Chapter 10
Geocell Applications in Stabilizing Waste Materials for Sustainable Pavement Constructions

M. N. Asha and V. Divya

Abstract Utilization of waste materials for infrastructure development has become a sustainable solution for waste management. However, assessment of the suitability of these materials for construction has become a challenge. The present paper explores the potential of using four different waste materials in unreinforced and reinforced conditions for highway construction. The different waste materials considered are demolition waste, pond ash, quarry dust and tyre shreds. For reinforcing the waste materials, geocell reinforcement is used. The experimental studies were conducted in a steel tank 750 mm × 750 mm in plan, using plate load test set up. The test arrangement consists of geocell reinforced sections of 100 mm height prepared over a cohesionless fill of 400 mm height at 85% relative density. Since tyre shreds are compressible in nature, they are used along with quarry dust in three different volume proportions. The pressure versus settlement responses for both reinforced and unreinforced sections are studied. Among the various waste materials tested, it is observed that pond ash proves to be a suitable material for pavements as they sustain higher bearing pressure and reduce the surface heave extensively.

Keywords Demolition waste · Pond ash · Tyre shreds · Quarry dust · Geocell

10.1 Introduction

Infrastructure development is reflective of the growth of a country, but to support such a growth availability of construction materials is very important. Strong and stable in situ soil is also one of the requirements for this rapid development. However, the foundation soil may not be strong to support this hasty growth which has led to the development of innovative materials, methods and technologies for stabilizing the

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T. G. Sitharam et al. (eds.), *Geocells*, Springer Transactions in Civil and Environmental Engineering,
https://doi.org/10.1007/978-981-15-6095-8_10

in situ ground. Development of technology is always associated with the generation of tonnes of waste materials and managing the same has become a major challenge. Hence, the development of sustainable and cost-effective solutions for waste management is essential to maintain the overall balance of the eco-system. Extensive research studies are happening to find suitable alternative construction materials which impact the ecosystem in a positive way. As a result, reliable substitutes have found its way for various construction-related activities. Leverage of waste materials as backfill material in retaining walls, stabilizers in embankment construction or as admixtures in concrete are different examples of this.

The different waste materials that are getting accumulated in the landfills by virtue of infrastructure development or rapid increase in population or imbalance in ecosystem include plastic wastes, construction waste, e-waste, domestic and commercial wastes, animal wastes, biomedical wastes, industrial solid wastes, biodegradable wastes and so on. The last two decades have witnessed an enormous growth in the number of vehicles plying on the road. As a by-product of this growth, disposal of scrap tyres has also become an alarming concern in waste management. Recent years have witnessed extensive research towards deploying the different waste materials for different sustainable constructions.

Fly ash and bottom ash are the by-products of thermal power plants. The pond ash is a waste product obtained from the wet disposal of the fly ash, which when gets mixed with bottom ash is disposed off in large pond or dykes as slurry. Over the last two decades, research studies have been carried out to investigate the properties of the ashes generated. The suitability of fly/bottom ash mixtures as fill materials in highway embankments was investigated by Kim et al. (2005). According to Pandian (2013), fly ash by virtue of its low specific gravity, free-draining properties and high frictional angle (greater than 30°) makes it suitable for geotechnical applications when used in combination with other additives. Saride and Dutta (2016) have reported that fly ash can be used for stabilization of expansive soils and it is used as an admixture in such soils increases its shear modulus and decreases the damping ratio irrespective of curing. Jakka et al. (2010) have studied the shear behaviour of pond ash to assess its liquefaction resistance. Ghosh (2009) has studied the possibility of stabilizing pond ash using lime and phosphogypsum which extends its application for road base and subbase construction. Kumar and Gupta (2016) have studied the effect of addition of pond ash, rice husk ash, cement and fibres on strength characteristics of clay. The studies revealed the potential of using pond ash as a lightweight fill material in the construction of various structures.

The suitability of recycled construction and demolition materials as alternative pipe backfilling materials for storm water and sewer pipes was studied by Rahman et al. (2014). Cardoso et al. (2016) have carried out a comprehensive review on the use of recycled aggregates derived from construction and demolition waste. From their review, it was observed that pavements constructed using recycled aggregate exhibit high CBR and resilient moduli over time; however, the permeability characteristics of the matrix containing recycled aggregate need to be further investigated.

Use of waste rubber tyre shreds for civil engineering application has several advantages. Some of its advantages are its lightweight, cost-effectiveness, easiness to compact, free-draining property and incompressibility. Additionally, this use is beneficial to the environment since a waste material is recycled and reused. Stiffness and strength properties of tyre shreds and rubber sand were studied by Lee et al. (1999) through laboratory tests. The analysis indicated that the performance of rubber sand was satisfactory when compared with that of sandy gravel and make it suitable as a backfill material. Hazarika et al. (2012) have reported that the tyre shreds should be used in combination with sand and can decrease the shear strain which makes it a potential material of earthquake-resistant constructions. The low specific gravity of tyre shreds decreases the lateral earth pressure and hence lower design requirements (Reddy and Krishna 2017).

Geocells are strong three-dimensional systems fabricated from high-density polymers. These expandable panels open up more avenues of applications in the field of geotechnical engineering ranging from providing strength to geo-systems to protection against erosion. The concept of lateral confinement of geocells was developed by the Army Corps of Engineers in the late 1970s for rapid roadway/runway construction (Webster 1979). The strength properties of geocell–soil composite systems and the frictional resistance of the infill were studied by Bathurst and Karpurapu (1993). Since then many researchers have been studying the effectiveness of geocell. Rajagopal et al. (1999), Saride (2005), Tafreshi and Dawson (2012) are a few who have investigated the potential of using geocells for a wide variety of engineering applications. However, majority of the literature has reported the beneficial effect of geocell with the use of sand as infill in it.

The choice of infill for geocell or performance of geocell bed for different infill itself has been a topic of research. Hedge and Sitharam (2015) have studied the performance of three different infills, viz. aggregate, sand and red mud within the geocell. From the experimental and simulation studies carried out by them, it was reported the performance of geocells is immaterial of the type of infill because of marginal variations. Nair and Latha (2016) have investigated the performance of geocell beds with granular sub-bases. Pokharel et al. (2010) have studied the performance of single geocell for two different bases, viz. Kansas River sand and quarry dust to investigate the effect of fines in the geocell performance. Thakur et al. (2012) have reported that the use of recycled asphalt pavement along with geocell offers a stable base course over weak subgrade, and the infill density is critical as far as the performance of geocell is concerned. Dutta and Mandal (2017) have reported the effectiveness of a composite system comprising of geocell encased flyash column along with a geocell mattress in stabilizing foundation beds. In their study, the sustainable use of two different waste materials, viz. plastic bottles and flyash, has been explored. Arulrajah et al. (2013) have studied the viability of using three different types of construction and demolition waste, viz. recycled concrete aggregate, crushed brick and reclaimed asphalt pavement, when used in combination with geogrid. Han and Thakur (2015) have reported that use of waste materials like recycled asphalt pavement, recycled aggregate and recycled ballast when used in combination with geosynethtics can reduce horizontal and vertical settlements with reduced creep and permanent deformations. Xiao et al. (2012) have reported the uses of tyre derived aggregates in combination with geogrids as backfill has higher seismic resistance against conventional granular backfill. Latha et al. (2010) have reported that performance of tyre shred embedded road section is in par with that of geotextile reinforced sections.

From the literature review, it can be summarized that geocells are quite effective in stabilizing subgrade soil. At the same time, over the years researchers have been using different waste materials for sustainable constructions. In this paper, the viability of using waste materials in combination with geocell reinforcement has been studied. The various waste materials considered for the present study are quarry dust, demolition waste and tyre shreds. Since tyre shreds are compressible in nature, they are used along with quarry dust in three different volume proportions. Model plate load tests have been carried out on the unreinforced and reinforced beds to investigate the performance improvement of the geocell reinforced beds.

10.2 Methodology

The methodology adopted in the present experimental study can be sequenced as follows:

1. Characterization of raw materials
2. Design of dimensions of the testing facility
3. Development of test set-up
4. Design of test sections
5. Performance evaluation of geocell reinforced beds over unreinforced ones
6. Discussions and conclusions

10.3 Characterization of Materials

The different materials used in the present study are

1. White sand
2. Quarry dust
3. Demolition waste
4. Pond ash
5. Tyre shreds
6. Geocell reinforcement

The properties of the different materials used in the experimental studies are given below.

10.3.1 White Sand

While preparing model sections, the white sand was used as the foundation material. All the unreinforced and reinforced beds were prepared over this bed. The maximum and minimum dry unit weights of white sand were determined as per IS 2720 (Part 14) 1983 and were recorded as 1760 kg/m^3 and 1400 kg/m^3, respectively. The material had a specific gravity of 2.58 with an angle of internal friction of 24.22° as determined from direct shear tests at a density of 1600 kg/m^3.

10.3.2 Quarry Dust

Quarry dust used for the experiments was collected from a nearby quarry. The quarry dust (QD) used for the study was uniformly graded and had an effective size of 0.42 mm with a specific gravity of 2.55. The maximum and minimum dry unit weights of quarry dust were recorded as 1940 kg/m^3 and 1460 kg/m^3, respectively. The material had an angle of internal friction of 32.33° and cohesion of 7.83 kPa as determined from direct shear tests at a unit weight of 1850 kg/m^3.

10.3.3 Demolition Waste

Demolition waste used for the studies was collected from a nearby site. The construction used for the experimental studies mainly comprised of plaster waste. The waste was crushed in the laboratory such that it had an average size of 2 mm. The maximum and minimum dry unit weights of quarry dust were recorded as 1829 kg/m^3 and 1293 kg/m^3, respectively, with a specific gravity of 2.67. The material had an angle of internal friction of 45.4° and cohesion of 1.84 kPa as determined from direct shear test.

10.3.4 Pond Ash

Pond ash used for the experiments was uniform graded and had a specific gravity of 1.86. It was mixed with 16% of water content and compacted at dry density of 1375 kg/m^3 (85% relative compaction). The material possessed an angle of internal friction of 27.47° and cohesion of 2.81 kPa as determined from direct shear test.

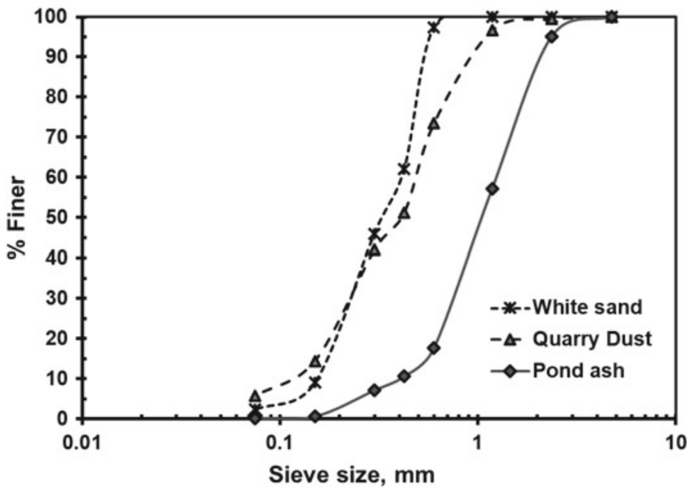

Fig. 10.1 Gradation curve for white sand, quarry dust and pond ash

10.3.5 Tyre Shreds

Tyre shreds used for the experiments had an average size of 2 mm × 5 mm with a specific gravity of 1.18. Since tyre shreds have high compressibility, in the experimental studies they were used in combination with quarry dust. Tyre shreds were mixed with quarry dust in three different volume proportions, viz. 2.5, 5 and 7.5%, such that the mixture had a density of 1850 kg/m^3. The grain size distribution curve of the different materials used in the experimental studies is presented in Fig. 10.1. Photograph of the different material used for the experimental study is shown in Fig. 10.2. Summary of the different properties is presented in Table 10.1.

10.3.6 Geocells

A geocell is an array of lightweight containment cells resembling a honeycomb structure which is usually filled with granular infill. When subjected to vertical pressure, the confined cohesionless infill within a geocell induces lateral stresses and thereby causing it to deform laterally. But this lateral deformation is restricted, the adjacent cells are also full with infill material. The generation of high hoop strength of the geocell wall along with frictional resistance developed along the wall constrains the lateral movement of the infills and offers a higher stability to the bed. This process increases the shear strength of the confined soil, hence creating a stiff mattress, which helps in distributing load over a wider area. This horizontal stress acting normal to the cell wall increases the vertical frictional

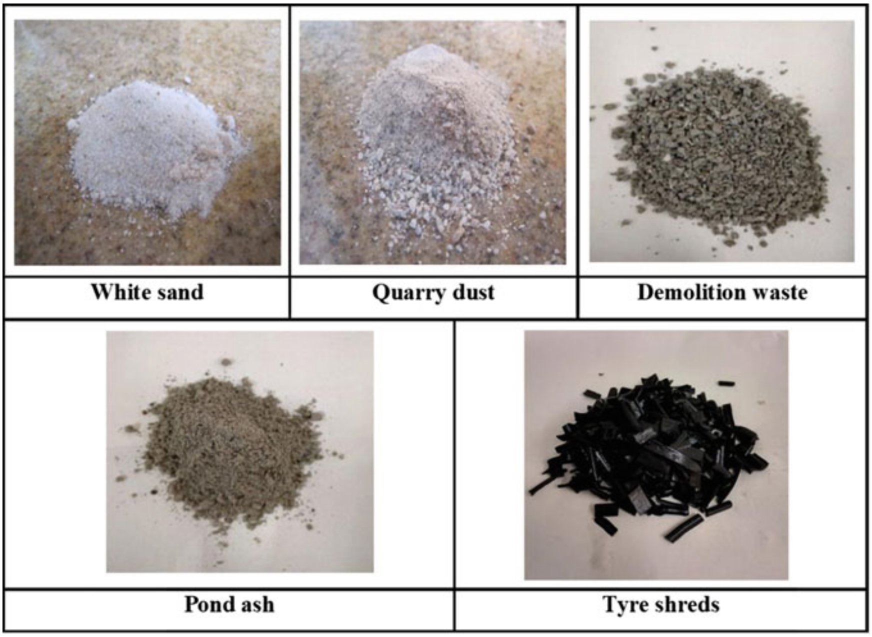

Fig. 10.2 Photograph of the different materials used for the experimental studies

Table 10.1 Properties of the different materials used in the study

Property	Material			
	White sand	Quarry dust	Construction waste	Pond ash
Specific gravity	2.58	2.55	2.67	1.86
Maximum density (kg/m^3)	1760	1940	1829	1375[a]
Minimum density (kg/m^3)	1400	1460	1293	–
Shear parameter, c, in kPa	0	7.83	1.84	2.81
Shear parameter, φ in degrees	24.22	32.33	45.43	27.47

[a]Due to the presence of fines, compaction test was carried out on pond ash and a maximum dry density of 1375 kg/m^3 was obtained at an optimum moisture content of 16%

resistance between the infill and the geocell wall, which in turn diminishes the stress applied to the ground below geocell.

Commercially available geocells were used in the experimental studies. The geocells used were perforated on the sides and had a pocket size of 330 mm × 170 mm (when expanded) with a weld thickness of 30 mm. The geocell specimen had target seam strength of 14.2 kN/m (as provided by the supplier).

10.4 Design of Dimensions of the Testing Facility

The dimensions of the testing facility have been decided on the basis of an extensive literature review. In the model tests on road sections carried out by earlier researchers (Palmeria and Antunes 2010; Hedge and Sitharam 2015), the length/width of the tank was at least equal to 5 times the size of the loading plate, whereas height of the fill inside the tank was 2.7–5 times the size of the loading plate. In the present study, the dimensions of the tank and the loading plate were decided such that it conforms with the literature and there exists no interference with the boundary, i.e. width of tank is 5 times the size of the plate and height of fill is 4 times the size of loading plate. The thickness of the different model sections has also been designed in accordance with the literature.

10.5 Development of Test Setup

Experimental studies were carried out in a steel tank of 750 mm × 750 mm in plan and 620 mm height. White sand was used as the bottom fill in all the experiments for a total thickness of 400 mm. Bottom fill was filled in the test tank in 4 layers, each of 100 mm thickness at 85% relative density. Over white sand, the overlying fill was filled in three layers comprising of two bottom lifts of 50 mm thickness and one top lift of 20 mm thickness (total 120 mm thickness). Compaction of the fills was done using rammer, and the number of blows and height of fall was adjusted such that prescribed density will be achieved. After preparing each layer, the surface was checked for its horizontality using a levelling head. Figure 10.3 presents the schematic of the model section.

The reinforced sections were prepared by placing the geocell at the interface and then stretching in position with the help of weights or blocks. The geocell was filled with different waste materials to one-third height initially as shown in Fig. 10.4. Progressively, it was filled to two-third height and then finally after removing the weights or blocks, the pockets were filled to the full height. For preparing infills within geocell, the rammer was used.

Static loading was applied to the model sections using a loading plate of 150 mm diameter and 12 mm thickness. Vertical settlements of the plate were measured using 50 mm dial gauge, and to measure surface heave, two dial gauges were placed at a distance of 190 mm from the centre. Figure 10.5 presents the instrumented model section in which construction waste is used as infill.

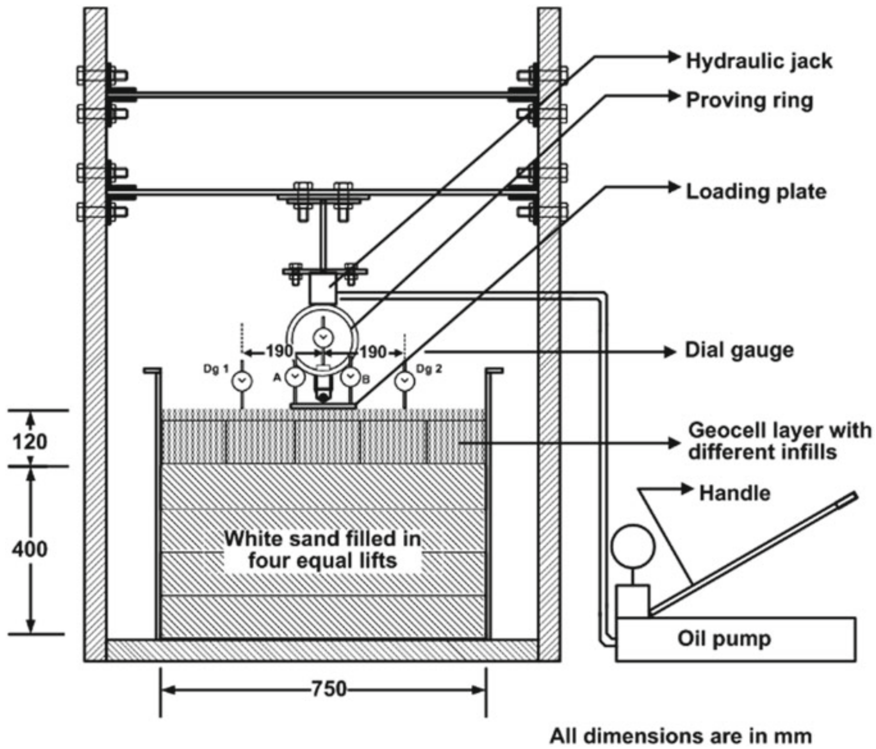

Fig. 10.3 Schematic of the test set-up

10.6 Design of Test Sections

In all the model tests carried out, the underlying foundation remained the same, viz. 400 mm thick bed of white sand. Different tests were planned by varying the infills in the geocell layer. The test plan adopted for the present study, and the abbreviations used are presented in Table 10.2.

The performance of different test sections is analysed by comparing the bearing pressures sustained with respect to settlement. Surface heave and improvement factors developed in the different sections are also studied to compare the effectiveness of geocell. From the experimental studies, an optimum percentage of tyre shreds are also arrived at. Efforts are made to understand the mobilization of tensile strength of these sections over higher deformations.

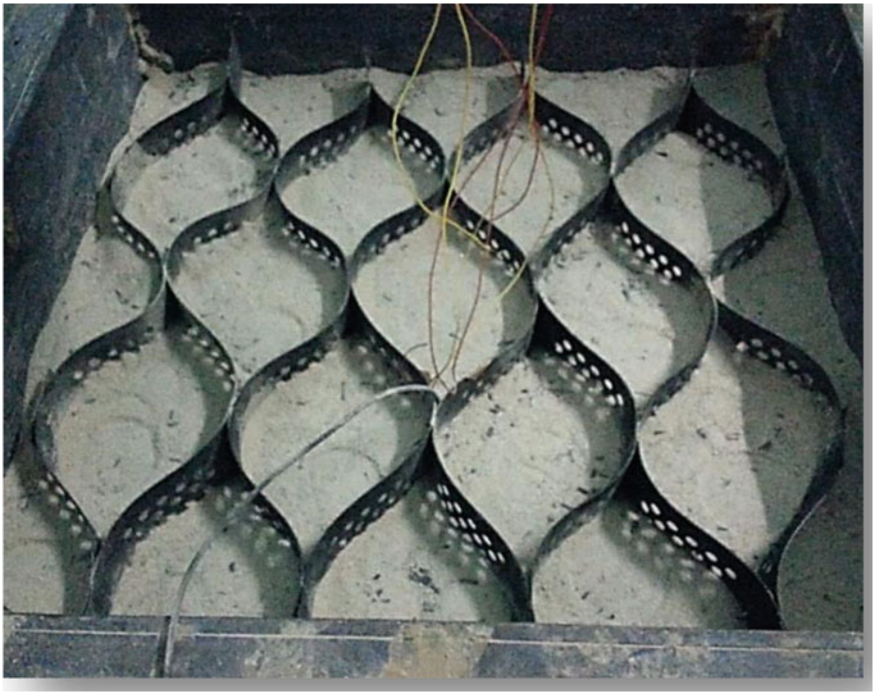

Fig. 10.4 Expanded form of geocells used in the experimental studies

10.7 Results and Comparisons

10.7.1 Optimum Percentage of Tyre Shreds

The proportion of tyre shreds added to the quarry dust was decided on the basis of the literature review. From the literature, it is observed that in most of the cyclic/repeated tests carried out on tyre shred embedded sections, the percentage of tyre shreds added range from 10% to 50 (Hataf and Rahimi 2006; Reddy and Krishna (2017), whereas in most of the static tests carried out on tyre shred embedded beds the percentage of tyre shreds was maintained less than 10% (Özkul and Baykal 2007; Cabalar et al. 2014).

Figure 10.6 presents the pressure versus settlement relationships for quarry dust (QD) mixed with different percentages of tyre shreds (TS). From the figure, it is observed that the pressure–settlement relationship is almost the same for a settlement up to 5 mm. However, beyond 5 mm there is a slight difference in the settlements of the different sections. On increasing the percentage of tyre shreds, it is observed that the pressure sustained by the model section increases and the settlement of the sections also increases. High settlements are not desirable as far as any construction is concerned because allowable bearing capacity is dependent on both shear and

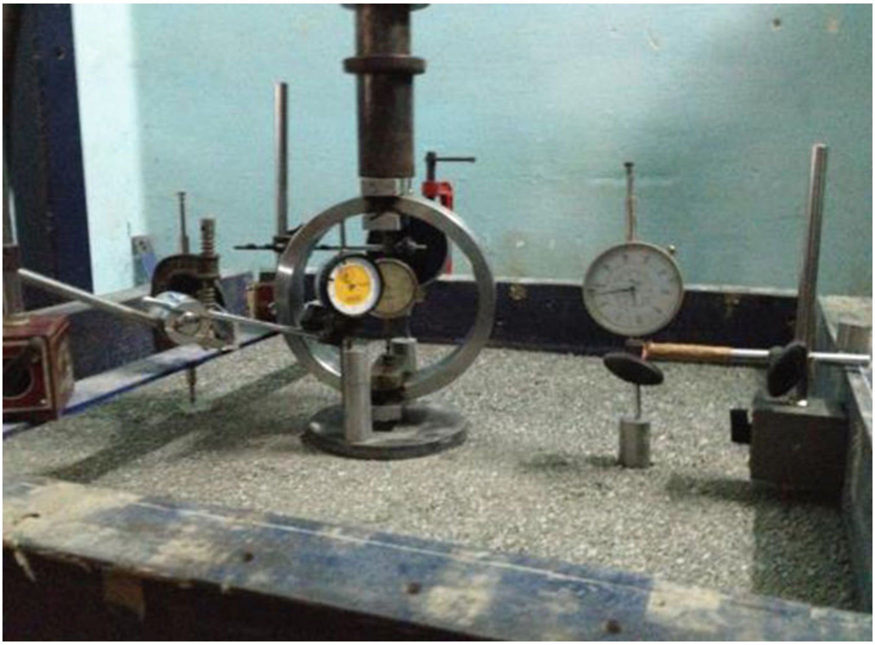

Fig. 10.5 Instrumented model section with construction waste as overlying fill

Table 10.2 Test plan and the abbreviations used

S. No.	Details of tests carried out with respect to different base courses or infills	Abbreviations
1	Quarry dust with 0% Tyre shreds	QD + 0% TS
2	Quarry dust with 2.5% Tyre shreds	QD + 2.5% TS
3	Quarry dust with 5% Tyre shreds	QD + 5% TS
4	Quarry dust with 7.5% Tyre shreds	QD + 7.5% TS
5	Demolition waste	DW
6	Pond Ash	PA

settlement criterion. For any settlement, the pressure sustained by 5% tyre shreds is the highest. Hence, the optimum percentage of tyre shreds was decided as 5% in the later tests with geocell confinement.

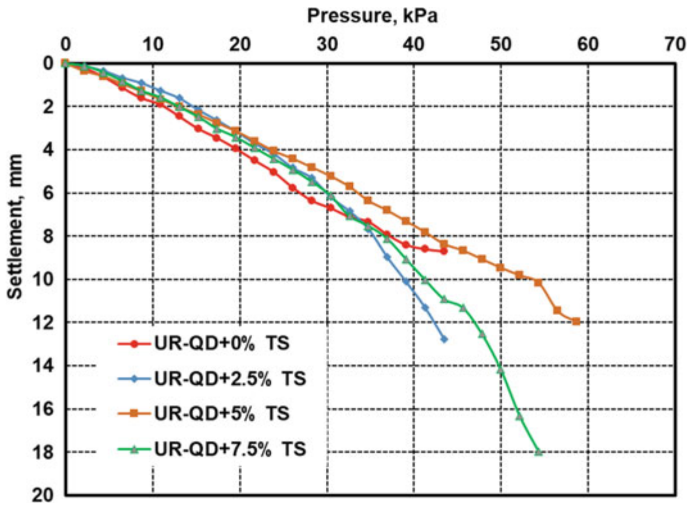

Fig. 10.6 Pressure–settlement relationship for quarry dust mixed with different percentages of tyre shreds

10.7.2 Effect of Geocell Confinement on Different Waste Materials

For comparing the effectiveness in stabilizing waste materials, four different waste materials are considered as infills, viz. geocell with quarry dust (R-QD), geocell with quarry dust and 5% tyre shreds (R-QD + 2.5% TS), geocell with demolition waste (R-DW), geocell with pond ash (R-PA). Figure 10.7 compares pressure versus settlement response for geocell reinforced model sections. From the figure, it is observed that demolition waste had higher bearing resistance compared to pond ash. However, the beneficial effect of geocell is more for pond ash.

To quantify the effectiveness of geocell in reducing surface heave and settlement, the different model sections have been compared, viz. UR-PA, R-PA, UR-QD + 5%TS and R-QD + 5% TS, and the result is presented in Fig. 10.8. In the figure, D represents the width of the footing. This graphical representation helps us to compare the surface heave induced for unreinforced and reinforced sections with respect to settlements. Here, comparisons are made with reference to normalized surface heave and normalized surface settlement (Saride 2005).

As expected the geocell was quite effective in reducing the vertical settlement and surface heave. However, the extent of this improvement is dependent upon the properties of infill. From Fig. 10.8, it is observed that the heave and settlements are more in tyre shreds when compared to pond ash. The geocell is effective in arresting heave completely in the case of pond ash. In the case of tyre shreds, also the effectiveness of geocell is there but the heave induced is more than pond ash.

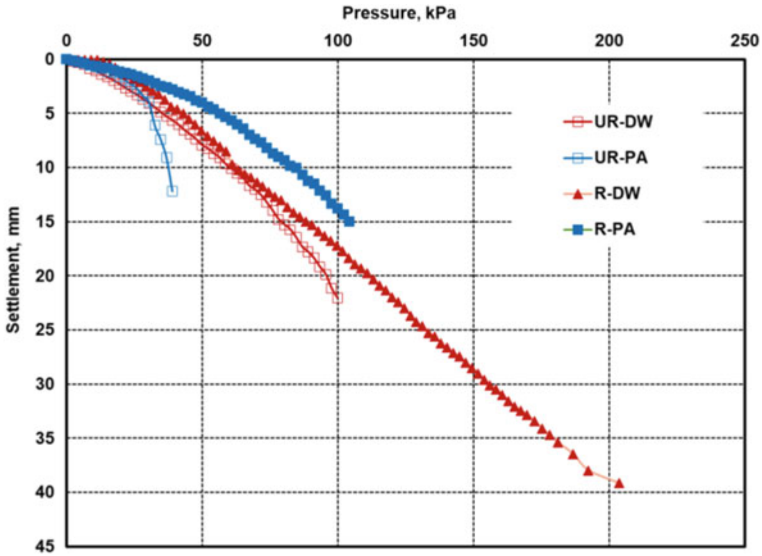

Fig. 10.7 Pressure versus settlement graph for unreinforced and geocell embedded model sections for two different infills

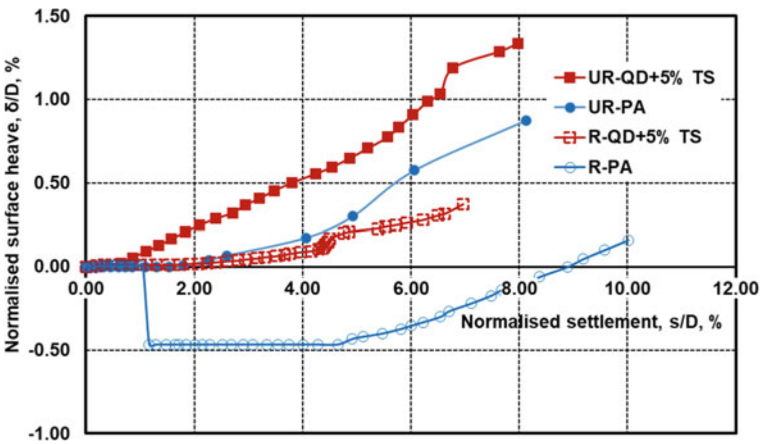

Fig. 10.8 Normalized surface heave versus normalized settlement curves for unreinforced and geocell embedded model sections of quarry dust with 5% tyre shreds and pond ash as infill

This is because pond ash has low specific gravity and the addition of moisture (@ 16% optimum moisture content) makes it more compressible.

10.7.3 Variation in Improvement Factor of Geocell Reinforced Sections

A dimensionless factor, I_f has been used extensively by researchers (Hedge and Sitharam 2015) to quantify the beneficial effect of geocell in arresting settlement and increasing the bearing resistance. It is defined as follows:

$$I_{\mathrm{f}} = \frac{q_{\mathrm{r}}}{q_{\mathrm{u}}} \tag{10.1}$$

where q_r is the bearing resistance of reinforced model section and q_u is the bearing resistance of unreinforced model section at the same settlement. Mobilization of geocell reinforcement can happen at high levels of displacement. Hence, it is important to know the settlement range at which geocells are effective for different infills. A comparison of the improvement factors over settlements has been made for different infills and is presented in Fig. 10.9. Geocell reinforcement increased the bearing resistance of all the sections seen in Fig. 10.9. The least improvement was exhibited by demolition waste (I_{f} in the range 1.5–1.2). The highest improvement was exhibited by pond ash (I_{f} in the range 1.4–2) but those sections exhibited high range of settlements. The inclusion of tyre shreds makes the quarry dust ductile. A comparison of the different materials concludes that geocell reinforced pond ash helps the system sustain more bearing pressure, and hence, serviceability criteria can be ensured by such systems even under high displacements.

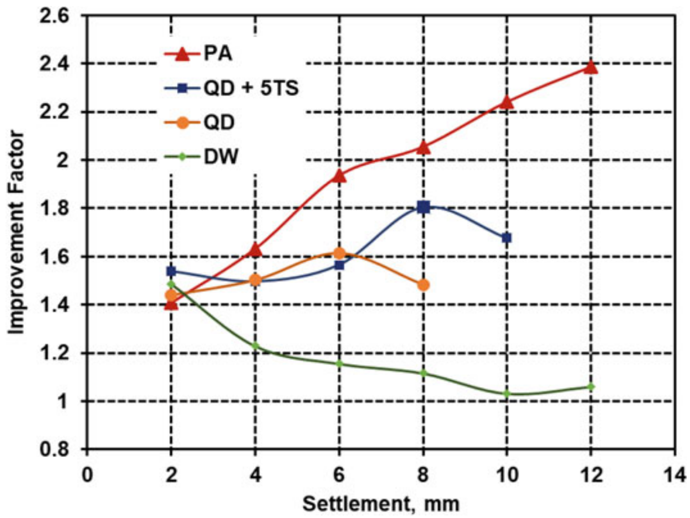

Fig. 10.9 Settlement versus improvement factor for geocell confined waste materials

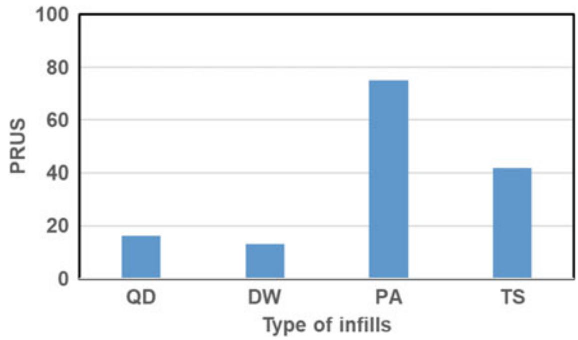

Fig. 10.10 Percentage reduction in ultimate settlement for different infills

10.7.4 Effect on Percentage Reduction in Ultimate Settlement (PRUS)

Many researchers have used the concept of percentage reduction in ultimate settlement for quantifying the benefit of geosynthetics. The percentage reduction in settlement can be estimated as follows:

$$\text{PRUS} = \frac{S_u - S_r}{S_u} \times 100 \tag{10.2}$$

where S_u is the settlement of unreinforced bed corresponding to ultimate bearing resistance and S_r is the settlement of reinforced bed corresponding to ultimate bearing resistance of unreinforced model section. The ultimate bearing resistance of the unreinforced bed is taken as the minimum of the following:

1. The bearing resistance corresponding to 10% of the foundation width (D) (Hegde and Sitharam 2015) or
2. The maximum bearing resistance sustained by the infill (wherein the infill could sustain a settlement less than 10% of the foundation width (D))

From Fig. 10.10, it is clear that the beneficial effect of geocell is high is for pond ash and this highlights the fact that for other waste materials especially for demolition waste and quarry dust, the beneficial effect of geocell is evident only at very large settlements. This is because of the large strains required for mobilizing the strength of the geocell.

10.7.5 Effect on Modulus of Sub-Grade Reaction (K)

Though there are different applications where these waste materials can be used, highway construction is one area where bulk utilization of these waste materials can be made. Modulus of subgrade reaction is a measure of the stiffness of subgrade, and

Table 10.3 Summary of modulus of subgrade reaction different sections

Material specification	Corrected value of modulus of subgrade reaction, k (KPa/m)		
	Unreinforced section (kPa/m)	Reinforced section (kPa/m)	$\frac{k_r}{k_u}$
Quarry dust	5600	8294	1.48
Quarry dust + 5% tyre shreds	6400	10,189	1.59
Pond ash	14,400	17,578	1.22
Demolition waste	8000	17,122	2.14

this property is used for the design of rigid or airfield pavements (Miura et al. 1990; Hedge and Sitharam 2015). Modulus of subgrade reaction is defined as follows

$$k(\text{kPa/m}) = \frac{q_{1.25}(\text{kPa})}{0.00125} \tag{10.3}$$

Table 10.3 compares the modulus of subgrade reaction of the different sections in unreinforced and reinforced condition. A comparison of the values reveals that all the waste materials considered are good substitutes for pavement construction. The modulus of subgrade reaction has increased with the embedment of geocell reinforcement. However, the increase in stiffness offered by geocell layer range from 1.2 to 2.2. The modulus of subgrade reaction of reinforced sections has not exhibited an enormous increase at a deformation of 1.25 mm.

10.8 Analysis and Discussions

Since the inception of the technology of using cellular confinement or geocell for soil stabilization, researchers have been carrying out parametric studies with reference to type of the material used for making geocell, types of infills, its shape, its configuration, its position in the foundation bed, field application and so on. This paper offers the advantage of comparing the performance of geocells with respect to two different parameters as listed below:

1. Effectiveness of geocell as a reinforcing material.
2. Effectiveness of different waste materials.

10.8.1 Effectiveness of Geocell as a Reinforcing Material

Geocells have been found to be effective for most of the infills. However, the effectiveness of geocells is dependent upon the infills. For instance, Bathurst and Karpurapu

(1993) have reported that the peak friction angle of the infill decides the performance of the geocell. Similarly, the effectiveness of geocell is dependent upon the shear strength of the foundation bed. For weak foundations like the one made of soft clay, the performance of geocell reinforced beds is more effective when compared to that of strong foundations. For example, in the studies reported by Hedge and Sitharam (2015), the subgrade modulus increased by 8 times when the foundation bed is of soft clay. However, in the present study, the increase in stiffness ranges from 1.2 to 2.2 (similar to Pokharel et al. 2010) because the foundation bed is comparatively strong (made of white sand). Performance of such reinforced beds is dependent upon the relative stiffness of the stabilized bed and the underlying foundation soil.

10.8.2 Suitability of Different Waste Materials

Majority of the literature work discusses the application of geocells with sand as the infill. However, in the last decade few literatures have been reported, that emphasize on the use of geocells for stabilizing waste materials. However, the reinforcing action of geocells is dependent mainly upon the infills. Vieira and Pereira (2015) have reported that the recycled aggregates have very high frictional resistance. But such materials undergo large amount of crushing on repeated loading. This crushing can cause an increase in the fines to present and tend to reduce friction angle. This could be the reason for decrease in the improvement factor of the geocell reinforcement with demolition waste as infill in the present study.

Similarly, pond ash used for different studies can vary in size. Jakka et al. (2010) have investigated the liquefaction resistance of ash collected at different points of ash pond. From the experimental studies, it has been reported that the ash collected at the inflow point is coarser and the shear behaviour of such materials is almost in par or better than that of sand. On the contrary, the ash collected at the outflow point is finer and their performance is inferior to that of the sand itself. In the present study, the pond ash selected in the study is coarser, and probably, this could be the reason for the better performance of pond ash.

According to the literature, the presence of moisture can impair the performance of reinforced bed which is indirectly related to the fines present. The presence of fines increases the apparent cohesion of the infill (Pokharel et al. 2010). Similarly, Hedge and Sitharam (2015) have reported that the use of coarser infill like aggregates ensures a better performance of geocell reinforced bed when compared to sand or clay. In the present study, for all the waste materials the fine percentage was less than 7% and except pond ash all infills were placed in dry condition. Owing to the dust generated in pond ash, it was placed at 85% relative compaction. However, the performance of geocell bed is at the maximum for pond ash. This ensures that more than the presence of moisture, it is the grain size of the material that ensures its performance as an infill. However, further investigations are required on pond ash (microstructure and leachate studies) to study its potential in pavement bases which can be a promising solution to the waste generation from thermal plants.

Rao and Dutta [36] have reported that the inclusion of tyre chips in sand beyond 20% may cause a drastic increase in compressibility (owed to direct contact) and the vertical strains induced also decrease with decrease in the size of the chips. Also, they have reported that initial tangent modulus and secant modulus decreases with increase in the percentage of tyre shreds with the decrease being drastic at a percentage replacement greater than 5%. In the present studies, with the inclusion of tyre shreds there is an increase in the improvement factor and stiffness. However, a detailed study on the same is required for varying sizes and aspect ratios of tyre shreds for developing design guidelines on the same.

10.9 Conclusions

From the present experimental study, the following conclusions can be drawn:

- Use of quarry dust blended with tyre shreds in foundation beds sustains greater bearing resistance at less settlements (Fig. 10.6).
- Geocells are effective in reinforcing foundation beds and pavement bases (Fig. 10.7).
- Geocell reinforced beds are effective in reducing surface heave and settlements (Fig. 10.8).
- Among the different geocell infills, pond ash was considered to be the best with reference to improvement factor and percentage reduction in ultimate settlement, i.e. 75% (Fig. 10.10).
- Use of geocell as a reinforcing material in the foundation bed increases the stiffness of the foundation in the range of 1.2–2.2 (Table 10.3).
- The beneficial effect of geocell was evident in demolition waste at initial levels of plate settlement (Table 10.3). With the increase in plate settlement, this beneficial effect decreased (Fig. 10.9).

10.10 Scope for Future Study

A comparison of the present work with the literature reveals that there exist no design standards for construction with waste materials. However, further studies are required in this area before it can be applied to field. A review of the literature reveals that crushing of particles under static and cyclic loading needs further investigation. This is highly important as far as the use of demolition waste is concerned. Similarly, the presence of moisture in the infill also needs to be studied. These parametric studies along with detailed investigations of the frictional characteristics of infill can help the practicing engineer to make the right choice of infill and provide a sustainable solution for waste management.

Acknowledgements The authors would like to express their sincere thanks to Dr. G. Madhavi Latha for giving permission to utilize the facilities at the Indian Institute of Science, Bengaluru, to carry out the experimental studies. The authors are also thankful to the undergraduate students Mr. Fateh, Ms. Priya, Mr. Sashi and Mr. Khaja for providing support in conducting the experimental studies. Authors also appreciate the help extended by Mr. Anthony in performing the experiments.

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