Behaviour of Geosynthetic Reinforced Reclaimed Asphalt Pavement Bases Under Static Loading

Ishfaq Rashid Sheikh, M. Y. Shah, and K. M. N. Saquib Wani

1 Introduction

The use of RAP is treated as a sustainable solution for pavement construction that is cost effective and environment efficient. The RAP extracted from pavements is considered as a waste material having less load bearing capacity [2, 30]; thus in order to reuse the RAP as a base course, it needs improvement. The presence of excessive asphalt content increases the rutting of RAP base; thus, geocell as reinforcement increases the stress distribution by confining the infill material [10, 11]. Geocell reinforcement redistributes footing load over a wider area, leading to decreased settlement relative to other planar and randomly dispersed mesh elements [8]. The vertical stresses decrease on top of subgrade by inclusion of geocell, and the vertical stress distribution angle also increases [29, 33]. Researchers found that the strength of pavement depends upon the unbound materials used as base course material and subgrade [34]. The studies conducted so far have shown that the geocell reinforcement reduces the vertical stresses transferred towards weak subgrade [31, 32]. The use of geocell reinforces base course material by restricting the lateral spreading of infill material, and the vertical stress transferred to the wider spread reduces the vertical and horizontal strains in pavement [3, 14]. Both cyclic and static plate loads show the similar load versus vertical stress behaviour, and the vertical stress improves by the inclusion of geocell [16, 23]. Since the geocell is a three-dimensional honeycomb structure, the lateral movement of infill material is restricted to a greater extent [18, 21]. Researchers found that the vertical stress distribution angle increases with geocell height [6, 7]. The reclaimed asphalt pavement (RAP) base shows increase in vertical stress distribution angle from 26 to 61° [32]. Vertical stress distribution due to inclusion of geocell increases to a wider spread [13]. The friction between the walls of geocell and soil restricts the upward movement of infill material, thus

I. R. Sheikh (✉) · M. Y. Shah · K. M. N. S. Wani
National Institute of Technology, Srinagar, Srinagar, Union Territory of Jammu and Kashmir, India

C. N. V. Satyanarayana Reddy et al. (eds.), *Transportation, Water and Environmental Geotechnics*, Lecture Notes in Civil Engineering 159,
https://doi.org/10.1007/978-981-16-2260-1_24

confining it vertically under vertical loading [27]. The geosynthetic reinforced bases can distribute the applied load to a wider spread and reduce net stress onto the subgrade as compared to the unreinforced bases [35]. Geocell reinforcement redistributes footing load over a wider area, leading to decreased settlement relative to other planar and randomly dispersed mesh elements [8]. The geocell reinforcement has three key mechanisms: vertical and horizontal confinement, beam effect and load distribution at a wider angle [8, 12, 28, 36, 37].

The objective of this study is to evaluate the use of geocell reinforcement for RAP base course. Experimental investigation was conducted on geocell-reinforced and geocell-unreinforced base under static loading. The series of static and repeated loading were conducted [24, 25]. The results show positive benefits of geocell reinforcement by reducing the vertical stress on top of subgrade and increase the bearing capacity.

2 Material Properties

2.1 Geocell and Geotextile

The high-density polyethylene (HDPE) manufactured by Strata Geosystems Pvt. Ltd. was used to reinforce base course material. The geocell with three different heights 100, 125 and 150 mm was used in this study. The tensile strength of geocell was 1.77 kN/m^2, and geocell walls were rough to prevent the uplifting of infill material. The geocell confines the base course material in lateral and vertical direction. The non-woven geotextile of 350 GSM was used as a separator between base and subgrade. It prevents the penetration of aggregates into weak subgrade, thus lowering the rut depth of base course.

2.2 Subgrade

Subgrade in this study was dredged sediments extracted from Shalimar basin of Dal Lake, Srinagar (34.143196 N, 74.861621 E). The dredging process leads to accumulation of huge quantity of dredged sediments, which needs to be disposed so as to preserve environment. The study aims to present the reuse of dredged soil as an alternative material for subgrade construction. Table 1 shows the engineering properties of dredged soil. Based on the properties, dredged soil needs improvement. Thus in this study, the stresses transferred on top of subgrade are decreased by inclusion of geosynthetics in base course. The gradation curve of subgrade is shown in Fig. 2.

Table 1 Properties of dredged soil used as subgrade

Properties	Description (value)
Liquid limit (%)	42
Plastic limit (%)	29
Plasticity index (%)	13
Classification	MI
Maximum dry unit weight (kN/m^3)	16
OMC (%)	19
CBR	5

2.3 Recycled Asphalt Pavement

The recycled asphalt pavement (RAP) was collected from an ongoing project of construction of NH1A at Pampore in Jammu and Kashmir, India. The RAP was collected and transported in bags from the demolition site to the geotechnical engineering laboratory. The maximum dry density (MDD) of RAP was found to be 1.86 g/cc, and CBR value of 26.4% was recorded. The particle size distribution of RAP is shown in Fig. 1. Due to the presence of huge asphalt content in RAP, it undergoes excessive deformation which leads to increase in vertical stress on top of subgrade. The geocell reinforcement prevents the excessive deformation in base course by confining the infill material. The slab action of geocell restrains the vertical movement of infill material in base course.

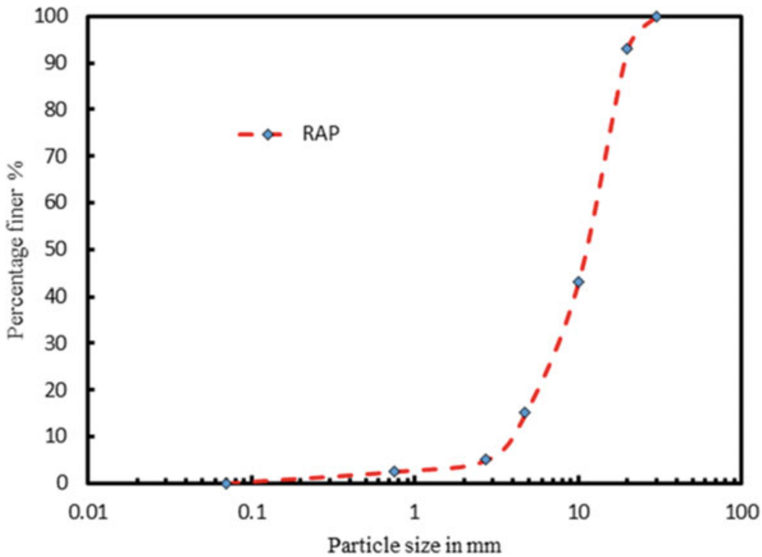

Fig. 1 Gradation curve of RAP used in this study

Fig. 2 Test set-up used in this study

3 Test Equipment and Set-up

The testing facility of geotechnical engineering laboratory at National Institute of Technology Srinagar was used for this study. The testing facility includes the loading frame and a jack of capacity 150 kN, with a steel tank of 1 m^3 in volume. Loading was applied manually in increments to evaluate the behaviour of RAP base under vertical loading. Loading was applied on a circular footing of diameter 30 cm, to simulate traffic load on pavement. The instruments used to record data were earth pressure cell (EPC) and a data logger. The EPCs were used to measure the vertical stress on top of weak subgrade. Similar set-up was used by various researchers [31, 32]. Figure 2 shows the test set-up used in this study.

4 Test Section Preparation

The unpaved test section consists of subgrade and base course; the subgrade was compacted at a CBR value of 5% to simulate field conditions. The RAP as an infill material was compacted with a hammer so as to get uniform compaction. The geotextile was used as a separator between base and subgrade, and it prevents the penetration of aggregates into weak subgrade, thus preventing excessive vertical stresses. The test sections consist of 120-, 150- and 200-mm-thick base. The geocell height used in this study was 100, 125 and 150 mm. The 120-mm-thick reinforced base consists of 100-mm-high geocell and a layer of geotextile as a separator. A 150-mm-thick base consists of 100- and 125-mm-high geocell and with a layer of geotextile. Similarly, RAP base of 200-mm thick consists of 125- and 150-mm high geocell and a layer of non-woven geotextile. The cover maintained in reinforced test sections was recommended by various researchers in order to prevent geocell from damage caused by footing [25].

5 Test Results and Discussion

5.1 Vertical Stress

Vertical stress was measured using EPC placed at the centre of test tank below the circular loading plate. The vertical stress at each load increment was recorded using data logger for each test section. The vertical stress at single axel load of 40 kN [4, 9] was observed from the plot. It was observed from each test the vertical stress was concentrated on the centre earth pressure cell, but due to inclusion of the geocell the load distributes to a wider spread. Geocell reinforcement confines the RAP bases thus restricts the lateral spreading of infill material, the friction between the walls of geocell and infill materials restricts the vertical movement of RAP material. The geotextile as a separator at the interface of base and subgrade restricts the penetration of aggregates into the weak subgrade, thus making the reuse of weak subgrade and recycled material for pavement construction. From Fig. 3, the unreinforced base of 120-mm thick shows the increasing trend, and vertical stress increases with increase in applied load. As the geocell reinforces the base course, the vertical stress decreases from 325 to 285 kPa as compared to unreinforced base course of same thickness. The decrease in the vertical stress at the centre EPC below the loading plate shows that the geocell distributes load over a wider spread. Similarly, the combined use of geocell- and geotextile-reinforced base course decreases the lateral spreading of infill material and also the geotextile prevents the penetration of aggregates into weak subgrade, thus reducing vertical stress on top of subgrade. Figure 3 shows 30 kPa decrease in the vertical stress due to combined use of geocell and geotextile.

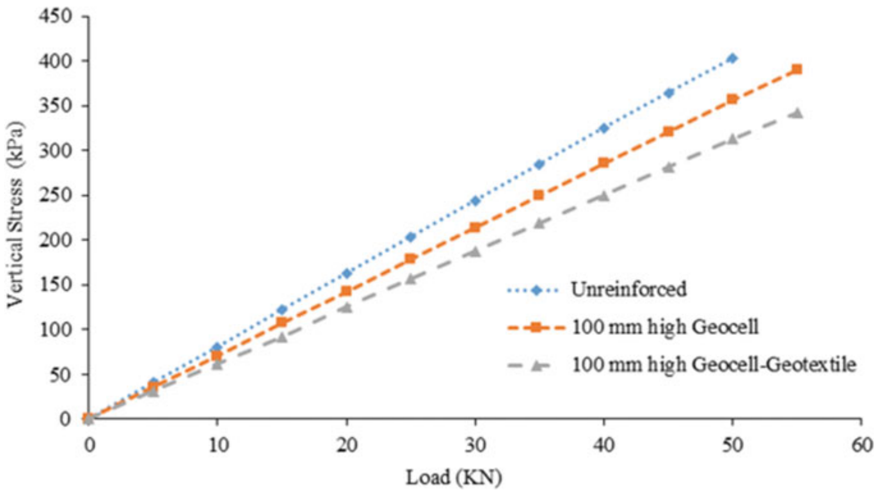

Fig. 3 120-mm-thick unreinforced and geosynthetic reinforced RAP base course

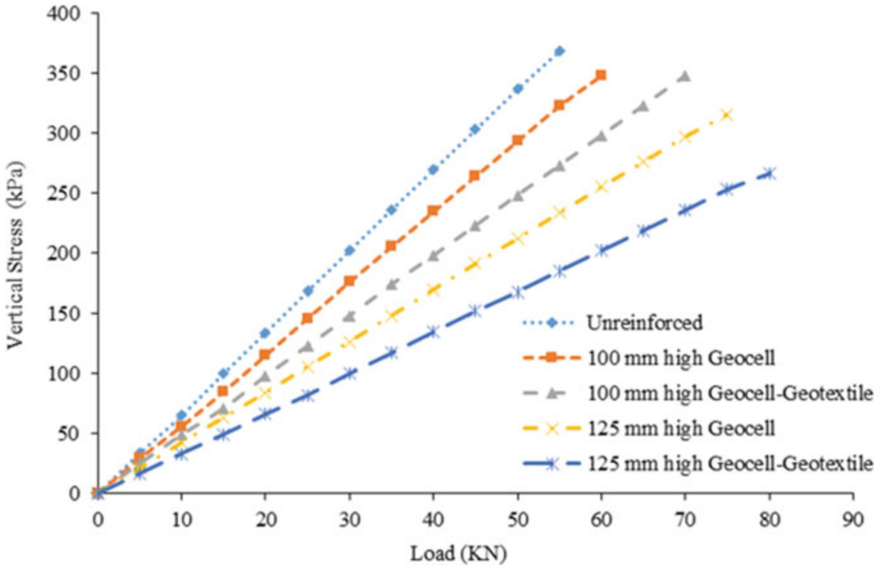

Fig. 4 150-mm-thick unreinforced and reinforced RAP base course

The 150 unreinforced bases show 270 kPa of vertical stress which is shown in Fig. 4, and the curve shows increasing trend. Excessive vertical stress on top of centre EPC placed on top of weak subgrade increases the vertical deformation on the surface of test section. The test section consists of two layers subgrade and base course, as the vertical stress increases the deformation replicates from bottom layer subgrade to base course. Thus in order to reduce the vertical stresses, the layer of geocell is placed at the interface of base and subgrade. The 100-mm-high geocell reinforcement decreases vertical stress by 35 kPa in 150-mm-thick geocell-reinforced base. The RAP bases are prone to vertical settlement which directly increases the vertical stress; thus, a layer of non-woven geotextile acts as a separator between base and subgrade. The combined use of 100-mm-high geocell and geotextile in same thickness of RAP base performs better as compared to geocell-reinforced RAP base. It was observed that the vertical stress decreases from 235 to 196 kPa in 150-mm-thick base as shown in Fig. 4. By varying geocell height within same thickness of base, the vertical stress decreases, and it was observed that the 125-mm-high geocell decreases the vertical stress by 65 kPa as compared to 100-mm-high geocell. The combined use of 125-mm-high geocell and geotextile decreases the vertical stress from 170 to 135 kPa as shown in Fig. 4. The obtained results are in good agreement with the results obtained by various researchers [1, 31, 32]. Figure 5 shows the 200-mm-thick RAP base reinforced and unreinforced with varying geocell height. The vertical stress of 125-mm-high geocell reinforcement decreases by 125 kPa as compared to unreinforced base. The decrease in the vertical stresses is attributed to the confining effect provided by geocell reinforcement. The combined use of 125-mm-high geocell and geotextile with same thickness of base course further decreases

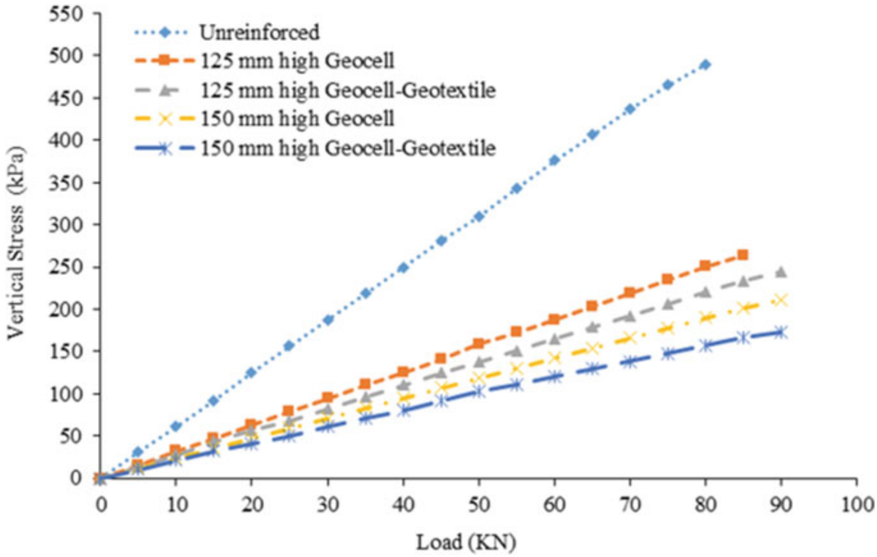

Fig. 5 200-mm-thick unreinforced and geosynthetic reinforced RAP base

the vertical stresses by 15 kPa. Similarly, the increase in height of geocell by 25 mm decreases the vertical stresses by 30 kPa. The geotextile and geocell inclusion within test section decreases vertical stress by 15 kPa as shown in Fig. 5. The above results are in good agreement with the results obtained by various researchers [15, 17, 22].

5.2 *Vertical Stress Distribution Angle*

The vertical stress distribution angle gives the concentration of vertical stress on top of centre EPC; more the stress distribution angle, lesser will be the vertical stress on top of weak subgrade. The RAP base lying on weak subgrade is more prone to vertical stresses on centre EPC. In order to reduce the concentration of vertical stresses transferred towards the subgrade, geosynthetic reinforcement distributes the stresses to a greater spread. The stress distribution angle can be calculated by Eq. 1 [11]. The vertical stress distribution angle calculated is given in Table 1 at 40 kN applied load.

$$pi = \frac{P}{\pi(r + h\tan\alpha)^2} \qquad (1)$$

The vertical stress distribution in case of 120-mm-thick unreinforced RAP base shows 26° stress distribution angle at 40 kN load. The less stress distribution angle gives the measure that the vertical stresses are concentrated on centre EPC only, and few stresses are transferred towards the adjacent EPC. Figure 6 shows the load versus vertical stress distribution of various test sections. Stress distribution angle data from plot at 40 kN load are compared to study the influence of geocell height and thickness on vertical stress distribution. The RAP base of same thickness reinforced with 100-mm-high geocell shows 30° distribution angle. The combined use of geocell and geotextile increases the stress distribution angle to 34°. The test section with non-woven geotextile and geocell performs well as compared to geocell-reinforced base which can be seen in Fig. 6.

The 150-mm-thick unreinforced base shows the increase in the stress distribution angle by 6° as compared to 120-mm-thick unreinforced base. Increase in the thickness of base course can improve the stress distribution angle to some extent, but the ready availability of infill material for construction of pavement are limited [19, 26]. The base course reinforced with geosynthetics proved cost effective and environmental efficient by disposal of RAP. Figure 7 shows the 100 mm geocell increases the stress distribution from 32° to 36° as compared to unreinforced base course. The increase in the vertical stress distribution angle is attributed to the confining effect of geocell, and the geocell restricts the lateral and vertical deformation of base course. The 100-mm-high geocell and geotextile decreases the distribution angle by 9° as compared to unreinforced base course of same thickness as shown in Fig. 7. Similarly, by varying the geocell height from 100 to 125 mm with same base course thickness the stress distribution angle increases by 9°. The 125-mm-high geocell and geotextile shows the improved stress distribution angle from 45° to 50° as compared to 125-mm-high geocell-reinforced RAP base.

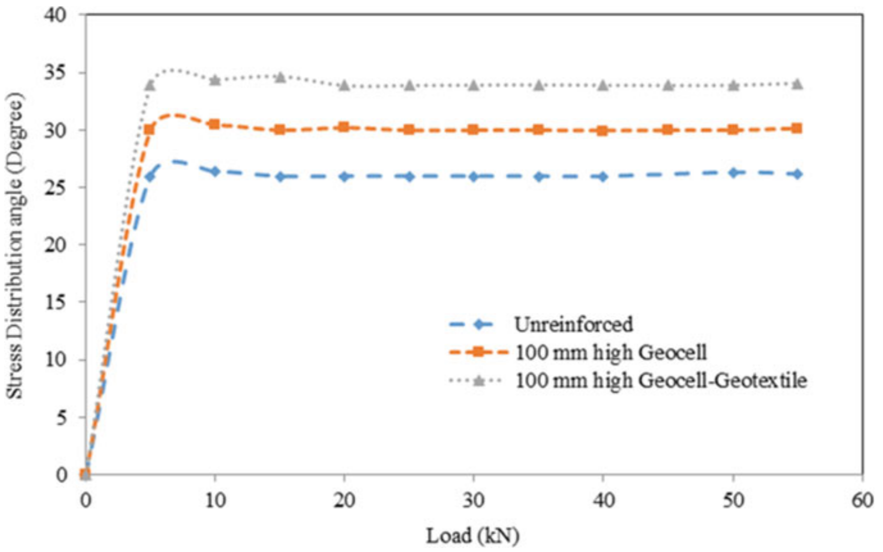

Fig. 6 Load versus stress distribution angle of 120-mm-thick reinforced and unreinforced RAP base

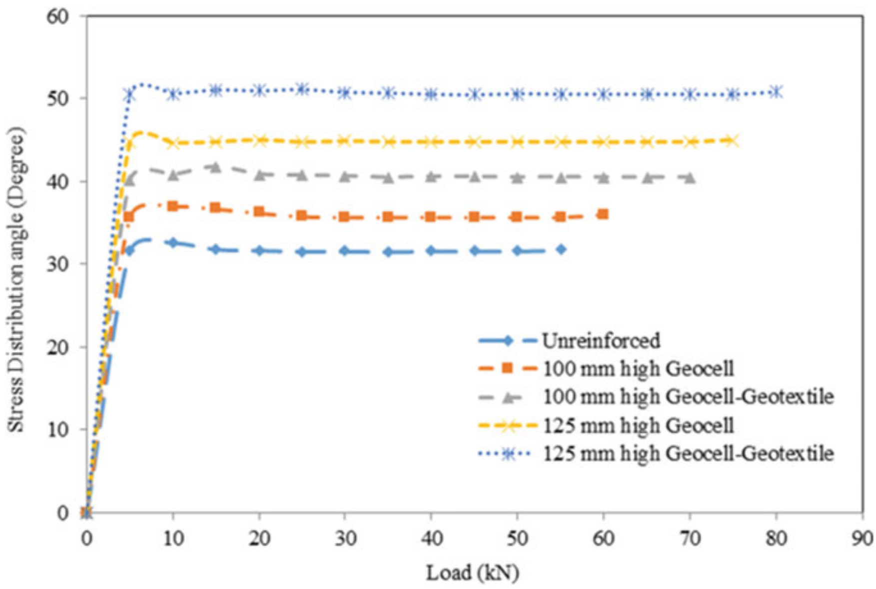

Fig. 7 Load versus stress distribution angle of 150-mm-thick reinforced and unreinforced RAP base

The load versus vertical stress distribution of 200-mm-thick reinforced and unreinforced base course is shown in Fig. 8. The stress distribution angle for 125-mm-high geocell-reinforced base was observed to be 34° which is higher as compared to unreinforced base. The decrease in vertical stress distribution angle is attributed to the confining effect provided by the geocell reinforcement. Vertical stress distribution angle for 125-mm-high geocell and geotextile reinforcement increases from 52° to 55°. Similarly, for same thickness of base course the 150-mm-high geocell improves the vertical stress distribution angle by 58°. The geocell of 150-mm-high and geotextile improves the vertical stress distribution by 61° as shown in Fig. 8. The similar results were obtained by various researchers [5, 20, 27].

6 Conclusions

Based on the results, the following conclusion can be drawn:

1. The average decrease in the vertical stress due to inclusion of geosynthetic reinforcement in RAP bases for 120-mm, 150-mm and 200-mm thick was found to be 58 kPa, 85 kPa and 148 kPa, respectively.
2. For each 25 mm of addition of geocell height, the average vertical stress decreases by 55 kPa.

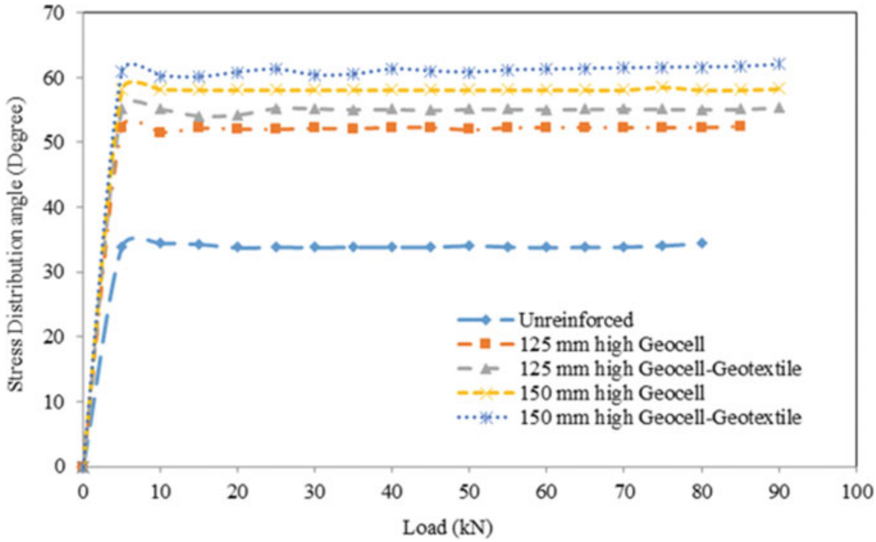

Fig. 8 Load versus stress distribution angle of 200-mm-thick reinforced and unreinforced RAP base

3. The average vertical stress distribution angle at 40 kN load for 120-mm-, 150-mm- and 200-mm-thick geosynthetic reinforced base was calculated to be 6°, 12° and 22°.
4. The above results proved that geosynthetics distribute the load over a wider spread, thus distributing the footing load to a wider spread in unpaved test sections.
5. The RAP used in this study proved to be more cost effective and environmental efficient.

References

1. Arias, J.L., Inti, S., Tandon, V.: Influence of geocell reinforcement on bearing capacity of low-volume roads. Transp. Dev. Econ. **6**(1), 5 (2020)
2. Arulrajah, A., Disfani, M.M., Horpibulsuk, S., Suksiripattanapong, C., Prongmanee, N.: Physical properties and shear strength responses of recycled construction and demolition materials in unbound pavement base/subbase applications. Constr. Build. Mater. **58**, 245–257 (2014)
3. Banerjee, L., Chawla, S., Bhandari, G.: Experimental and 3-D finite element analyses on geocell-reinforced embankments. J. Test. Eval. **47**(3), 1876–1899 (2018)
4. Bose, T., Zania, V., Levenberg, E.: Experimental investigation of a ballastless asphalt track mockup under vertical loads. Constr. Build. Mater. **261**, 119711 (2020)
5. Chen, R.H., Wu, C.P., Huang, F.C., Shen, C.W.: Numerical analysis of geocell-reinforced retaining structures. Geotext. Geomembr. **39**, 51–62 (2013)
6. Chen, Y., Saha, S., Lytton, R.L.: Prediction of the pre-erosion stage of faulting in jointed concrete pavement with axle load distribution. Transp. Geotech. 100343 (2020)

7. Dash, S.K., Choudhary, A.K.: Geocell reinforcement for performance improvement of vertical plate anchors in sand. Geotext. Geomembr. **46**(2), 214–225 (2018)
8. Dash, S.K., Rajagopal, K., Krishnaswamy, N.R.: Performance of different geosynthetic reinforcement materials in sand foundations. Geosynth. Int. **11**(1), 35–42 (2004)
9. De Pue, J., Lamandé, M., Schjønning, P., Cornelis, W.M.: DEM simulation of stress transmission under agricultural traffic. Part 3: evaluation with field experiment. Soil Tillage Res. **200**, 104606 (2020)
10. George, A.M., Banerjee, A., Puppala, A.J., Saladhi, M.: Performance evaluation of geocell-reinforced reclaimed asphalt pavement (RAP) bases in flexible pavements. Int. J. Pavement Eng. 1–11 (2019)
11. Han, J., Pokharel, S.K., Yang, X., Manandhar, C., Leshchinsky, D., Halahmi, I., Parsons, R.L.: Performance of geocell-reinforced RAP bases over weak subgrade under full-scale moving wheel loads. J. Mater. Civ. Eng. **23**(11), 1525–1534 (2011)
12. Han, J., Yang, X., Leshchinsky, D., Parsons, R.L.: Behaviour of geocell-reinforced sand under a vertical load. Transp. Res. Rec. **2045**(1), 95–101 (2008)
13. Hegde, A.M., Sitharam, T.G.: Three-dimensional numerical analysis of geocell-reinforced soft clay beds by considering the actual geometry of geocell pockets. Can. Geotech. J. **52**(9), 1396–1407 (2015)
14. Indraratna, B., Sun, Q., Grant, J.: Behaviour of subballast reinforced with used tyre and potential application in rail tracks. Transp. Geotech. **12**, 26–36 (2017)
15. Isik, A., Gurbuz, A.: Pullout behavior of geocell reinforcement in cohesionless soils. Geotext. Geomembr. **48**(1), 71–81 (2020)
16. Khalaj, O., Moghaddas Tafreshi, S.N., Mask, B., Dawson, A.R.: Improvement of pavement foundation response with multi-layers of geocell reinforcement: cyclic plate load test. Geomech. Eng. **9**(3), 373–395 (2015)
17. Khan, M.A., Biswas, N., Banerjee, A., Puppala, A.J.: Field performance of geocell reinforced recycled asphalt pavement base layer. Transp. Res. Rec. **2674**(3), 69–80 (2020)
18. Kolathayar, S.: Vibration isolation of foundation using HDPE and natural geocells—a review. In: International Congress and Exhibition “Sustainable Civil Infrastructures: Innovative Infrastructure Geotechnology”, pp. 75–86 (2018)
19. Leng, J., Gabr, M.A.: Deformation-resistance model for geogrid-reinforced unpaved road. Transp. Res. Rec. **1975**(1), 146–154 (2006)
20. Leshchinsky, B., Ling, H.: Effects of geocell confinement on strength and deformation behavior of gravel. J. Geotech. Geoenviron. Eng. **139**(2), 340–352 (2013)
21. Liu, Y., Deng, A., Jaksa, M.: Three-dimensional modeling of geocell-reinforced straight and curved ballast embankments. Comput. Geotech. **102**, 53–65 (2018)
22. Mehrjardi, G.T., Tafreshi, S.N.M.: Geocell-reinforced foundations. In: Geocells, pp. 77–130. Springer, Singapore (2020)
23. Ngo, N.T., Indraratna, B., Rujikiatkamjorn, C., Mahdi Biabani, M.: Experimental and discrete element modeling of geocell-stabilized subballast subjected to cyclic loading. J. Geotech. Geoenviron. Eng. **142**(4), 04015100 (2016)
24. Pokharel, S.K., Han, J., Leshchinsky, D., Parsons, R.L., Halahmi, I.: Behaviour of geocell-reinforced granular bases under static and repeated loads. In: International Foundation Congress & Equipment Expo, pp. 409–416 (2009)
25. Pokharel, S.K., Han, J., Leshchinsky, D., Parsons, R.L., Halahmi, I.: Investigation of factors influencing behaviour of single geocell-reinforced bases under static loading. Geotext. Geomembr. **28**(6), 570–578 (2010)
26. Qian, Y., Han, J., Pokharel, S.K., Parsons, R.L.: Performance of triangular aperture geogrid-reinforced base courses over weak subgrade under cyclic loading. J. Mater. Civ. Eng. **25**(8), 1013–1021 (2013)
27. Rahimi, M., Tafreshi, S.M., Leshchinsky, B., Dawson, A.R.: Experimental and numerical investigation of the uplift capacity of plate anchors in geocell-reinforced sand. Geotext. Geomembr. **46**(6), 801–816 (2018)

28. Rajagopal, K., Krishnaswamy, N.R., Latha, G.M.: Behaviour of sand confined with single and multiple geocells. Geotext. Geomembr. **17**(3), 171–184 (1999)
29. Satyal, S.R., Leshchinsky, B., Han, J., Neupane, M.: Use of cellular confinement for improved railway performance on soft subgrades. Geotext. Geomembr. **46**(2), 190–205 (2018)
30. Seferoglu, A.G., Seferoglu, M.T., Akpınar, M.V.: Investigation of the effect of recycled asphalt pavement material on permeability and bearing capacity in the base layer. Adv. Civ. Eng. (2018)
31. Sheikh, I.R., Shah, M.Y.: Experimental study on geocell reinforced base over dredged soil using static plate load test. Int. J. Pavement Res. Technol. 1–10 (2020a)
32. Sheikh, I.R., Shah, M.Y.: Experimental investigation on the reuse of reclaimed asphalt pavement over weak subgrade. Transp. Infrastruct. Geotechnol. 1–17 (2020b)
33. Thakur, J.K., Han, J., Pokharel, S.K., Parsons, R.L.: Performance of geocell-reinforced recycled asphalt pavement (RAP) bases over weak subgrade under cyclic plate loading. Geotext. Geomembr. **35**, 14–24 (2012)
34. Ullah, S., Tanyu, B.F.: Methodology to develop design guidelines to construct unbound base course with reclaimed asphalt pavement (RAP). Constr. Build. Mater. **223**, 463–476 (2019)
35. Wayne, M.H., Han, J., Akins, K.: The design of geosynthetic reinforced foundations. In: Geosynthetics in Foundation Reinforcement and Erosion Control Systems, pp. 1–18. ASCE (1998)
36. Yang, X., Han, J., Parsons, R.L., Leshchinsky, D.: Three-dimensional numerical modeling of single geocell-reinforced sand. Front. Archit. Civ. Eng. China **4**(2), 233–240 (2010)
37. Zhou, H., Wen, X.: Model studies on geogrid- or geocell-reinforced sand cushion on soft soil. Geotext. Geomembr. **26**(3), 231–238 (2008)