Experimental Study on Geocell and of Fibre Reinforced Soil Sub-grade Under Static and Repetitive Load

A. Ramesh, Ch. Nageshwar Rao and M. Kumar

Abstract Development of transportation infrastructure will provide an overall development of country's economy. This is achieved by providing better quality and longevity of roads. To improve the quality of pavement structure, soil sub-grade properties play a vital role. As known fact that soil sub-grade handles the vehicular wheel load transmitted from the pavement structure. A few soils when used in pavement construction do not provide desirable properties. The performance of such soils can be improved with reinforcement of non-traditional materials. In this paper, an attempt is made to enhance the properties of silty soil in two stages. In the first stage of study, soil is reinforced with basalt fibre (non-traditional material) with varying length (i.e. 25, 50 and 75 mm) and percentages (0.2, 0.4 and 0.6). CBR, resilient modulus (M_R) and UCS values were enhanced with reinforcement of basalt fibre for 50 mm length and 0.4%, when compared with natural soil. In the second stage of study, lateral confinement is achieved by providing plastic PET bottles of varying diameter of 50, 80 and 100 mm in the form of geocell. These PET bottles are provided at 1/3H and 1/2H. CBR and resilient modulus (M_R) values were observed to be higher for 80 mm diameter PET bottles provided at 1/3H.

Keywords Resilient modulus · CBR · Fibres · Plastics · PET bottles

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(a) Chopped Basalt fiber


(b) PET Bottle of different diameter

Fig. 1 Fibre PET bottle used in the study

1 Introduction

Developing countries like India is curtailed for providing complete road network system due to limited financial constraints. Predominately pavements are constructed in layers as sub-grade, sub-base, base and are greatly influenced on quality and life of pavement. One of the most important materials among the other is nature of sub-grade soil materials. The real challenge lies in construction flexible pavements over a weak sub-grade having low California bearing ratio (CBR). Constructing pavements on such weak sub-grade requires more thickness. In order to improve the engineering soil properties of such weak soil, replacement of existing soil might not be a challenging solution. On the other hand, if the stability of the local soil is not adequate for supporting the vehicular wheel loads, the properties of existing soil can be improved by soil stabilization/modification techniques. Randomly, distributed fibre when used at regular intervals on highway pavements will produce better performance in the stabilization process of weak soil sub-grade. Polyethylene terephthalate (PET) plastic wastes are destroying the societal environment.

The current study focuses on improving local soil using basalt fibre and PET bottle as confinement in the form of geocell. Optimum fibre content and influence of PET bottle as confinement in local soil are assessed in the laboratory. Figure 1 provides fibre and PET bottle used in the study.

2 Background of Study

Many studies have been conducted by researchers for investigating the behaviour of weak soil when reinforced with different types of fibre and providing confinement through laboratory experimental tests. Consoli et al. (2003) conducted response studies on thick homogenous stratum of compacted sandy soil with polypropylene

(PP) fibres. The PP-reinforced fibre exhibited axial strains greater than 20%, than unreinforced soil specimens. Kumar et al (2006) tested on highly compressible clay in unconfined compressive strength with varying percentages of flat and crimped polyester fibre. The test results indicate that as the fibre length and/or fibre content increases, there is an improvement in UCS value. Chegenizadeh (2013) studied the effect of fibre inclusion on CBR ratio. The test results indicate that the CBR ratio for reinforced clay increased by two times as fibre content and length increased.

Tang et al. (2006), Akbulut et al. (2007), Sadek et al. (2010), Babu & Chouksey (2011) conducted studies on reinforcing soil with plastic waste. Their findings on reinforcing soil with plastic waste increase the strength, CBR and reduce the compressibility. In this study, the authors have focused on the analysis of engineering behaviour of soil reinforced with polyethylene terephthalate (PET) plastic waste (Athanasopoulos 1993) and addition of varying length and proportion of fibre. From the literature, most of the authors have attempted in fibre reinforcement and soil confinement. In this paper, we have made an attempt in understanding the effect of reinforcement and confinement on CBR, M_R and UCS parameters.

3 Methodology and Experimental Programme

In the present investigation, a methodology is proposed for evaluation of natural soil when reinforced with basalt fibre and provided lateral confinement with plastic PET bottle of different diameter at different heights. Table 1 provides details of study methodology.

The soil was collected from site near forest training academy, Dulapally village, Hyderabad city, and fibre is collected from HDM, New Delhi, and plastic PET bottles collected from local shredding yard in Hyderabad city. The initial properties of soil are determined in the laboratory, and particle size distribution is shown in Fig. 2. The physical properties of basalt fibre are obtained from the supplier. Table 2 provides the properties of soil, Table 3 provides properties of fibre and Table 4 provides properties of PET bottle.

Table 1 Methodology adopted for study

Stage No.	Description
1.	Literature survey and collection of materials
2.	Physical properties of material used in the study
3.	Estimation of index properties, dry density, OMC, CBR, resilient characteristics (M_R) and UCS for natural soil
4.	Assessment of CBR, resilient characteristics (M_R) and UCS parameters for soil reinforced with fibre of varying length and providing lateral confinement with different diameter and heights
5.	Discussion on above laboratory results and conclusions

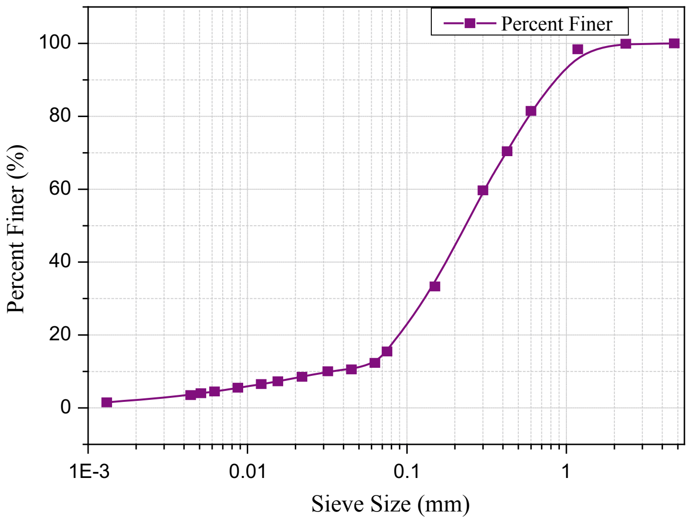

Fig. 2 Particle size distribution

Table 2 Properties of silty sand

Properties	Test results	IS Test specifications
Liquid limit (%)	35	IS 2720 (Part V) 1985
Plastic limit (%)	18	IS 2720 (Part V) 1985
Plasticity index (%)	17	–
Specific gravity	2.6	IS 2720 (Part III/Sec 1) 1980
Maximum dry density (g/cc)	1.95	IS 2720 (Part VIII) 1983
Optimum moisture content (%)	12	IS 2720 (Part VIII) 1983
IS Classification	Silty sand	IS 2720 (Part IV) 1985
Unconfined compressive strength (kPa)	356	IS 2720 (Part X) 1973
Particle size distribution		
Percentage of sand (%)	46	IS 2720 (Part IV) 1985
Percentage of silt (%)	47.5	
Percentage of clay (%)	6.5	

Table 3 Properties of basalt fibre

Properties	Limits
Tensile strength (MPa)	2800–4800
Elastic modulus (GPa)	86–90
Strain at break (mm/mm)	0.0315
Specific gravity	2.7

Table 4 Properties of polyethylene terephthalate (PET bottle)

Properties	Limits
Tensile strength (MPa)	450
Elastic modulus (N/mm^2)	3100
Ultimate elongation (%)	11.2
Density kg/m^3	1380

Source Chowdhury et al. (2013)

In the present study, the improvement of sub-grade soil when treated with fibre and plastic PET bottles placed at 1/3H and 1/2H (H is the height of mould from top) of CBR mould is determined by conducting soaked test as per IS 2720: (Part XVI) 1987. Basalt fibre of 25, 50 and 75 mm length is mixed at OMC with careful monitoring and after visual satisfaction in uniformity of fibre when reinforced in soil. As the length and percentage of fibre are less, segregation has not observed during the process of sample preparation. The soil in CBR mould is compacted at modified proctor density. The penetration and load were observed from load cell and LVDT arrangement through online DAQ connected to CBR instrument (Fig. 3). Soil samples are tested after 4 days of soaking in water. PET bottles are provided as geocells for different diameters and varying height.

Resilient modulus (AASHTO 2007) (M_R) is an important mechanical property widely used for the analysis and design of pavements. A repeated axial cyclic stress of fixed magnitude with load duration of 0.1 s and rest period of 0.9 s rest is applied to cylindrical test specimen. Total period of loading and unloading (rest period) together constitutes one loading cycle (1 s) which amounts to 1 Hz frequency. The stress pulse shape was haversine in nature. The repeated load tests were performed on CBR mould. Each combination is applied in 100 cycles after preconditioning of 500 cycles. The total resilient or recoverable axial deformation response of the specimens is used to calculate resilient modulus. The tests were terminated when the total vertical permanent strain exceeds 5%. Figure 4 provides the set-up of repeated load test for determining resilient modulus (M_R).

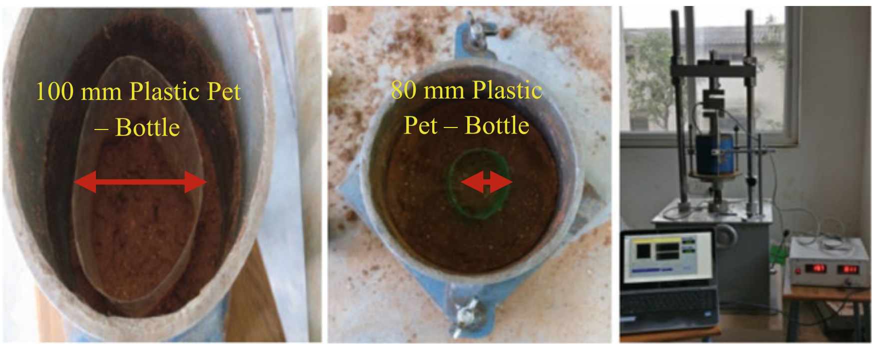

Fig. 3 Plastic confinement preparation and CBR test performed through online DAQ

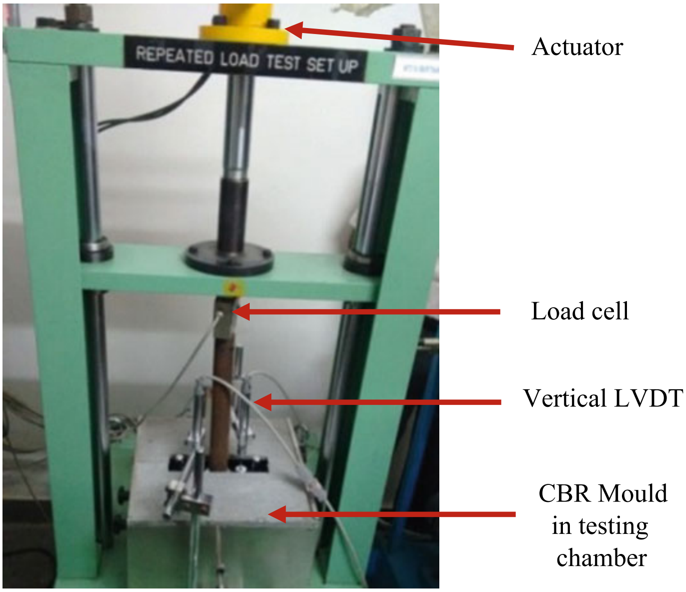

Fig. 4 Repeated load test set-up for M_R determination

4 Results and Discussion

The CBR values of soaked soil with and without fibre reinforcement and lateral confinement by plastic PET bottles were determined in the laboratory. The fibre reinforcement is provided by varying length of 25, 50 and 75 mm and percentages of 0.2, 0.4 and 0.6, respectively. Lateral confinement is provided at 1/3H and 1/2H from top of the mould. The maximum CBR value is 14.67%, obtained with the inclusion of fibre of 50 mm length of 0.4%. Natural soil when confined with PET bottle of 80 mm diameter has enhanced its CBR value by 13.33% at H/3 and is more because it is within the pressure bulb, whereas when placed at 1/2H as it is away from the pressure bulb the CBR value observed is 10.56%. The CBR value of fibre-reinforced soil in soaked condition also observed to be improved from 6.3% to 14.67% for the fibre length of 50 mm with 0.4%. Table 5 provides test results for fibre-reinforced soil mixes, and Table 6 provides PET bottle confinement for soil mixes, respectively.

Similar trend of increase in CBR, resilient modulus and UCS for the fibre percentage 0.4 and length 50 mm, respectively, are shown in Figs. 5, 6 and 7.

Resilient modulus (M_R) test was carried on CBR mould for defined number of passes and to achieve deformation of 2.5 mm. It is observed that 50 mm length and 0.4% fibre reinforcement has improved the resilient characteristics from 67 to 250 MPa when compared with natural soil. Similar trend was observed for lateral confinement of soil when provided with plastic PET bottle at H/3 and 80 mm diameter. Figure 8 provides variation in resilient characteristics for lateral confinement.

Table 5 Comparison of CBR, M_R and UCS values for soaked specimens treated with fibre

Basalt fibre length (mm)	Per cent fibre (%)	CBR Value (%)	M_R (kPa) × 10^3	UCS (kPa)
0	**0**	**6.30**	**67**	**356**
25	0.2	10.30	118	395
	0.4	10.50	121	410
	0.6	10.10	112	382
50	0.2	14.40	242	501
	0.4	14.67	250	512
	0.6	13.91	232	498
75	0.2	12.55	182	472
	0.4	13.22	189	481
	0.6	11.63	178	465

Table 6 CBR values for soaked specimens with lateral confinement

PET bottle confinement dia. mm	Test No.	CBR			
		(@ H/3)	Average (@H/3)	@ H/2	Average (@H/2)
0	1	7.0	6.3	7.0	6.33
	2	6.1		6.0	
	3	5.9		6.0	
50	1	8.8	9.0	8.0	7.83
	2	8.9		7.5	
	3	9.3		8	
80	1	12.9	13.33	10.0	10.56
	2	14.2		10.5	
	3	12.9		11.2	
100	1	11.8	12.63	9.1	9.56
	2	13.2		9.9	
	3	12.9		9.7	

It is observed from Table 5 that unconfined compressive strength (UCS) is increased from 356 to 512 kPa for fibre length of 50 mm and 0.4%, and thereafter, UCS values reduced. This is because more length of fibre induces lubrication effect and resulted in decreased trend. Similarly at 25 mm fibre length, the UCS value observed to be lesser than 50 mm, and this is because of insufficient length of fibre for development of friction from surrounding soil. From Table 5, similar inferences can be drawn in case of M_R values for respective fibre length, percentages and in

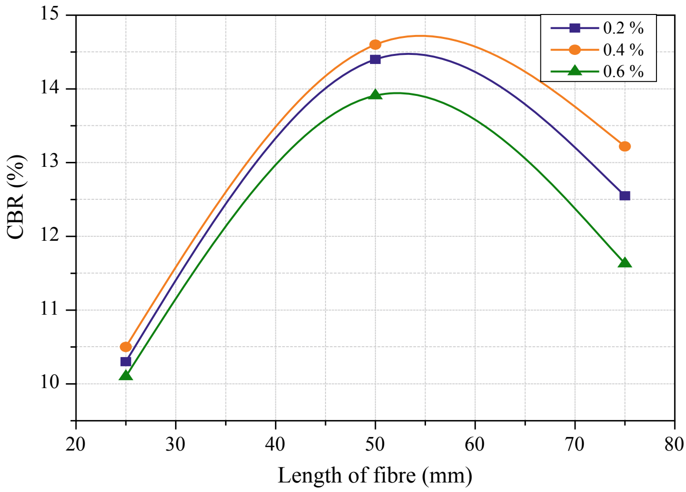

Fig. 5 Variation of CBR value with reference to length of fibre and percentage

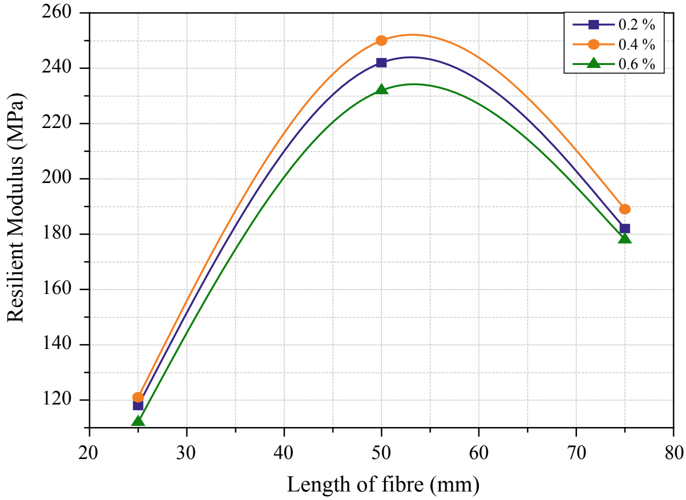

Fig. 6 Variation of resilient modulus with reference to length of fibre and percentage

case of lateral confinement too. In the field, the same concept can be implemented wherever week soils zones are met with during pavement constructions. However, the waste PET bottles can be reused in the form of geocells by moulding process. Further investigations are required in test tracks before implementation in the field.

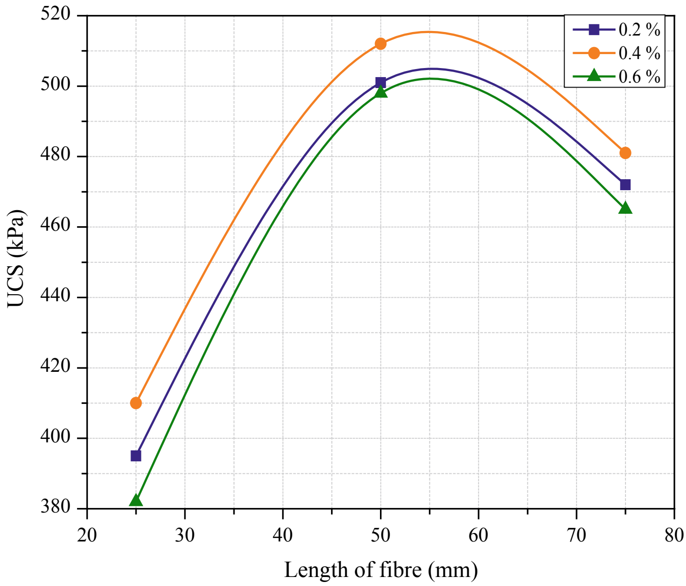

Fig. 7 Variation of UCS value with reference to length of fibre and percentage

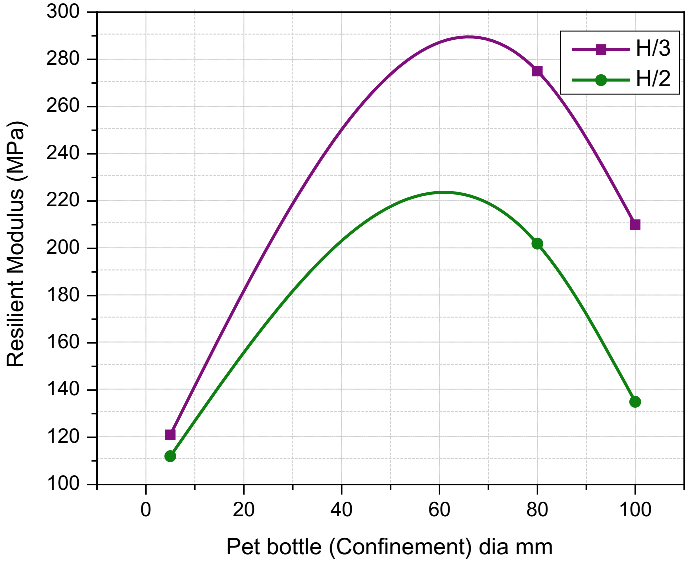

Fig. 8 Variation of resilient characteristics for lateral confinement

5 Conclusions

The strength development in terms of CBR value, UCS and modulus of resilient measured soil reinforced with basalt and PET—bottle confinement on silty soils. Based on the results, the following conclusions are drawn.

(a) The addition of basalt fibre is effecting in enhancing the CBR, UCS and M_R values. This could be due to the mobilization of frictional resistance between fibre and surrounding soil.
(b) Confinement with PET—Bottle enhanced the CBR and M_R by offering soil resistance to lateral yield due to confinement.
(c) UCS value increased by addition of fibre by offering resistance to strain developed in the soil by fibre when compared to natural soil.
(d) CBR, resilient modulus and UCS for the fibre percentage of 0.4 and length 50 mm increased. At 0.2 and 0.6%, of lengths 25 and 75 mm, respectively, are shown decreased trend due to obvious reason that at 0.2% and 25 mm length has insufficient frictional resistance, whereas at 0.6% and 75 mm length slip might have occurred between fibre and surrounding soil, respectively.

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