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Flexural and Rutting Behaviour of Subgrade Reinforced with Geocell and Demolition Waste as Infill

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Abstract. From various past studies it was observed that the infill material used could affect the performance of the geocell reinforced subgrade. So, the use of waste materials as infill in geocell reinforced subgrade may prove to be more effective, economical. environment-friendly. The performance of demolition waste as an infill was studied using flexure testing and rutting analysis and compared the results with that of the other infill materials; soil and sand. Flexural behavior is very important to the geosynthetic application in pavements as it acts as a flexible layer embedded in pavements and leads to an improvement in stress distribution and reduction in stress on the soil subgrade. The flexural behavior was determined using four-point bending tests and results were expressed in terms of modulus improvement factor (MIF). The flexural behavior was tested in a plywood-polywood three-layered beam model. Elastic modulus of the soil-geocell composite was calculated using closed-form solutions. The rutting analysis was carried out using KENPAVE software. The geocells were prepared with three different aspect ratios 0.45, 0.67 and 1. The demolition waste infilled geocell mattress with aspect ratio 0.67 showed improved flexural behavior with MIF of 1.63 followed by soil and sand. The improvement was also seen in terms Traffic Benefit Ratio. Hence the use of geocell infilled with demolition waste due to its improved flexural and rutting behavior could be used in pavement subgrade as it can increase the performance and can also curb the difficulties caused by demolition waste.

Keywords: Beam Model, Demolition Waste, Traffic Benefit Ratio.

1 Introduction

The use of third-dimensional confinement systems in the area of geotechnical engineering were discovered many years ago. The three-dimensional confinement systems known as geocells are considered as cost effective, environment friendly, durable and easy to use. Infill materials used in geocell can greatly affect the performance of the geocell reinforced section. In the present scenario when there are huge developments in the infrastructure have resulted in the use of even weak ground for construction purposes. Use of reinforcement is more feasible for such massive applications were replacement of the soil and ground improvement by additives may not be economically and environmentally feasible. The developing infrastructure have also resulted in the demolition of old buildings and as a result, demolition waste are produced in tonnes all around the world in every year. Only quarter amount of this generated demolition waste is recycled. The remaining usually possess environmental and landfill problems. The use of demolition waste along with reinforcement can be used in subgrade if its effect is properly studied using laboratory experiments. With such a combined application, problems from the pollution caused by demolition waste can be reduced and low bearing lands can be used for infrastructure developments.

The improvement in the pavement behaviour is generally characterized by the subgrade strength and improved rut life. The rutting phenomena is a reflection of the flexural effect of the underlying strata. Kenpave is Microsoft windows-based software version and is commonly used in analysis of flexible and rigid pavements. Kenpave software in general provides changes in pavement structures at different locations when subject to traffic loads in terms of stresses, strains and deflections by considering the material properties.

1.1 Literature Review

The combined use of geocell and planar geogrid was studied and it was observed that planar geogrid placed at the bottom of the geocell enhanced the performance in terms of load carrying capacity.[1] When the geogrid ribs in the geocell wall are in the horizontal and vertical directions, they effectively resist against footing penetration through the mobilization of vertical compression and horizontal anchorage. Hence, the geocell mattress should be made of the geogrid with a square or rectangular aperture opening and its ribs oriented perpendicular and parallel to the footing. [2]. The flexural behaviour of geocell is believed to be one of the governing factors of the application of geocell in pavements as the geocell reinforced layer acts as flexible beam embedded between the layers and causes wider stress distribution resulting in lesser stress on the top of the subgrade soil layer. The results as obtained from three-layered beam models tests showed that the geocell reinforcement at higher load levels gives resistance to flexural deformation. It indicates that the geocell reinforcing effectiveness is greater when geocells are subjected to larger loads.[3]. To study the beam effect of geocell reinforcement for slope stability analysis of the reinforced section, a beam model was used so as to simulate the geocell behaviour as a flexible slab foundation capable of carrying both bending and membrane stresses. The interface friction between soil and geocell were also considered.[4] It was observed that the reinforcement acted as a wide slab and it restrains the failure surface development and there was also an increase in the bending moment taken by the geocell reinforcement. Flexural behaviour is considered to be an important factor that determines the application of geosynthetics in pavements as the reinforcement acts as a flexible layer embedded in pavements and results in an improved stress distribution and thereby causing a reduction of stress on the soil subgrade.[5]. The height of the geocell affects the rut depth as it was observed that there was an increase in life of one layer reinforced road section with geocell height 7.5cm by 1.3 times as that of unreinforced section and by 1.8 times for the reinforced section with one layer of with geocell height of 10-cm to reach the same rut depth of 7.5 cm. The height of geocell must selected so as to achieve the optimum performance as cells with height more than 10 cm may be good for confinement of infill but can cause difficulty in compaction of infill. Therefore, a compromise in the selection of cell height has to be made to achieve the optimum performance.[6]. For pavement analysis, KENLAYER can be applied to layered systems with each layer that behave differently under single, dual, dual-tandem, or dual-tridem wheels.Yang,2014). Kenlayer is based on finite element theory and effect of surface layer change and position ratio in the displacement and stress distribution of a given pavement system were examined.[7]. It is necessary to evaluate mechanical behavior of materials so as to calculate the distress parameters of flexible pavements. The results obtained from ANSYS were compared with KENPAVE and IITPAVE simulations to study the mechanical behaviour of a typical conventional pavement with hot bituminous surfacing, with cold recycled emulsified and foamed base pavements with fresh overlay. Stresses and strains at critical locations of pavement sections are computed using stress analysis software by modelling flexible pavement as a linear elastic multilayer structure. The results match well in linear elastic analysis of both KENPAVE and IITPAVE and high vertical strains if obtained are generally linked with increased possibility of rutting. [8]. The advantages of using recycled waste is that the cost of the raw material at the quarry or gravel pit; and transport costs, both financial and environmental, which are frequently the higher of the two. Locally available materials are obviously to be preferred. To this must be added the fact that if in situ recycling can be achieved, there are substantial time savings, beneficial for both the road authority and the user.[9]. So, from the literatures reviewed, it is seen that geocell has great potential in improving the performance of soil due to its load transferring mechanism. The performance in turn is affected by the infill material used. The use of geocell in pavement section is influenced by its flexural behaviour. And studies focussing on the rutting effect have stated that the rutting effect with the inclusion of geocell may be due to the flexural stiffness offered by the geocell mattress. There is no study that considers both the flexural and rutting behaviour simultaneously. Studies focussing on the utilization of demolition waste as infill to geocell is minimal. So, with simultaneous study of flexural and rutting behaviour the underlying principle of improved flexural behaviour results in the improved rutting behaviour with the inclusion of geocell mattress.

1.2 Need and Objectives of the study

The performance of road section is greatly affected by the behaviour of pavement layers out of which subgrade behaviour is a critical factor. Strain on the subgrade layer is considered as a fundamental factor that affects its performance. Excessivestrain in subgrade can reflect as rutting in the pavement layer. The strain thus is reliant upon the flexural behaviour of the reinforced subgrade layer. So, the study with exact focus on the flexural behaviour of reinforced subgrade can throw light on the effect of three-dimensional confinement and the infill material on the behaviour of a weak soil subgrade.

The main objectives of this study are to investigate the behavioural change of weak subgrade in terms of flexure and rut, with the inclusion of geocell and how it varies with different infill materials and change in aspect ratio.

2 Materials and Methodology

The geocell was made from geonet with nominal thickness of 1.01mm and opening size of 0.17x0.18cm. The tensile strength was obtained as 7.5kN/m. Three infills used were sand, demolition waste and soil which was also taken as the subgrade.

Table 1. Properties of soil

Properties	Value
Percentage of gravel	28.1%
Percentage of sand	36%
Percentage of silt and clay	35.9%
Maximum dry density(kN/m^3)	17.6
Optimum Moisture content	14.5%
Liquid Limit	62%
Plastic Limit	34%
Specific gravity	2.56
Natural water content	15.5%
Soil type	SM

The demolition waste used in the study was crushed into smaller pieces and its properties were determined.

Table 2. Particle size distribution of crushed demolition waste

Sieve Size	Percentage Passing	Limits as per MoRTH
20	100	100
12.5	92.37	90-100
10	42.87	40-85
4.75	4.70	0-10

Table 3. Properties of crushed demolition waste

Properties	Value
Specific Gravity	2.46
Impact Value (%)	31.2

Density(kN/m^3)	18.2
Angularity No	13
Nominal size(mm)	12.5

The sand used was sea sand having maximum density as 17.2 kN/m^3 and minimum density 14.4 kN/m^3. For the test, relative density of 35% was maintained.

Table 4. Properties of sand

Properties	Value
Specific Gravity	2.66
Cu	1.57
Cc	1.131
Gradation	Uniformly graded

For the flexure test, the testing beam was made using plywood and polywood sheets forming a three-layered beam model as shown in figure 1. They were procured from Trivandrum City. The polywood and plywood sheets used had a thickness of 18mm and 10mm respectively. The top and bottom portion of the flexure testing beam were made using polywood sheets and sides were made with plywood beams. The test beam had a dimension of 1m x 0.25m x 0.3m. The dimension of the flexure testing beam was fixed as per IS 1734-Part 11,2003.

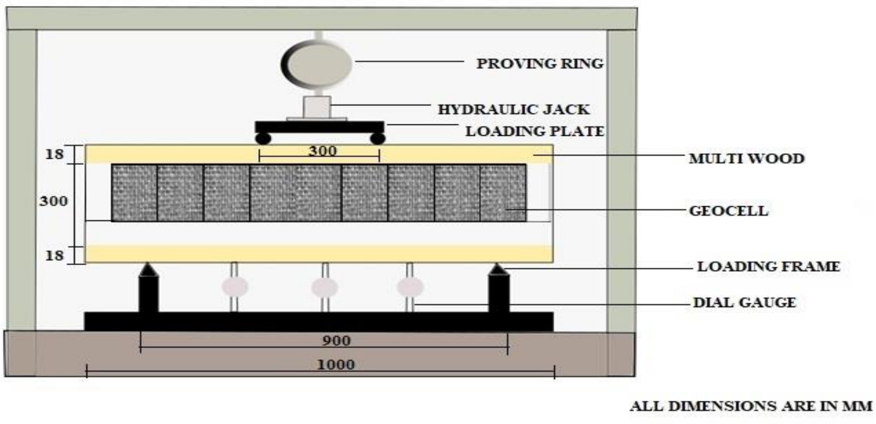

Fig. 1. Experimental Setup

Subgrade was prepared with thickness 300mm in three layers. After filling bottom two layers of soil at maximum dry density, geonet was placed. On top of geonet, geocell was placed and infill was filled. Polywood sheet was placed top on the subgrade section and loading plate was placed at center to ensure two-point loading. On top of it the manually operated hydraulic jack was placed. Load increments of 100N was given to the test section. Dial gauges were placed at bottom of the beam to measure deflections.

Fig. 2. Laboratory Flexure Test Setup.

Elastic modulus of the middle layer i.e. geocell reinforced layer was determined according to equations proposed by (Tang and Yang, 2013)

$$w_{l/2} = \frac{23PL^3}{648D} - \frac{fbtL^3}{12D}$$

$$w_{l/4} = \frac{29PL^3}{1152D} - \frac{11fbtL^3}{192D} \tag{1}$$

Where is the P- load(N) L- span(mm) b-width of beam(mm) t- thickness of polywood (mm) D- composite modulus(N/mm^2)

E1, I1 = Elastic modulus and moment of inertia of polywood beam

E2, I2 = Elastic modulus and moment of inertia of middle layer.

The modulus obtained from flexure test were used to determine the pavement thickness using CBR values of each section using equations given in IRC 37-2018.

$$Elastic\ modulus\ of\ a\ material = 17.6 * (CBR)^{0.64} \tag{2}$$

The modulus obtained was then quantified in terms of modulus improvement factor (MIF). Modulus improvement factor has very crucial role in the design of pavement sections. A higher modulus improvement factor implies a higher stiffness of the reinforced section compared to unreinforced section. The increased stiffness in turn result in better load distribution capacity and improved performance of the pavement section.

It depends on the material of the geosynthetics used and the properties of the infill used.

$$Modulus\ Improvement\ Factor = \frac{Modulus\ of\ the\ reinforced\ base\ with\ an\ infill}{Modulus\ of\ unreinforced\ base} \quad (3)$$

The pavement thickness, modulus and poisons ratio were given as the input to KENPAVE software and the subgrade rutting was obtained in terms of vertical strain on top of the subgrade. The strain was then converted to subgrade rutting life(Nr) using the equation given in IRC 37-2018 as given below.

$$N_R = 1.4100 * 10^{-08}(1/\varepsilon_v)^{4.5337} \quad (4)$$

Where N_R is the subgrade rutting life cumulative equivalent number of 80 kN standard axle loads that can be served by the pavement before the critical rut depth 20 mm or more occurs and ε_v vertical compressive strain at the top of the subgrade calculated using linear elastic layered theory by applying standard axle load at the surface of the selected pavement system. The subgrade rutting was used to determine the traffic benefit ratio (TBR) using the equation given below.

$$Traffic\ Benefit\ Ratio(TBR) = \frac{No.of\ load\ cycles\ on\ reinforced\ Section}{No.of\ load\ cycles\ on\ unreinforced\ Section} \quad (5)$$

3 Results and Discussions

The load deflection plot obtained from the flexure test is shown below.

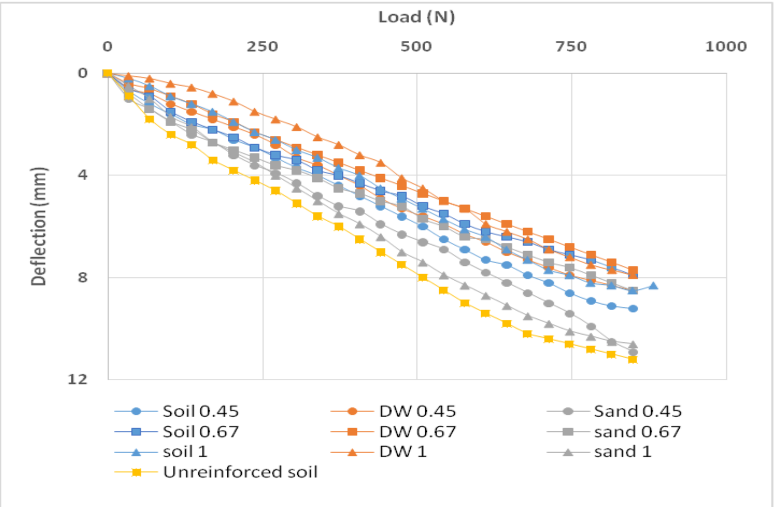

Fig. 3. Load -deflection plot for all combination of aspect ratio and infills.

From all the results it is observed that inclusion of geocell reinforcement considerably influenced the behaviour of the subgrade system. This shows that the three-dimensional confinement system resists the bending of the section by imposing the beam effect and provide adequate confinement to resist the deformation due to the loading system. From the graph, using equation 1, the modulus value of each combination of aspect ratio and infill were calculated.

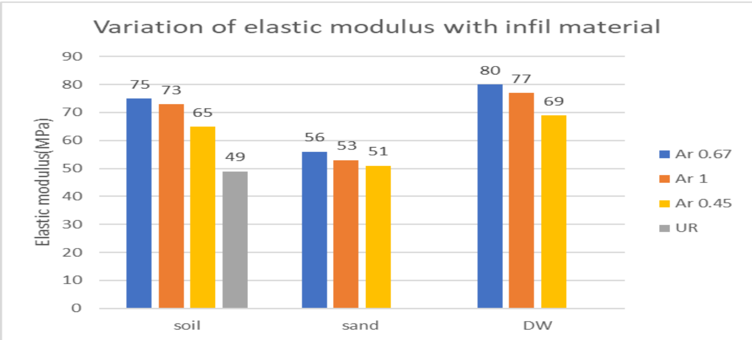

Fig. 4. Variation of elastic modulus with infill and aspect ratio

The modulus of elasticity for the various combinations of aspect ratio and infill material is shown above.

From the graph it is evident that with every infill materials, geocell with aspect ratio 0.67 gave better results followed by aspect ratios 1 and 0.45. Though the modulus of elasticity improved when compared with unreinforced bed, the improvement was minimal when compared to other aspect ratios.

Sine the height was small for aspect ratio 0.45 geocells as the aspect ratio was varied by keeping the diameter of the geocell constant and by changing its height, lower confinement of the infill material may have resulted in a comparatively lower modulus value and steeper load-deflection curve than other aspect ratios due to its lower flexural stiffness. From the modulus obtained, MIF was calculated using equation 3.

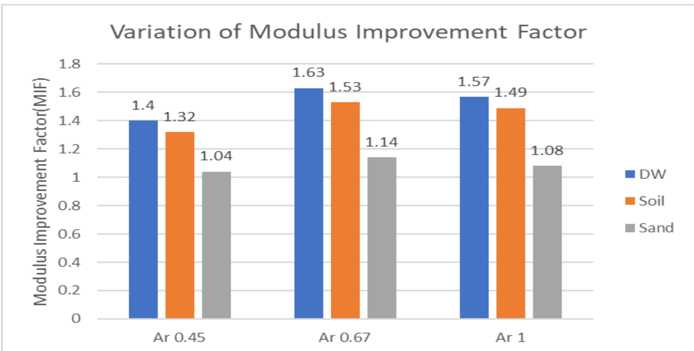

Fig. 5. Variation of modulus improvement factor

Modulus improvement factor has very crucial role in the design of pavement sections. A higher modulus improvement factor implies a higher stiffness of the reinforced section compared to unreinforced section. The increased stiffness in turn result in better load distribution capacity and improved performance of the pavement section. It depends on the material of the geosynthetics used and the properties of the infill used. The IRC SP 59-2019 specifies an indicative range of modulus improvement factor 1.4 to 2. The obtained results satisfy the criteria as per IRC code

Table 5. Variation of CBR and Pavement Thickness with Modulus.

Infill	Aspect Ratio	CBR	Total Thickness(mm)
	0.45	8.5	295
DW	0.67	10.6	245
	1	10.1	245
	0.45	7.7	320
Soil	0.67	9.6	295
	1	9.2	295
	0.45	5.2	345
Sand	0.67	6.1	320
	1	5.6	320
UR		4.95	345

The thickness was obtained from IRC SP 72-2015 corresponding to CBR values obtained by back calculating the modulus value. It was seen that CBR value is high for the subgrade reinforced with geocell having aspect ratio 0.67 with infill as DW. From all the infill and aspect ratio combination it is observed that aspect ratio 0.67 gives better CBR values than aspect ratio 0.45 and 1.

It can also be seen that demolition waste gave the maximum CBR value followed by soil with aspect ratios 0.67 and 1 respectively though aspect ratio 0.45 gave slight improvement in all the three infill materials when compared with unreinforced soil. Same trend was observed with the thickness also. The thickness obtained from IRC SP 72-2015 were given as input to the pavement analysis software: KENPAVE. The major input values were the thickness, poisons ratio and modulus value. The poisons ratio of each layer was taken as 0.35 as given in IRC 37-2018. The strains obtained were converted to subgrade rutting life as equation mentioned in the previous section. The subgrade rutting values obtained from the software analysis is shown in the table below.

Table 6. Subgrade rutting values

Infill	Aspect Ratio (Ar)	Strain at subgrade	Subgrade Rutting (ESAL)
	0.45	1.16E-03	287135
DW	0.67	1.12E-03	336651
	1	1.15E-03	302187
	0.45	1.24E-03	210669
Soil	0.67	1.18E-03	262681
	1	1.20E-03	246227
	0.45	1.36E-03	139603
Sand	0.67	1.32E-03	159835
	1	1.35E-03	143387
UR		1.43E-03	112613

The subgrade rutting values were converted to Traffic Benefit Ratio (TBR) using the equation stated above.

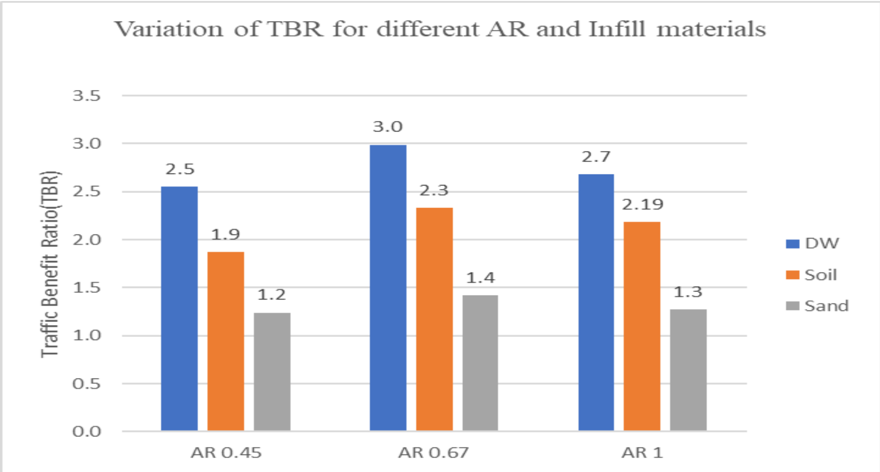

Fig. 6. Variation of Traffic Benefit Ratio for different aspect ratio and infill.

The above bar chart shows the variation of traffic benefit ratio with different materials and aspect ratio. It is well evident that with aspect rati0 0.67 and with demolition waste infill gave the maximum value of TBR followed by soil and sand. When comparing the performance based on aspect ratio, a trend similar to that observed during the flexure test was seen. The lowest performing was aspect ratio 0.45 and the best performing was aspect ratio 0.67 emphasising that aspect ratio 0.67 can give a more strong and resilient support to the pavement system.

4 Conclusion

Infill materials affect the performance of the geocell reinforced subgrade. Demolition waste gave the best improvement for both flexural and rutting behaviour. Aspect ratio 0.67 was better performing than aspect ratios 0.45 and 1. A reduction in performance was observed for aspect ratio 1 when compared with 0.67 as this may be due to the buckling of the geocell due to increased height of the geocell pockets. Flexural behaviour affects the rutting of the subgrade layer as the combination that gave best flexural behaviour also gave the best improved rutting behaviour. The modulus of the subgrade section also changed with infills and demolition waste gave the highest modulus and this have resulted in an increase in subgrade rutting life in terms of Equivalent Single Axle Load(ESAL).Traffic benefit ratio (TBR) also signifies that the use of demolition waste in subgrade within the geocell pockets can improve the performance of the pavement as a whole. In this study, demolition waste considered had a nominal size of 12.5mm and sand was filled at a relative density of 35%. Hence further studies focussing on varying size of demolition waste and relative density of sand can be done thereby increasing the scope of the studySo, without taking up large quantity of natural materials for pavement construction, a better performing pavement with improved rutting life and flexural rigidity can be obtained with the inclusion of geocell and no cost demolition waste within the subgrade.

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