Evaluation of Resilient Modulus of Geosynthetic Reinforced Layers Using Repeated Load Triaxial Tests

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ABSTRACT: The stiffness and strength of the pavement layers are the major parameters that influence the design of highway pavements which in turn decides the thickness of various pavement layers. Studies have shown that the thickness of the base layer plays a crucial role in limiting the rutting of the in situ subgrade soil. Due to the lack of availability of aggregates, there is a dire need to minimize the thickness of the base. Geosynthetics in the form of geogrid and geocell have long been used for reinforcing unbound base/subbase layers in paved and unpaved roads and have been found to be effective in reducing the base thickness. A few laboratory studies have been conducted to evaluate the different aspects of geosynthetic reinforced base layers, and further studies are required to examine the behavior of these reinforced sections under elastic and plastic shake down range. The purpose of the current study is to evaluate and compare the resilient modulus of geogrid reinforced, geocell reinforced and the unreinforced granular base under repeated loading using the Repeated Load Triaxial tests. The response of aggregate under repeated loading expressed in terms of resilient modulus is a key parameter in the new Mechanistic Empirical Pavement Design Guide (MEPDG). The permanent strains of aggregates are also compared in the study to get an overall idea about the reinforcement effect in the granular base.

KEYWORDS: Repeated Load Triaxial Test, Resilient Modulus, Deformation, Geogrid, Geocell.

1. INTRODUCTION

Resilient modulus is an important aspect of flexible pavement engineering design. The deformational behavior of unbound granular base materials under static and repeated loading and the effects of the state of stress, moisture content and loading conditions have to be analyzed in detail. The resilient modulus (Mr) of pavement materials is a key parameter in the current methods for predicting the structural response of pavements and for characterizing materials in pavement design and evaluation. In India and many other developing countries, road construction activities are on a large scale and involve the use of considerable quantities of unbound materials. There is a need for understanding the stress strain response of these materials and the evaluation of models that describe the constitutive behavior of these materials. In order to fulfill these requirements and establish more rational pavement design and construction criteria, it is essential to understand the behavior of granular materials under traffic loading. When pavement materials are subjected to a cycle of stress, they sustain deformations, which consist of two components resilient and permanent deformations. The behavior of these materials influences the extent of these deformations. The resilient elastic modulus is calculated from the resilient strain and the change in stress, usually measured on unloading and the permanent strain is found from the permanent change caused in the material, and it increases under repeated stress cycles (Frost et. al 2004). Many factors affect the magnitude of each of these strains, and consequently the material performance in a pavement. A number of factors also influence the resilient modulus confining pressure, deviatoric stresses, grain size, and moisture content. However, Most of the earlier studies concentrated on the response of aggregate in the elastic range. Another major factor that enhances the pavement performance is the use of geosynthetics. Studies by earlier researchers (Jamnejad et al. 1986; Kazerani and Jamnejad 1987, Bathurst and Karpurapu 1994, Rajagopal et al. 1999, Chang et al. 2007, 2008; Thakur 2012, Nair et al. 2015) showed the effectiveness of geosynthetics in reducing the permanent deformation and increasing the resilient modulus of the pavement. In their study, Latha and Murthy (2007) revealed that the geocells are relatively more beneficial because of all round confining effect. Abu Farsakh et al. (2012) also depicted the benefit of geogrid reinforcement under repeated load triaxial tests. However, these studies were also confined to the elastic range of loading applied to the sample.

2. MATERIALS AND METHODS

The selected gradation of the aggregate for the current study, correspond to the gradation III specified by Ministry of Rural Road Development INDIA. The optimum moisture content and the maximum dry density of the aggregates were obtained as per ASTM D 1157 (2007). The soaked and unsoaked CBR value of the aggregate was 78.45 and 115 respectively. Crushing and impact tests were also carried out on the aggregates, and the aggregate crushing and impact values were both reported to be 24. In the present study repeated load triaxial tests were conducted for three confining pressures 50, 100 and 150kPa for the aggregate materials. The sample size considered for all the tests was 100 × 200mm. For each confining pressure, three deviatoric stresses were applied on different specimens. The magnitude of the deviatoric stresses applied on the sample was 125, 250 and 500kPa respectively. During testing, the sample was subjected to a dynamic cyclic stress and a static confining stress by means of a triaxial pressure chamber. Each loading was applied for 1000cycles or till the sample collapsed. The test provides an excellent mean for comparing the behavior of pavement construction materials under different loading conditions and confining pressure. Studies (Boyce et al. 1976, Sousa and Monismith 1987) showed that the frequency of loading had little or no effect on the resilient modulus of the sample. Hence, the loading frequency adopted for the repeated load triaxial test was 1Hz. The deformation of the triaxial sample mainly has two parts, permanent and resilient deformation. The reversible component that is recovered after each cycle is called resilient deformation and the irreversible component is known as the permanent deformation.

3. EFFECT OF GEOSYNTHETICS ON PAVEMENT PERFORMANCE

Geosynthetics plays a major role in enhancing the pavement performance. However, studies by the earlier researchers were mostly restricted to the stresses in the elastic range and elastic shakedown range. In the current section, the results of the geogrid and geocell reinforced sections are compared with the results of the unreinforced section. Testing is carried out on the triaxial samples for two different stress ranges, and the section can be further divided into two. In the first sections, loading was applied in the elastic and elastic shakedown range as per AASTHO T-307. The resilient modulus of the geogrid and geocell reinforced sections are compared for different loading sequences as presented in Table 1. In the next section, the loading was applied on the sample in the plastic shakedown range and incremental collapse range. The results of the permanent strains and resilient modulus of the sections are compared with the corresponding results of the unreinforced section. The section thus provides the response of reinforced and unreinforced sections for a broad range of stresses.

Table 1: Loading sequence for repeated load triaxial test of Base material

Sequences (200 Cycles each)	**Confining pressure (σ_3) kPa**	**Cyclic Stress [σ_d] $\sigma_1 - \sigma_3$ kPa**	**Bulk Stress [θ] $\sigma_1 + 2\sigma_3$ kPa**
0 (500 to 1000 cycles)	103.4	93.1	403.3
1	20.7	18.6	80.7
2	20.7	37.3	99.4
3	20.7	55.9	118.0
4	34.5	31.0	134.5
5	34.5	62.0	165.5
6	34.5	93.1	196.6
7	68.9	62.0	268.7
8	68.9	124.1	330.8
9	68.9	186.1	392.8
10	103.4	62.0	372.2
11	103.4	93.1	403.3
12	103.4	186.1	496.3
13	137.9	93.1	506.8
14	137.9	124.1	537.8
15	137.9	248.2	661.9

4. EFFECT OF GEOGRID AND GEOCELL REINFORCEMENT ON RESILIENT MODULUS (AASTHO T-307)

In this section, the effect of geogrid and geocell reinforcement in increasing the resilient modulus of the triaxial sample is studied in detail in the elastic shakedown region of the base material. The properties of the geocell and geogrid used in the present study is given in Table 2. The loading was applied at 1Hz frequency followed by 9 second rest period. The size of the sample chosen for the study was 100mm × 200mm. The total amount of material required to prepare the sample was weighed and then divided into four sections. During the preparation of geocell reinforced sample, the mould was first filled upto 50mm and then a geocell pocket was placed in the midlle of the sample. Geocell pocket used in the current study had a diameter of 50mm and a height of 150mm. The geocell was placed at the top of the sample. After placing the geocell pocket the sample preparation was completed by filling with the rest of the weighed aggregate material. In the case of the geogrid reinforced section, Abu Farsakh et al. (2012) showed that the geogrid placed at one third height from the top provided maximum reduction in permanent strains of the triaxial sample. The results also showed that the geogrid placed at mid height of the sample also provided a comparable reduction in permanent strains compared to geogrid placed at one third height from the top. Thus, for the current study, the geogrids were placed at mid height of the triaxial sample i.e. at 100mm depth from the top of the sample. The sample was prepared by filling the mould with the aggregate material upto 100mm and then placing the geogrid followed by filling the aggregate material upto 200mm height. Figure 1 (a) and (b) shows the sample prepared for the geocell reinforced and geogrid reinforced triaxial test. Figure 2 illustrates the comparison of resilient modulus at different bulk stresses for unreinforced and reinforced sections.

It can be seen from Figure 2 that the geosynthetics increase the resilient modulus of the material. The resilient modulus obtained for the geocell reinforcement was similar to that obtained for the geogrid reinforced samples. The increase in resilient modulus with bulk stress was also evident. The increase in resilient modulus of the geocell reinforced section can be attributed to the confinement effect of the geocell. Geocell provides higher confinement which results in decreasing the resilient deformation and subsequent increase in resilient modulus. The major mechanism through which the geogrid reduces the permanent strains is the membrane effect as well as the interlocking effect. In the current study, due to both the effects, geogrids effectively reduces the permanent deformation as well as the resilient deformation. This, in turn, increases the resilient modulus of the geogrid reinforced section.

Table 2: Properties of geosynthetics

Properties	**Values**
Geocell	
Height	150 mm
Thickness	1.3 mm
Tensile strength	21 kN/m
Tensile strain at break (%)	93.20 %
Geogrid	
Polymer	Polypropylene
Aperture Size (MD, XMD)	30 mm, 30 mm
Ultimate tensile strength	20 kN/m

Figure 1 (a): Geocell sample prepared

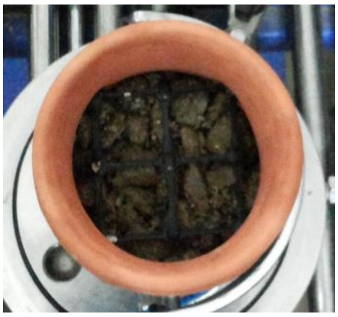


Figure 1 (b): Geogrid sample prepared

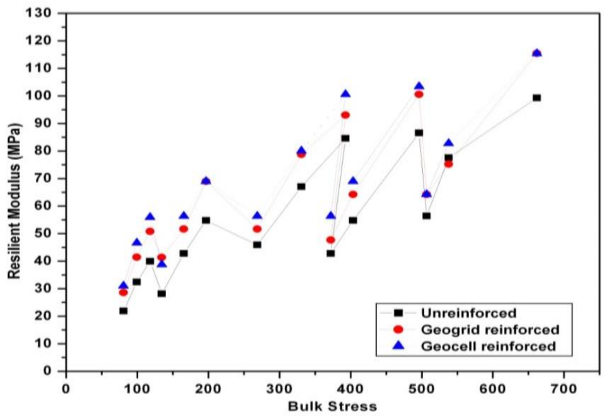


Figure 2: Resilient modulus vs. Bulk stress for unreinforced, geogrid reinforced and geocell reinforced samples

5. EFFECT OF GEOGRID AND GEOCELL REINFORCEMENT ON RESILIENT MODULUS (PLASTIC SHAKEDOWN AND INCREMENTAL COLLAPSE RANGE)

Earlier studies by researchers (Collin et al. (1996), Haas et al. (1988)) suggested that geogrids and geocells enhanced the performance of pavements. Brown et al. (1982) showed the importance of geosynthetics in reducing the rutting and permanent deformation of pavements. The reinforcements reduce the permanent deformation by mainly increasing the resilient modulus of the pavement layer. Studies were carried out on geogrid, and geocell reinforced triaxial samples to understand the effect of geosynthetic reinforcement. Abu Farsakh et al. (2012) showed that the position of the geogrid played a major role in reducing the permanent strains while the effect of stiffness of the geogrid was minimal. The experiments are carried out for two different confining pressures of 100kPa and 150kPa respectively. The repeated loadings used for the current study are 125kPa and 250kPa respectively. The loading is applied on the sample without rest period as explained in the previous section. The geogrid and geocell reinforced samples are isotropically consolidated. In the current study, the results of the permanent strains and resilient modulus obtained for the experiments conducted on geogrid and geocell reinforced samples are compared with the results for the isotropically consolidated unreinforced sample. Further, the results of the permanent and resilient strains of the reinforced samples obtained from the current studies are used for calibrating permanent deformation model parameters in the following chapters.

5.1. Permanent Strains

The studies by earlier researchers pointed out the importance of geogrids and geocells in reducing the permanent strains of pavements. In the current study, the effect of geogrid and geocell reinforcement in the base material is examined in detail. Geogrids are placed at the middle of the sample and geocells are placed at the top of the sample. Studies are carried out at two confining pressures of 100kPa and 150kPa under two deviatoric stresses of 125kPa and 250kPa. The deviatoric stresses were chosen in such a way that the triaxial samples would be in plastic shakedown range.

5.1.1. 100kPa Confining Pressure

In this section, permanent strains of isotropically consolidated unreinforced samples were compared with the isotropically consolidated geocell, and geogrid reinforced samples for a confining pressure of 100kPa. Figures 3(a) and (b) shows the comparison of permanent strains of the unreinforced section with geogrid and geocell reinforced sections for deviatoric stresses of 125 and 250kPa respectively.

From Figures 3(a) and (b) it is evident that the geogrid and geocell reinforcement reduces the permanent strains considerably. For an isotropically consolidated unreinforced sample, the permanent strains after 500 cycles for 125kPa deviatoric stress were reported to be 0.385%. However, the reinforcement reduced the permanent strains considerably. For geogrid reinforced section, the permanent strain after 500 cycles was observed to be 0.09% while for geocell reinforced section; the permanent strain was 0.06%. This indicated that the reinforcement effectively reduces the permanent strain by 80% compared to the unreinforced section. It could also be observed from the results that for both unreinforced and reinforced sections, the permanent strains increased with increase in deviatoric stress.

5.1.2. 150 kPa Confining Pressure

In this section, permanent strains of isotropically consolidated unreinforced samples were compared with geocell, and geogrid reinforced samples for a confining pressure of 150kPa. Figures 4(a) and (b) shows the comparison of permanent strains of the unreinforced section with geogrid and geocell reinforced sections for deviatoric stresses of 125 and 250kPa respectively.

From Figures 4(a) and (b) it can be concluded that the geogrid and geocell effectively reduce the permanent strain of the samples compared to the unreinforced sample. For a deviatoric stress of 125kPa, after 500 cycles, the permanent strain in the unreinforced sample was seen to be 0.73% while for geogrid reinforced specimens, the value was 0.04%.

For geocell reinforced sample, after 500 cycles, the permanent strain was observed to be 0.05%. For a deviatoric stress of 250kPa, after 500 cycles, the value of permanent strain of unreinforced section was observed to be 0.73%. For geogrid reinforced section the permanent strain was 0.1%, and for geocell reinforced section, the permanent strain was observed to be 0.15%. From Figures 4 (a) and (b) it can be observed that the permanent strain of the geogrid reinforced and geocell reinforced samples were almost equal. Table (3) shows the permanent strain after different cycles for the unreinforced, geocell and geogrid reinforced sections.

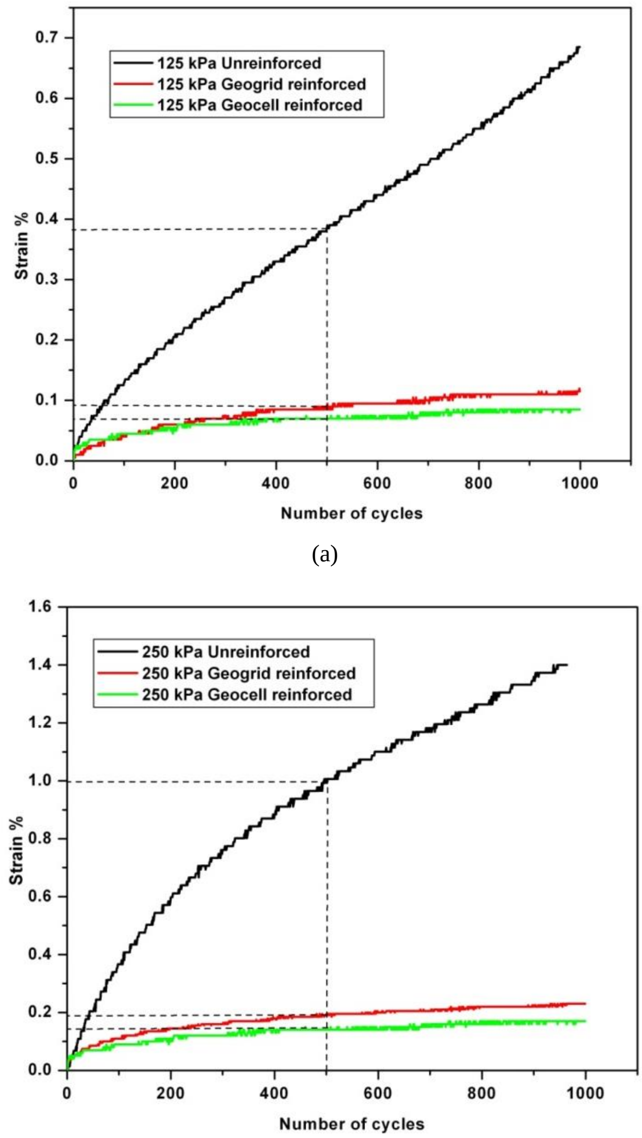
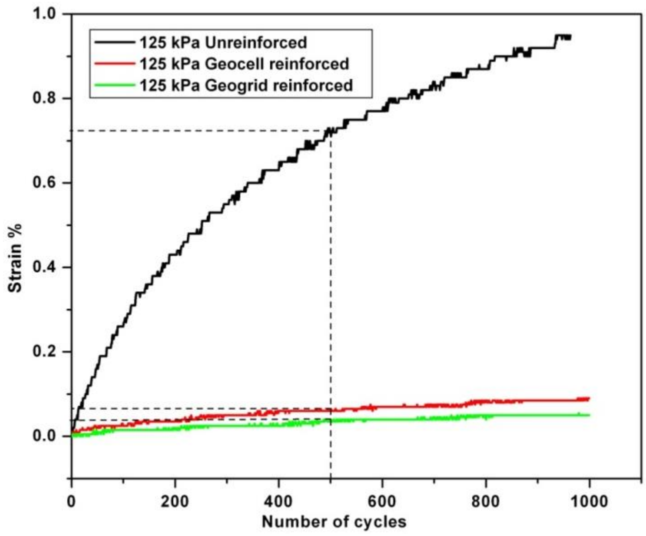
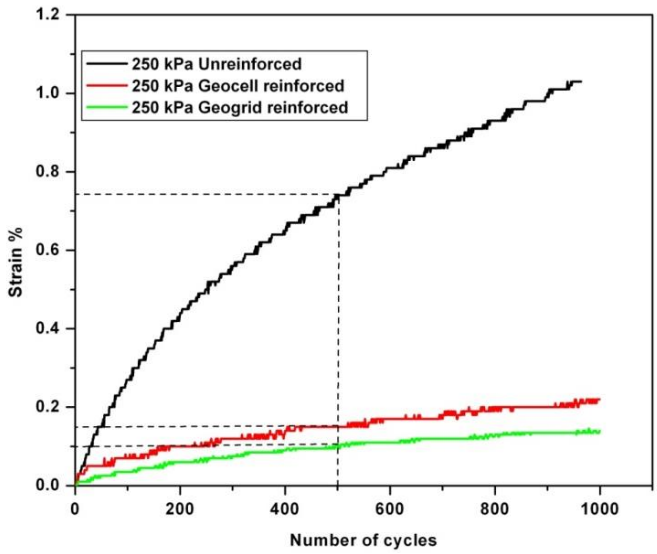


Figure 3: Permanent strain vs. no of cycles for reinforced and unreinforced samples at deviatoric stresses of (a) 125 kPa (b) 250kPa



(a)



(b)

Figure 4: Permanent strain vs. no of cycles for reinforced and unreinforced samples at deviatoric stresses of (a) 125kPa (b) 250kPa

A major observation from Table 3 is that for geogrid reinforced samples and unreinforced samples, the permanent strain decreases with an increase in the confining pressure. However, in the case of geocell reinforced section, the permanent strain remains constant for both 100kPa and 150kPa confining pressure. It can also be observed that for the same confining pressure, as the deviatoric stress increases, the permanent strain increases. It can also be concluded from Table 3 that irrespective of the confining pressure, the geocells and geogrid effectively reduced the permanent strain compared to the unreinforced section. The reinforcement reduced the permanent strains by more than 80%.

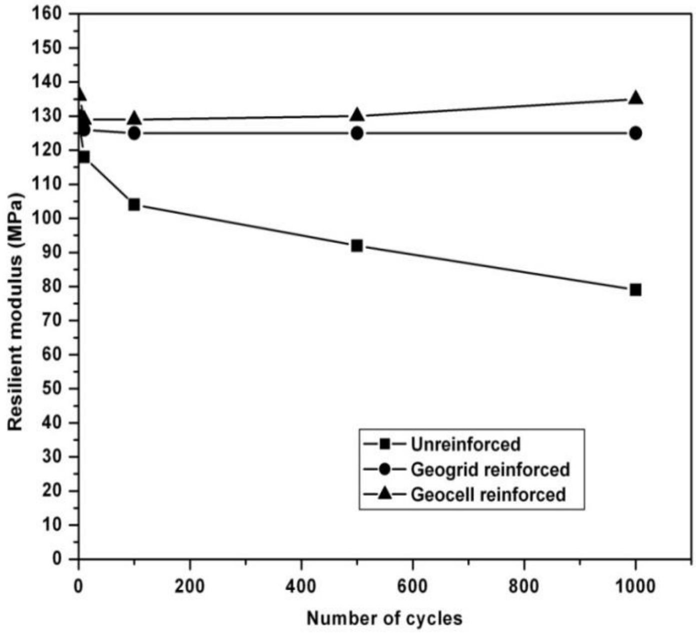
5.2. Resilient Modulus

The importance of resilient modulus has been discussed in detail in the previous sections. The results from the repeated load tests carried out in the previous section concluded that the resilient modulus of the geogrid and geocell reinforced section was higher compared to the unreinforced section. In the current section, the resilient modulus of the geocell and geogrid reinforced sections were compared with the unreinforced section. The studies were carried out for two confining pressures 100kPa and 150kPa. As explained earlier, the deviatoric stresses of 125kPa and 250kPa were chosen such that the sample was in plastic shakedown range.

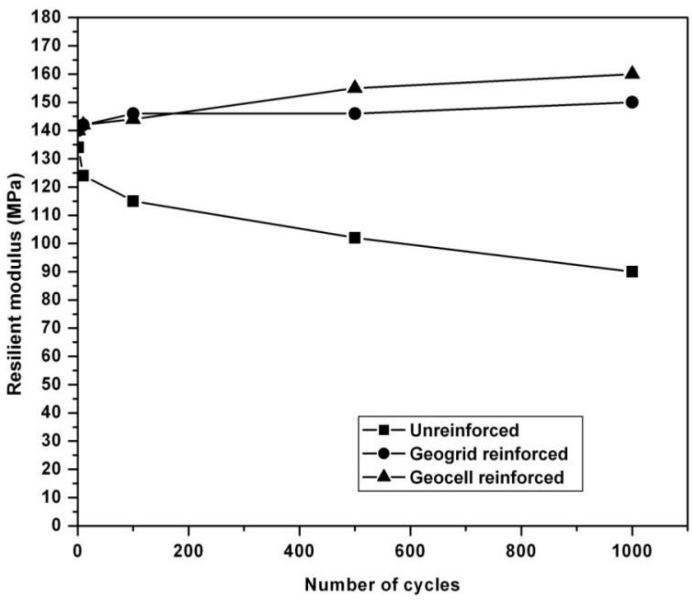
5.2.1. 100kPa Confining pressure

In this section, the resilient modulus of the unreinforced section is compared with the geocell, and geogrid reinforced section for a confining pressure of 100kPa. Figures 5(a) and (b) shows the comparison of the resilient modulus for deviatoric stresses 125kPa and 250kPa respectively.

Figures 5(a) and (b) were in accordance with the results obtained from the repeated load tests. The geocell and geogrid reinforced section had a higher resilient modulus compared to the unreinforced section. Further, it can be noted that the resilient modulus of the reinforced section increases or remains almost constant throughout the 1000 cycles while the resilient modulus of the unreinforced section decreases with increase in the number of cycles.



(a)



(b)

Figure 5: Resilient modulus vs. No of cycles for reinforced and unreinforced samples at deviatoric stresses of (a) 125kPa (b) 250kP

Table 3: Strain value at different cycles for reinforced and unreinforced samples

Confining Pressure	σ_d applied	Strain on unreinforced sample (%)		Strain on geogrid reinforced sample (%)		Strain on geocell reinforced sample (%)	
No of cycles		500th	1000th	500th	1000th	500th	1000th
100kPa	125kPa	0.39	0.7	0.1	0.12	0.08	0.09
	250kPa	0.92	1.4	0.2	0.22	0.17	0.21
150kPa	125kPa	0.36	0.46	0.04	0.06	0.05	0.09
	250kPa	0.73	1	0.1	0.18	0.15	0.21

It can also be noted from Figure 5 that the resilient modulus of the geogrid reinforced section was similar to the geocell reinforced section.

In the study, for an applied deviatoric stress of 125kPa, after 500 cycles, the resilient modulus of the geogrid reinforced sample was 128 and geocell reinforced sample was 130MPa respectively. For a unreinforced sample, the resilient modulus decreases from 128 during the initial cycles and reduces to 79 MPa after 1000 cycles. After 500 cycles, the resilient modulus for the unreinforced section was observed to be 92MPa. For samples where a deviatoric stress of 250kPa was applied, after 500 cycles, the resilient modulus of the geocell reinforced sample was 150MPa while for the geogrid reinforced sample, the resilient modulus was 146MPa. For unreinforced section, the resilient modulus decreased from 134MPa during the initial cycles and reached 102MPa after 500 cycles. An important observation from the study was that as the deviatoric stress increased for a sample, the resilient modulus also increased. However, the increase in resilient modulus of the samples with an increase in deviatoric stress was only marginal.

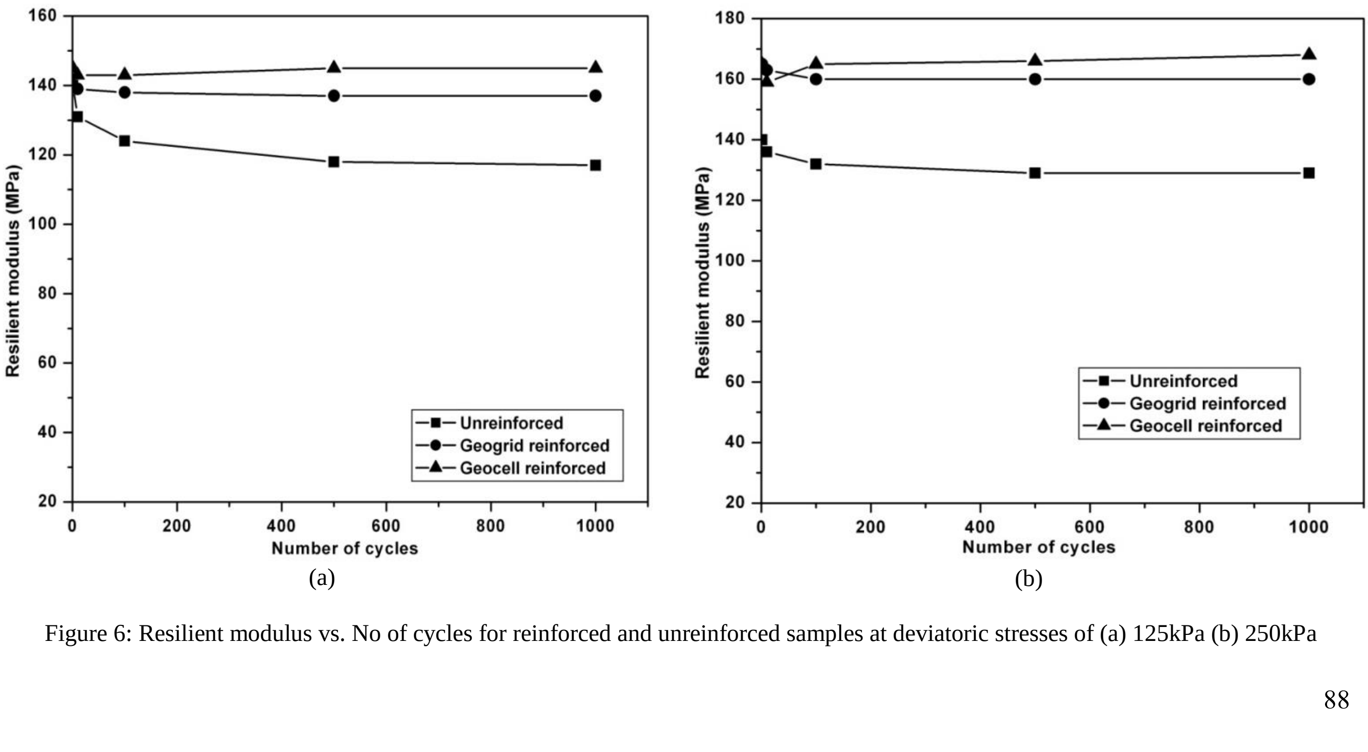
5.2.2. 150kPa Confining pressure

In the current study, the resilient modulus of the unreinforced section is compared with the geocell, and geogrid reinforced section for a confining pressure of 150kPa. Figures 6 (a) and (b) shows the comparison of the resilient modulus for deviatoric stresses 125kPa and 250kPa respectively. The results from the above studies were in accordance with the results of the studies carried out on 100kPa confining pressure. The resilient modulus of the geocell and geogrid reinforced samples were seen to be higher than the unreinforced sample.

For an applied deviatoric stress of 125kPa, after 500 cycles, for the unreinforced sample, the resilient modulus was 118MPa while for geogrid reinforced sample resilient modulus was reported to be 140MPa. The resilient modulus of the geocell reinforced section was observed to be 144MPa which was slightly higher than the geogrid reinforced sample.

When a deviatoric stress of 250kPa was applied, after 500 cycles, the resilient modulus of the unreinforced section was reported to be 129MPa while for the geogrid reinforced section, the resilient modulus was observed to be 160MPa. The geocell reinforced section had the highest resilient modulus value of 164MPa after 500 cycles. It could also be seen from Figure 6(a) and (b) that as the deviatoric stress increases, the resilient modulus of the samples increases. However, the increase was only marginal as seen in the case of samples tested at 100kPa confining pressure. The resilient modulus of the geogrid reinforced samples was comparable to the geocell reinforced samples. Table 4 shows the resilient modulus for the reinforced and unreinforced samples at different cycles. It is evident from Table 4 that the resilient moduli of the reinforced samples were higher compared to the resilient modulus of the unreinforced sample. Also, the value of resilient modulus obtained for the geogrid reinforced sample was comparable to the geocell reinforced sample.

From Table 4 it can also be concluded that the resilient modulus of the samples depended on the confining pressure and deviatoric stress applied on the sample. The resilient modulus of the samples increased with increase in confining pressure. The resilient modulus also increased with an increase in deviatoric stress. However, the increase was only marginal. It was also seen from the studies that the resilient modulus of the reinforced section increases or remains constant throughout the experiment while the resilient modulus of the unreinforced section shows a decreasing trend.



(a) (b)

Figure 6: Resilient modulus vs. No of cycles for reinforced and unreinforced samples at deviatoric stresses of (a) 125kPa (b) 250kPa

Table 4: Resilient Modulus at different cycles for reinforced and unreinforced samples

Confining Pressure	σ_d applied	Resilient Modulus- unreinforced Sample (MPa)			Resilient Modulus- geogrid reinforced samples (MPa)			Resilient Modulus- geocell reinforced samples (MPa)		
Cycle Number		1^{st}	500^{th}	1000^{th}	1^{st}	500^{th}	1000^{th}	1^{st}	500^{th}	1000^{th}
100kPa	125	128	92	79	129	128	128	130	130	134
	250	134	102	90	140	144	144	140	150	154
150kPa	125	138	118	117	141	140	140	146	144	144
	250	140	129	129	164	160	160	164	164	164

6. CONCLUSIONS

Resilient modulus and permanent strains are two important aspects that need careful consideration during the design of pavements. The resilient modulus of the unreinforced section is compared with the resilient modulus of the triaxial samples tested according to AASTHO T-307. The results showed that geocell and geogrid reinforced section showed higher resilient modulus compared to the unreinforced section. Studies were also carried out on geogrid, and geocell reinforced sections for loadings in the plastic shakedown and incremental collapse range, and the results were compared with the results of the unreinforced section. From the results, it could be concluded that the geogrid and geocell reinforcement improved the performance of the triaxial sample by reducing the permanent strains and increasing the resilient modulus compared to the unreinforced section. The improved performance by geocell reinforced section can be attributed to the additional confinement provided by the geocell while for geogrid, the enhanced performance was due to the interlocking and membrane effect of the geogrid. The limitation of this study is that due to size constraints of the triaxial sample only one geocell pocket was used in the study and thus the effect of additional confinement provided by adjacent geocell pockets are not explored. Lateral load distribution of geogrid reinforcement cannot be studied by using triaxial test setup and the same has to be studied in large experimental setups like plate load tests.

Acknowledgement

The authors thank the reviewers for critical comments which have been very useful in rewriting the paper. The authors also thank acknowledge the financial support provided by Department of Science and Technology, India through the research project entitled ‘Guidelines for the use of geo-cells in flexible pavements’.

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