Reuse of Plastic Waste in Foundation Soil Reinforcement Application

Réutilisation de déchets plastiques dans l'application de renforcement de sol de fondation

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ABSTRACT: Reinforced soil technology is widely adopted in roadways, railways, soil stability and foundation applications due to their ease of construction, performance, durability, aesthetics, design flexibility and time saving. Across the world, researchers are introducing new materials and technologies to address various infrastructural demands and to obtain sustainable solutions. This paper presents studies on reuse of waste plastic bottles to prepare reinforcement similar to conventional geogrid for its potential application to improve load – settlement behavior of soil. Soil beds of 2.1 m × 1.05 m × 0.9 m at 70% relative density were prepared using locally available river sand. Results of plate load tests on unreinforced soil was compared with that of conventional geogrid reinforced soil and plastic reinforced soil. Experimental results showed the ultimate bearing capacity of 254 kPa, 310 kPa (22% increase) and 292 kPa (15% increase) for the cases of unreinforced soil, geogrid reinforced soil and plastic reinforced soil, respectively. Further, cost comparison between geogrid and plastic bottle reinforcement indicated 60% cost saving when the latter is adopted.

RÉSUMÉ : La technologie des sols renforcés est largement adoptée dans les routes, les chemins de fer, la stabilité des sols et les applications de fondations en raison de leur facilité de construction, de performance, de durabilité, d'esthétique, de flexibilité de conception et de gain de temps. Partout dans le monde, les chercheurs introduisent de nouveaux matériaux et technologies pour répondre aux différentes demandes d'infrastructure et pour obtenir des solutions durables. Cet article présente des études sur la réutilisation de bouteilles de plastique usées pour préparer des armatures semblables à la géogrille classique pour son application potentielle afin d'améliorer le comportement de charge - établissement du sol. Des lits de sol de 2, 1 m × 1,05 m × 0,9 m à 70% de densité relative ont été préparés en utilisant du sable de rivière localement disponible. Les résultats des essais de charge sur des sols non renforcés ont été comparés à ceux des sols renforcés par des géogrilles conventionnelles et des sols renforcés de plastique. Les résultats expérimentaux montrent la capacité de charge finale de 254 kPa, 310 kPa (augmentation de 22%) et 292 kPa (augmentation de 15%) respectivement pour les sols non renforcés, le sol renforcé de géogrilles et le sol renforcé de matière plastique. En outre, la comparaison des coûts entre la géogrille et le renforcement des bouteilles en plastique indiquait une économie de 60% lorsque ce dernier est adopté.

KEYWORDS: Waste plastic bottles reuse, soil reinforcement, plate load test

1 INTRODUCTION

The foundation of any infrastructure is pivotal in transferring the load safely from superstructure to the underlying soil without compromising serviceability. However, many a times, foundations are to be built on loose/weak soil, causing excessive settlements due to lower bearing capacity. This may lead to structural damage, reduction in the durability, and/or deterioration in the performance level. One of the solutions is use of reinforced soil foundation (RSF) consisting composite zone (reinforced soil mass) to improve the load carrying capacity of the footing and provide better pressure distribution on top of the underlying weak soils, hence reducing the associated settlements (Sharma et al. 2008).

2 LITERATURE REVIEW

The use of reinforcement for improving performance of soil has been studied by the engineers over the past five decades. Soil reinforcement has been used in various forms, for example, metal strips (Binquet and Lee 1975; Fragaszy and Lawton 1984), metal bars (Huang and Tatsuoka 1990), rope fibers (Akinmusuru and Akinboladeh 1981), geotextiles (Guido et al. 1986), and geogrids (Guido et al. 1986; Yetimoglu et al. 1994; Omar et al. 1993; Adams and Collin 1997; Patra et al. 2005).

Mainly, the reinforcements in soil are designed to intersect potential failure surfaces in the soil mass, such that strains in the soil mass generate strains in the reinforcements, which in turn, generate tensile loads in the reinforcements. These tensile loads act to restrict soil movements and thus impart additional shear strength. This results in the composite soil/reinforcement system having significantly greater shear strength than the soil mass alone. This difference in strengths achieved is mainly due to the difference in mechanism of failure in the soil reinforced with geosynthetic material in different forms. The reinforcements are mostly provided in three forms: (i) planer (ii) randomly oriented and (iii) cellular. Horizontal geosynthetic layers improve the strength mainly by friction, and interlocking between soil and the reinforcement, whereas the randomly oriented fibers improve strength by friction and coiling around soil particles, and the geocells improve strength by friction and all-round confinement of soil (Latha and Murthy 2006).

2 .1 *Use of Plastic Bottles in Geotechnical Application*

In past researchers have utilized waste plastic bottles in various forms. For example, Benson and Khire (1994) prepared strips with aspect ratios of 4, 8 and 12 to examine how reinforcement of sand is affected by the length of strips. The increase in friction angle was observed as large as 18% during the study. Bueno (1997) investigated performance of mechanically stabilized soil walls with short, thin randomly oriented plastic strips of different lengths and observed increase in the bearing capacity of soil. Consoli et al. (2002) showed that the polyethylene terephthalate fiber reinforcement improved the peak and ultimate strength of both cemented and uncemented soil and somewhat reduced the brittleness of the cemented sand.

Dutta and Rao (2004) performed triaxial test on sand reinforced with plastic strips and observed improvement in the deviatoric load carrying capacity. Ashraf et al. (2011) conducted plate load tests on soil reinforced with layers of plastic bottles filled with sand and cut into two halves placed at middle or one third position of tank. The test results showed that cut bottles placed at middle position were the most efficient in increasing strength of soil. Experimental outcomes from past study revealed a good improvement in the strength of soil and considerable increase in bearing capacity with inclusion of plastic waste. This increase in the strength of soil is attributable to an increase in friction between soil and plastic waste that results in the development of tensile stress in the plastic waste (Babu and Chouksey 2012).

According to the International Bottled Water Association, 1.5 million tons of plastic are used to bottle water every year; unfortunately, the recycling process is messy and inefficient. It’s interesting to note that the rate of consumption of plastic water reaches 800 bottles per second and only 100 of those bottles are recycled (Babu and Chouksey 2012). This paper presents a simple way of recycling plastic water bottles in the field of geotechnical engineering as reinforcing material. Experimental studies on the use of PET bottles derived geogrid (P-geogrid) as an alternate to the conventional geogrid (C-geogrid) materials for foundation reinforcement applications was performed. Study was extended to understand load-settlement behavior of a square footing resting on unreinforced soil, P-geogrid reinforced soil and C-geogrid reinforced soils.

3 EXPERIMENTAL PROGRAM

Experimental study was carried out to observe effectiveness of C-geogrid and P-geogrid as reinforcement by plate load test setup. The backfill soil used in this study was locally available uniformly graded river sand, classified as SP according to Unified Soil Classification System (USCS) as shown in Fig. 1. Properties of soil were observed as: Specific Gravity (Gs) = 2.67, Coefficient of Permeability (k) = 0.0072 cm/sec, Angle of Internal Friction (ϕ) = 36°. Tensile strength of biaxial geogrid here named as C- geogrid, for 2% strain was observed as 4 kN/m.

Experimental setup consisted of a test pit of dimensions 2100 mm × 1050 mm × 900 mm (length × breadth × depth), which was filled with backfill sand as shown in Figs. 2-3. Markings were done throughout the depth of the pit at every 100 mm, sand was filled by weight in order to have finished layers of same thickness and using plate temping relative density of 70% was obtained. Considering the dimensions of test pit, a mild steel plate of 205 mm × 185 mm × 25 mm was selected as bearing plate to satisfy the width criterion. For reinforced soil, 4 layers of C-geogrid and P-geogrid reinforcements were provided. Pictorial view of both the geogrid used for soil reinforcement is shown in Fig. 4. The 1st layer was placed at 100 mm below the top surface, 2nd layer was placed at 100 mm below the 1st layer and the other two consecutive layers were placed at 200 mm below the respective previous layer.

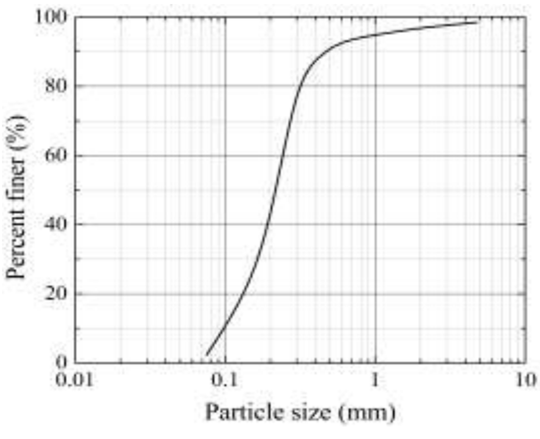

Figure 1. Particle size distribution of the backfill soil

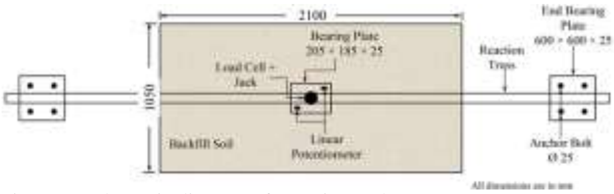

Figure 2. Schematic diagram of experimental setup

Figure 3. Pictorial view of experimental setup

The loading was applied using a steel reaction truss the ends of which are sandwiched between two end bearing plates anchored firmly with the anchor bolt. Load was applied using hydraulic jack to apply 25 kPa stress increment to the bearing plate. Applied load was monitored with a load cell (25 kN capacity) kept in contact with the hydraulic jack (capable to apply load up to 100 kN). The settlement of the plate was recorded with two linear potentiometers (of accuracy 0.02mm) placed at diagonal ends of the bearing plate. Next load increment was applied when the rate of settlement becomes less than 0.02 mm/hour. Total three experiments were performed with same backfill conditions to compare the results of stress-settlement behavior of soil with and without reinforcement and the results were obtained up to 25 mm of plate settlement.

Figure 4. View of soil reinforced with C-geogrid and P-geogrid

4 RESULTS AND DISCUSSION

The results obtained by performing the plate load tests are presented in Fig. 5-8. As shown in Fig. 5, ultimate bearing capacity obtained by tangent intercept method for unreinforced soil was found as 254 kPa. Marginal settlment was obsrved during the initial loading, while it showed a rapid increase after 200 kPa loading. Local shear failure was observed in the case unreinforced soil.

The stress-settlement behaviour of C-geogrid and P-geogrid are presented in Fig.6 and Fig.7, respectively. The ultimate bearing capacities were obtained as 312 kPa and 293 kPa, respectively. The stress-settlement behavious of reinforced soil shows ductile nature of the composite material due to inclusion of geogrid. The test was discontinued after 24 mm and 22 mm of bearing plate settlement for C-geogrid and P-geogrid, respectively. However, sudden increase in the settlement of the plate was missing. The ultimate bearing capacity was obtained pertaining to the last two readings by tangent intersection. Comparing the results of reinforced soil with unreinforced soil, bearing capacity of soil was increased by 22% and 15% due to provision of C-geogrid and P-geogrid.

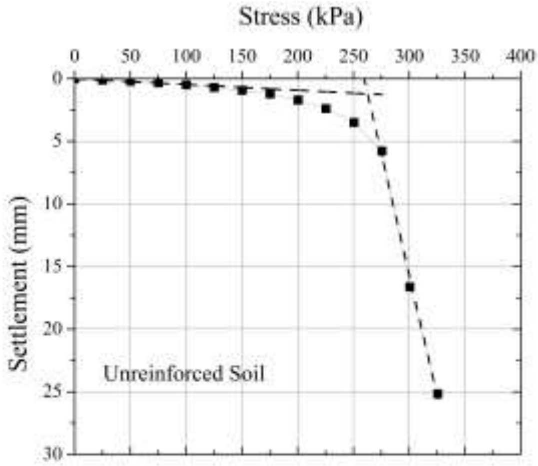

Figure 5. Stress – Settlement behavior of Unreinforced Soil

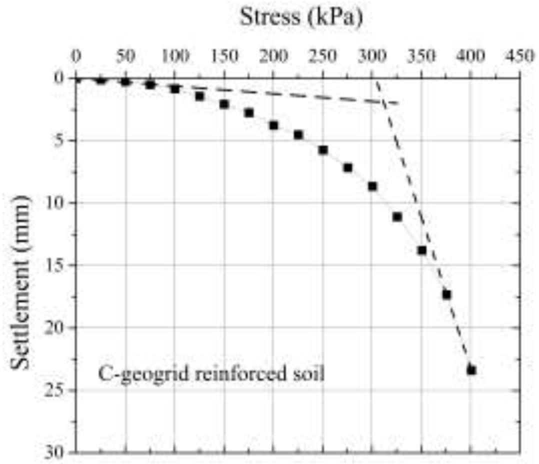

Figure 6. Stress – Settlement behavior of C-geogrid reinforced Soil

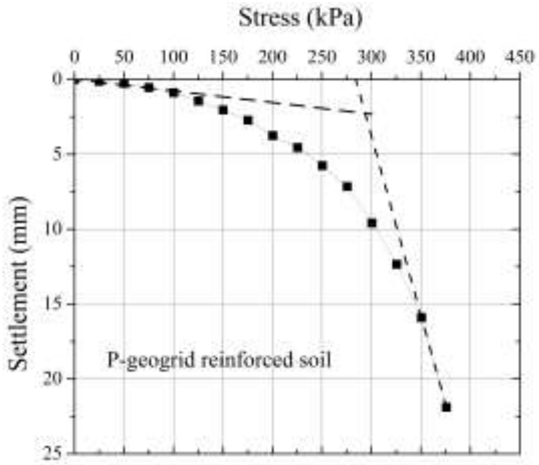

Figure 7. Stress – Settlement behavior of P-geogrid reinforced Soil

Further, to produce 1 m^2 plastic geogrid, about 48 bottles were required to cut down to plastic strips. Hence, if it is required to use waste plastic geogrid as reinforcement for an area of 30 acres (121406 m^2), about 5827488 waste bottles can be reused. Considering cost of geogrid as Rs. 70 -100 per m^2 (\$1.1 to \$1.5), whereas the cost of waste bottle collection, shredding and cost of adhesive to join the plastic strips is Rs. 28 (\$ 0.4) per m^2. It clearly means that as compared to C-geogrid, the use of P-geogrid can reduce the budget allotted to geogrid by about 60%. Further, the projects which require lower improvement in the bearing capacities, provision of P-geogrid can be one of the potential application for reuse of waste plastic bottles (PET bottles).

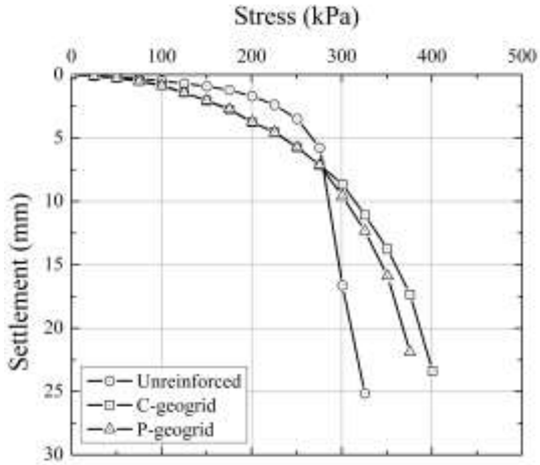

Figure 8. Combined Stress – Settlement behavior

5 CONCLUSIONS

Following are the major conclusions derived from the present studies:

- The ultimate bearing capacity of unreinforced soil was found as 254 kPa. While the ultimate bearing capcities for soil reinforced with C-geogrid and P-geogrid were obtained as 312 kPa and 293 kPa, respectively.
- Provision of geogrid increased the ultimate bearing capacity of soil by 22% and 15% for C-geogrid and P-geogrid, respectively.
- Provision of the reinforcement increases the ductility of the reinforced soil.
- As compared to C-geogrid, the use of P-geogrid can reduce the budget allotted to geogrid by about 60%.

6 ACKNOWLEDGEMENTS

Authors are thankful to Arijit Samanta, Shubham Mishra, Akash Gupta and Nipun Verma for helping in performing the experimental studies.

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