geogrid-reinforced sand slope,” Journal of Geotextiles and Geomembranes, vol. 19, pp. 279-298, February 2001.

[15] Cowland,J,W., Wong, S, C, K., “Performance of a road embankment on soft clay supported on a geocell mattress foundation,” Journal of Geotextiles and Geomembranes, vol.12, pp. 687-705, 1993.