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Behaviour of Geo-Synthetic Reinforced Reclaimed Asphalt Pavement Bases Under Static Loading

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Abstract. Reclaimed asphalt pavement (RAP) is increasingly used as base course material in pavement construction. Being environmental friendly and energy efficient, RAP material has been increasing used worldwide for construction of hot mix asphalt (HMA) mixes and in base courses. Due to the presence of asphalt, RAP causes excessive deformation leading to increased vertical stresses on top of subgrade. Geo-cell, a three dimensional cellular confinement confines the RAP and prevents the lateral spreading of the material. A layer of geotextile was also used as a separator between base and subgrade that restricted the aggregates to penetrate into weak subgrade thus decreasing surface deformations. Static plate load tests were conducted on reinforced and unreinforced bases to evaluate the geo-synthetic reinforcement on RAP bases over weak subgrade. Two types of geo-cell cell heights (100 and 125 mm) were used in this study and a total of eight geo-synthetic reinforced and unreinforced RAP sections were tested under static loading. The benefits of geo-synthetic reinforcement in RAP sections were evaluated in terms of angle of stress distribution at the interface of base and subgrade. The test results showed that the geo-synthetic reinforcement improved the performance of unpaved RAP sections by widening the stress distribution angle and reducing the rut depth, if the base courses were equally compacted in unreinforced and reinforced sections.

Keywords: Reclaimed asphalt pavement; Hot mix asphalt; Static Plate load test; Stress distribution

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 are considered as a waste material having less load bearing capacity (Seferoglu & Akpınar 2018, Arulrajah et al. 2014), thus in order to reuse the RAP as a base course it needs improvement. Presence of excessive asphalt content increase the rutting of RAP base thus geocell as reinforcement increases the stress distribution by confining the infill material (Han et al. 2011, George et al. 2019). Geocell reinforcement redistributes footing load over a wider area, leading in decreased settlement relative to other planar and randomly dispersed mesh elements (Dash et al 2004). The vertical stresses decrease on top of subgrade by inclusion of geocell, the vertical stress distribution angle also increases (Thakur et al. 2012, Satyal et al. 2018). Researchers found that the strength of pavement depends upon the unbound materials used as base course material and subgrade (Ullah and Tanyu 2019). The studies conducted so far shown that the geocell reinforcement reduces the vertical stresses transferred towards weak subgrade (Sheikh and Shah 2020a, b). The use of geocell reinforces base course material by restricting the lateral spreading of infill material, the vertical stress transferred to the wider spread reduces the vertical and horizontal strains in pavement (Indraratna et al 2017, Banerjee et al. 2018). Both cyclic and static plate load shows the similar load versus vertical stress behaviour, the vertical stress improves by the inclusion of geocell (Khalaj et al. 2015, Ngo et al. 2016). Since the geocell is a three dimensional honeycomb structure the lateral movement of infill material is restricted to a greater extent (Kolathayar 2018, Liu et al. 2018). Researchers found that the vertical stress distribution angle increases with geocell height (Dash and Choudhary 2018). The RAP (Reclaimed Asphalt pavement) base shows increase in vertical stress distribution angle from 26^{O} to 61^{O} (Sheikh and Shah 2020b). Vertical stress distribution due to inclusion of geocell increases to a wider spread (Hegde and Sitharam 2015). The friction between the walls of geocell and soil restricts the upward movement of infill material, thus confines it vertically under vertical loading (Rahimi et al. 2018). 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 (Wayne et al. 1998). Geocell reinforcement redistributes footing load over a wider area, leading in decreased settlement relative to other planar and randomly dispersed mesh elements (Dash et al 2004). The geocell reinforcement has three key mechanisms: vertical and horizontal confinement, beam effect, and load distribution at a wider angle (Dash et al. 2004; Rajagopal et al. 1999; Zhou and Wen 2008; Han et al. 2008; Yang et al. 2010).

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 unreinforced base under static loading. The series of static and repeated loading were conducted (Pokharel et al. 2009, 2010; Han et al. 2010). The results show positive benefits of geocell reinforcement by reducing the vertical stress on top of subgrade and increases 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 100mm, 125mm and 150mm was used in this study. The tensile strength of geocell were 1.77 kN/m2, geocell walls was 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 lowers the rut depth of base course.

2.2 Subgrade

Subgrade in this study was dredged sediments extracted from Shalimar basin of Dal lake Srinagar (34.143196N, 74.861621E). The dredging process leads to accumulation of huge of 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 is showing 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. Material similar to such properties was also used by researchers for improvement (Wani and Mir 2019, 2020).

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 RAP (Recycled Asphalt pavement) were collected from an ongoing project of construction of NH1A at Pampore in Jammu and Kashmir, India. The RAP were collected and transported in bags from the demolition site to the geotechnical engineering laboratory. The MDD (maximum dry density) of RAP were found to be 1.86 g/cc and CBR value of 26.4% were recorded. The particle size distribution of RAP is shown in fig. 1. Due to 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.

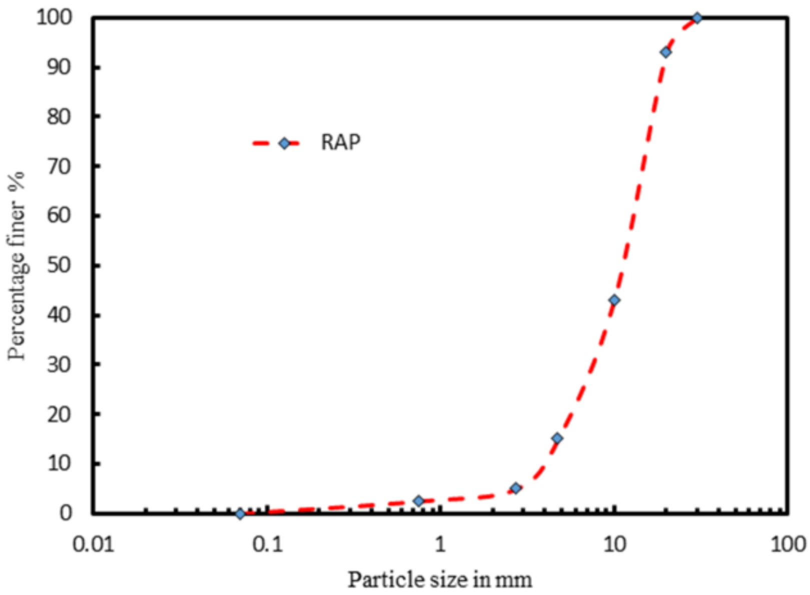

Fig. 1. Shows gradation curve of RAP used in this study.

3 Test Equipment and Setup

The testing facility of geotechnical engineering laboratory at National institute of technology Srinagar were used for this study. The testing facility includes the loading frame and a jack of capacity 150 kN, with a steel tank of 1m3 in volume. Loading were applied manually in increments to evaluate the behaviour of RAP base under vertical loading. Loading were 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's (EPC) and a data logger. The EPC's were used to measure the vertical stress on top of weak subgrade. Similar setup was used by various researchers [Sheikh & Shah 2020a, b]. Fig. 2 is showing the test setup used in this study.

Fig. 2. Test setup 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 were compacted with a hammer so as to get uniform compaction. The geotextile was used as a separator between base and subgrade, it prevents the penetration of aggregates into weak subgrade thus prevents excessive vertical stresses. The test sections consist of 120 mm, 150 mm and 200 mm thick base. The geocell height used in this study was 100 mm ,125 mm and 150 mm. The 120 mm thick reinforced base consists of 100 mm high geocell and a layer of geotextile as a separator. 150 mm thick base consists of 100 mm and 125 mm high geocell and with a layer of geotextile. Similarly, RAP base of 200 mm thick consists of 125 mm and 150 mm high geocell and a layer of non-woven geotextile. The cover maintained in reinforced test sections were recommended by various researchers in order to prevent geocell from damage caused by footing (Pokharel et al. 2010).

5 Test Results and Discussion

5.1 Vertical stress

Vertical stress was measured using EPC place 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 (Bose et al. 2020, Pue et al. 2020) was observed from 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 makes 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, vertical stress increases with increase in applied load. As the geocell reinforces the base course the vertical stress decrease from 325 kPa 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 also the geotextile prevents the penetration of aggregates into weak subgrade thus reduces vertical stress on top of subgrade. The Fig. 3 shows 30 kPa decrease in the vertical stress due to combined use of geocell and geotextile.

The 150 unreinforced base shows 270 kPa of vertical stress which is shown in fig. 4, 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 unpaved 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 100mm high geocell reinforcement decreases vertical stress by 35kPa in 150mm 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 100mm 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 decrease from 235 kPa to 196 kPa in 150mm thick base as shown in fig. 4. By varying geocell height within same thickness of base the vertical stress decreases, it was observed that the 125mm high geocell decreases the vertical stress by 65 kPa as compared to 100mm high geocell. The combined use of 125mm high geocell and geotextile decreases the vertical stress from 170 kPa to 135kPa as shown in fig. 4. The obtained results are in good agreement with the results obtained by various researchers (Arias et al. 2020, Sheikh & Shah 2020a, b). Fig. 5 shows the 200mm thick RAP base reinforced and unreinforced with varying geocell height. The vertical stress of 125mm 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 125mm high geocell and geotextile with same thickness of base course further decreases the vertical stresses by 15 kPa. Similarly, the increase in height of geocell by 25mm 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 (Khan et al. 2020, Isik and Gurbuz 2020, Mehrjardi and Tafreshi 2020).

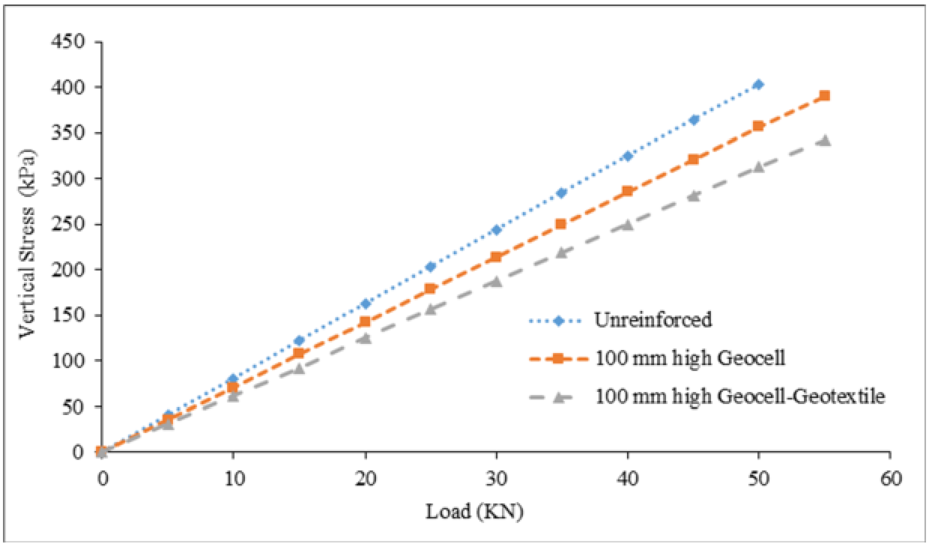

Fig. 3. Shows 120mm thick unreinforced and geosynthetic reinforced RAP base course.

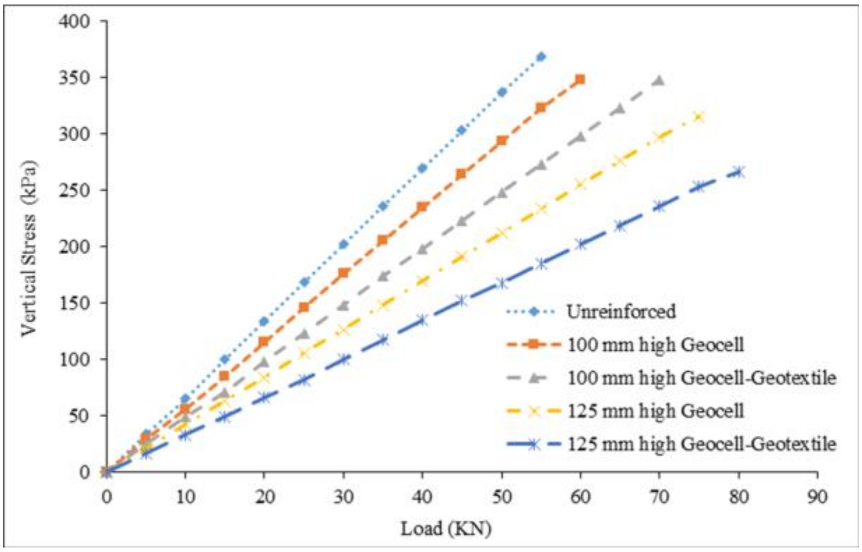

Fig. 4. Shows the 150mm thick unreinforced and reinforced RAP base course.

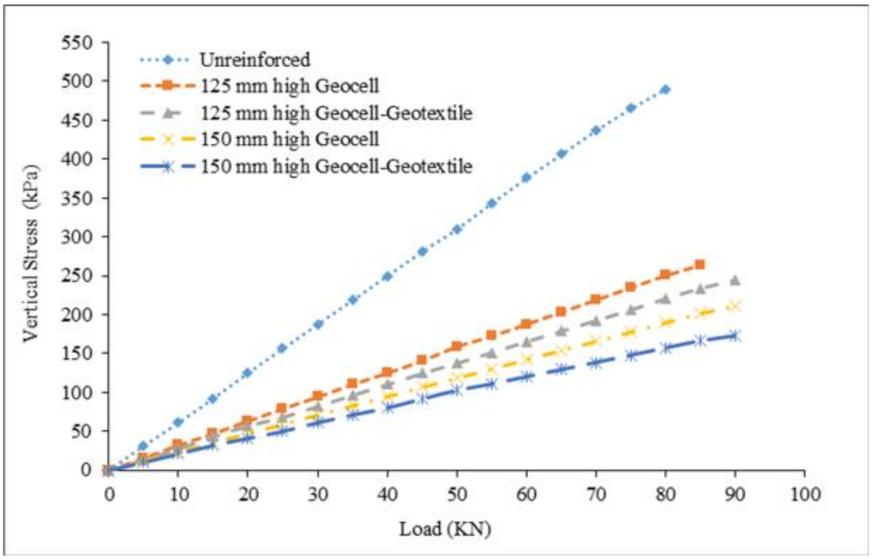

Fig. 5. Shows 200mm thick unreinforced and geosynthetic reinforced RAP base.

5.2 Vertical stress distribution angle

The vertical stress distribution angle gives the concentration of vertical stress on top of center EPC, more the stress distribution angle lesser will be the vertical stress on top of weak subgrade. The RAP base lying on weak subgrade are more prone to vertical stresses on center 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 equation 1 (Han et al. 2011). The vertical stress distribution angle calculated are tabulated in table 1 at 40kN applied load.

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

The vertical stress distribution in case of 120mm thick unreinforced RAP base shows 26^0 stress distribution angle at 40 kN load. The less stress distribution angle gives the measure that the vertical stresses are concentrated on center EPC only, few stresses are transferred towards the adjacent EPC. The fig. 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 100mm high geocell shows 30^0 distribution angle. The combined use of geocell and geotextile increases the stress distribution angle to 34^0. The tests section with non-woven geotextile and geocell perform well as compared to geocell reinforced base which can be seen from fig. 6.

The 150mm thick unreinforced base shows the increase in the stress distribution angle by 6^0 as compared to 120mm thick unreinforced base. Increase in the thickness of base course can improve the stress distribution angle to some extent, but due to lack of readily availability of infill material for construction of pavement are limited (Qian et al. 2013, Leng and Gabr 2006). The base course reinforced with geosynthetics proved cost effective and environmental efficient by disposal of RAP. Fig. 7 shows the 100mm geocell increases the stress distribution from 32^0 to 36^0 as compared to unreinforced base course. The increase in the vertical stress distribution angle is attributed to the confining effect of geocell, the geocell restrict the lateral and vertical deformation of base course. The 100mm high geocell and geotextile decreases the distribution angle by 9^0 as compared to unreinforced base course of same thickness as shown in fig. 7. Similarly, by varying the geocell height from 100mm to 125mm with same base course thickness the stress distribution angle increases by 9^0. The 125mm high geocell and geotextile shows the improved stress distribution angle from 45^0 to 50^0 as compared to 125mm high geocell reinforced RAP base.

The load versus vertical stress distribution of 200mm thick reinforced and unreinforced base course is shown in fig. 8. The stress distribution angle for 125mm high geocell reinforced base was observed to be 34^0 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 125mm high geocell and geotextile reinforcement increases from 52^0 to 55^0. Similarly, for same thickness of base course the 150mm high geocell improves the vertical stress distribution angle by 58^0. The geocell of 150 mm high and geotextile improves the vertical stress distribution by 61^0 as shown in fig. 8. The similar results were obtained by various researchers (Rahimi et al. 2018, Chen et al. 2013, Leshchinsky & Ling 2013)

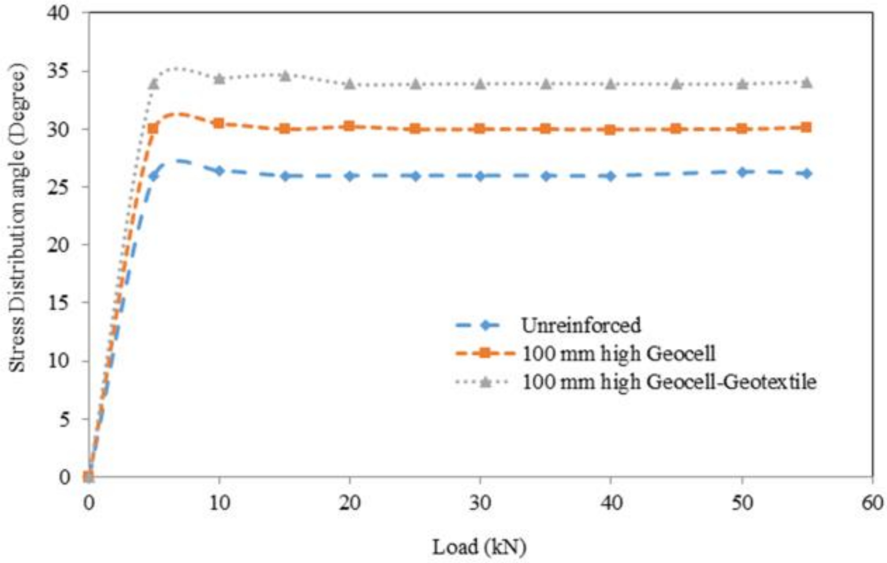

Fig. 6. Shows the load vs. stress distribution angle of 120mm thick reinforced and unreinforced RAP base.

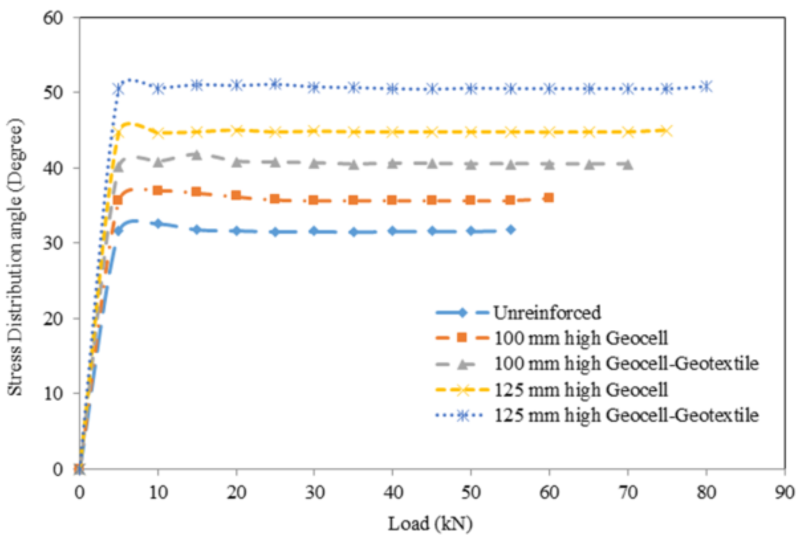

Fig. 7. Shows the load vs. stress distribution angle of 150mm thick reinforced and unreinforced RAP base.

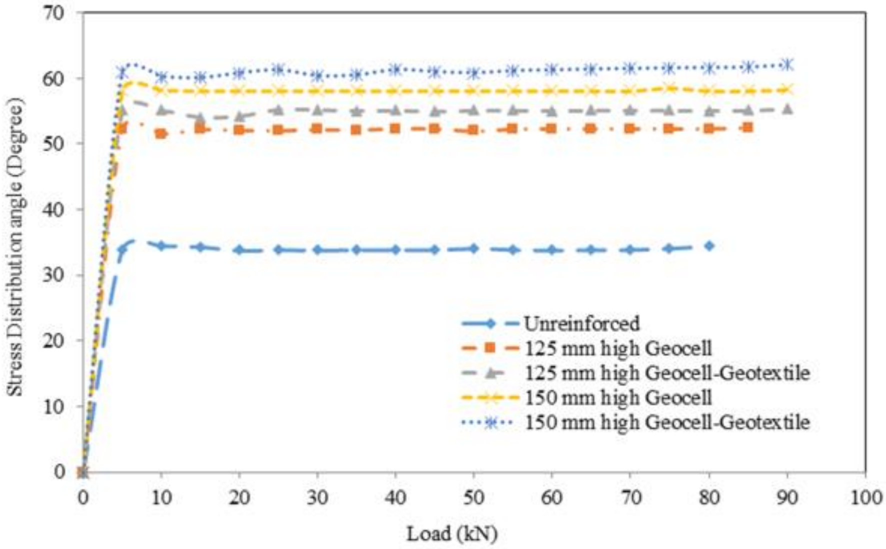

Fig. 8. Shows the load vs. stress distribution angle of 200mm thick reinforced and unreinforced RAP base.

6 Conclusions

Based on the results, 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 were found to be 58 kPa, 85 kPa and 148 kPa respectively.
2. For each 25mm of addition of geocell height the average vertical stress decreases by 55 kPa.
3. The average vertical stress distribution angle at 40 kN load for 120 mm, 150 mm and 200 mm thick geosynthetic reinforced base were calculated to be 6^0, 12^0, 22^0.
4. The above results proved that geosynthetics distribute the load over a wider spread, thus distributes 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.

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