IMPROVEMENT OF SHEAR STRENGTH OF CLAYEY SOIL USING RANDOMLY DISTRIBUTED PET BOTTLE STRIPS

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ABSTRACT

Waste plastics impart adverse environmental problems like clogging in drainage system and need of large space required for solid waste disposal in the metropolitan and over crowded cities. Recycling of plastic waste from water bottles is becoming one of the challenges worldwide. The bottled water is the fastest growing beverage industry in the world. Plastic bottle recycling has not kept pace with the dramatic increase in sale of virgin resin Poly Ethylene Terephthalate (PET) and the same are to reduce/reuse/recycle that has emerged as one of the important need for sustainable development. The introduction of randomly distributed plastic fibers in reinforcing soil has enabled geotechnical engineers to effectively use unsuitable soils as reliable construction material and foundation medium in a wide range of civil engineering applications for ground improvement, sub bases and sub grade preparation in building and road construction. In order to use waste plastic material as means of waste management an experimental work has been undertaken with one type of locally collected clayey soil and two types of amended soil (clayey soil with 10% sand and 20 % sand) reinforced with randomly mixed PET bottle strips of different percentages (varying from 0.5% to 2% by weight) with different values of aspect ratio (length/width) with constant width of 5 mm. The work has been done with the objective of examining the improvement of shear strength parameters of a clayey soil by mixing PET bottle strips. A series of triaxial compression tests were carried out adopting standard procedures on those three types of soil with different percentages of plastic strips with varying aspect ratio as mentioned. It is observed that angle of internal friction (ϕ) enhances with the elevated percentage of sand up to addition of 1 % of plastic strips by weight for values of aspect ratio (length/width) 1, 2 and 3. However beyond this value the angle of internal friction descends gradually, when other parameters do not vary. The present study provides an approach in improvement of strength of weak soil as well as in recycling plastic waste and also brings out change in shear strength parameters of soil with mixing of PET bottle strips in different proportions for its use in geotechnical engineering.

Key Words : Soil Improvement, Shear strength, Fiber reinforcement material, Recycling PET waste

INTRODUCTION

Waste and resource management is no longer the sole preserve of waste professionals, everyone in society has a role to play to some degree, particularly those involved in design and procurement. A better understanding of construction material will help Civil engineers, material consultants, surveyors, contractors, architects, planners, project managers and all other practitioners and researchers working with construction materials with the challenges that lie ahead, especially with regard to energy conservation. Green engineering is the process of using hardware and software technologies to reduce our impact on the environment. Through real-world measurement data, we can gain a better understanding of how we are consuming resources and receive insight into ways of improving efficiency, reducing waste and moving to cleaner alternatives.

Recycling plastic waste from water bottles has become one of the major challenges worldwide. The bottled water is the fastest growing beverage industry in the world. Plastic bottle recycling has
not kept pace with the dramatic increase in virgin resin (PET) sales and the last imperative in the ecological triad of reduce/reuse/recycle, has emerged as the one that needs to be given prominence. In 2007, it is reported a world’s annual consumption of PET drink covers of approximately 10 million tons and this number grows about 15% every year. On the other hand the number of recycled or returned bottles is very low. Hence, there needs to be concerted efforts in the reuse of plastic waste from water bottles and this study is in this direction.

The literature entail that the plastic water bottles can be recycled in the field of civil engineering as reinforcing material for ground improvement. The plastic waste amended soil behaves as reinforced soil, similar to fiber reinforced soil. The introduction of the soil reinforcing techniques will enable engineers to effectively use unsuitable in-situ soils as reliable construction materials in a wide range of civil engineering applications. Reinforced soil construction is an efficient and reliable technique for improving the strength and stability of soils.

The plastic waste results in improvement of soil response in the case of roads, buildings and embankments, soil being a natural resource, the quantity of soil can be reduced. Thus, it provides two beneficial advantages i.e. reuse of plastic waste materials and the other is the reduction in consumption of natural material like soil. In this proposed research, some aspects for recycling of plastic water bottles in the field of geotechnical engineering application as reinforcing material is taken into consideration.

In the recent years, several researchers are trying to develop solutions for the reuse of different types of wastes generated which has become one of the major challenges for the environmental issues in many countries. Wastes such as plastic waste tire shreds mixed with soil behave similar to fiber-reinforced soils and several researchers presented technique of using discrete fibers to enhance the strength of soil. Most of them used different types of fibers as reinforcing materials, such as natural fibers, glass fibers, plastic fibers, polypropylene and polyester fibers.

Experimental results reported by various researchers along with Sharma and Mane, Sivakumar Babu and Chouksey showed that the fiber reinforced soil is a potential composite material which can be advantageously employed in improving the structural behavior of soils. The tests were carried with different types of fibers in different proportions and the effects of fiber in improving strength and stability of soil were identified. Consoli et al. carried out an experimental study of the utilization of the polyethylene fibers derived from plastic wastes in the reinforcement of uncemented and artificially cemented sand and showed that the plastic waste improved the stress-strain response of uncemented and cemented sands. This is perhaps one of the earliest attempts advocating the use of plastic waste. Consoli et al. again proposed a field application for such materials designed for increasing the bearing capacity of spread foundations when placed on a layer of fiber-reinforced cemented sand built over a weak residual soil stratum. Consoli et al. carried out triaxial compression test on cemented and uncemented sand reinforced with various types of fibers to study the effect of fibers on mode of failure, ultimate deviator stress, ductility and energy absorption capacity. They observed that the inclusion of fibers changed the mode of failure from brittle to ductile.

Sivakumar Babu et al. presented the results based on numerical analysis of stress strain response of fiber reinforced sand. Numerical simulation results indicate that the presence of random reinforcing material in soils make the stress concentration more diffused and restricts the shear band formation. Numerical simulation results also indicate that pull-out resistance of fibers governs the stress strain response of random-reinforced soil. Sivakumar Babu and Vasudevan presented comprehensive experimental results using compacted soil-fiber specimens, with coir fibers randomly distributed in the soil specimen. Experiments were carried out for various fiber parameters such as fiber content, fiber length and fiber diameter. Results showed that the improvement in strength and stiffness response, reduction in compression indices, reduction in swelling behavior of soil. It is also observed that fibers reduce the seepage velocity of plain soil considerably and thus increase the piping resistance of soil. Based on critical state concepts, Sivakumar Babu and Chouksey...
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proposed a constitutive model to obtain stress strain response of coir fiber-reinforced soil as a function of fiber content. The above literature review clearly indicates that studies are available on the use of wastes from plastic water bottles are limited. The soil mixed with plastic waste is expected to behave as a fiber-reinforced soil. The patented procedures for the use of fiber-reinforced soil in the field are also available. To promote the recycling of plastic wastes on a large-scale in geotechnical applications where bulk utilization of waste materials is possible, in the present study, experimental results on stress strain response of plastic waster mixed soil are presented.

AIMS AND OBJECTIVES

The study includes experimental work with different proportions of plastic wastes. A series of unconfined compression (UCC), consolidated undrained (CU) and one dimensional compression tests were performed at four different percentages of fibers to determine stress–strain–pore water pressure and compression behavior of plastic waste mixed soil and observe the influence of plastic waste on shear strength of soil with various percentages at different confining pressures. The results indicate that the plastic waste mixed soils have higher strength than plain soil which is a useful consideration in the use of plastic waste in soil improvement.

MATERIAL AND METHODS

Clayey soil and plastic waste fibers

Soil is used in this study is a typical clayey soil used for routine construction in and around Kolkata, West Bengal State, India. The locally available sand of size between 0.425mm to 1.18mm was used at 10% and 20% by weight of clayey soil. The physical properties and compaction characteristics are given in Table 1.

Table 1 : Properties of soil

<table>
<thead>
<tr>
<th>Property</th>
<th>Soil type (adding sand with clayey soil)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A (0%)</td>
</tr>
<tr>
<td>Clay (%)</td>
<td>34</td>
</tr>
<tr>
<td>Silt (%)</td>
<td>59</td>
</tr>
<tr>
<td>Sand (%)</td>
<td>7</td>
</tr>
<tr>
<td>Liquid Limit (%)</td>
<td>54</td>
</tr>
<tr>
<td>Plastic Limit (%)</td>
<td>22.64</td>
</tr>
<tr>
<td>Plasticity Index (%)</td>
<td>31.36</td>
</tr>
<tr>
<td>Shrinkage limit (%)</td>
<td>18</td>
</tr>
<tr>
<td>Maximum Dry Density (gm/cm$^3$)</td>
<td>1.65</td>
</tr>
<tr>
<td>Optimum moisture Content (%)</td>
<td>19</td>
</tr>
<tr>
<td>Unconfined Compressive strength (kg/cm$^2$)</td>
<td>2.3</td>
</tr>
<tr>
<td>Cohesion (kg/cm$^2$),C</td>
<td>0.9</td>
</tr>
<tr>
<td>Angle of Internal Friction ($\phi$)</td>
<td>7$^\circ$</td>
</tr>
<tr>
<td>Modulus of Elasticity (kg/cm$^2$),E</td>
<td>13</td>
</tr>
</tbody>
</table>

Plastic waste fibers, obtained from local bazar, taking 2 litres kinley water bottles and cut into 5mm x 5mm, 5mm x 10mm and 5mmx15mm sizes of aspect ratio 1,2 and 3.The properties of plastic fibers are shown in Table 2.

Preparation of plastic fiber mixed soil samples

Clayey soil from the borrow area was air dried, oven dried and then sieved through 425µm sieve. Clayey soil and two types of amended soil(clayey soil with 10% sand and 20% sand) specimens were prepared with a optimum moisture content (moulding water content).Dry clayey soil of specified weight of plastic fibers(percent by dry weight of soil i.e.,0%,5%,1%,1.5% and 2%) was distributed uniformly over the wet soil and mixed uniformly. The fiber-soil mixture was then...
kept in a plastic bag for equilibration of moisture content of mix. The entire clayey soil-plastic fiber mixture was transferred to the Proctor cylindrical mould in three approximately equal layers and each layer was compacted by tamping to achieve a uniform density. Samples were drawn from the cylinder.

Table 2: Properties of plastic strips

<table>
<thead>
<tr>
<th>S/N</th>
<th>Test</th>
<th>Test method</th>
<th>Results obtained</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Average width</td>
<td>Measurement</td>
<td>5</td>
<td>mm</td>
</tr>
<tr>
<td>2</td>
<td>Average thickness</td>
<td>Measurement</td>
<td>0.5</td>
<td>mm</td>
</tr>
<tr>
<td>3</td>
<td>Average tensile strength</td>
<td>ASTM D638</td>
<td>184.80</td>
<td>Kg/cm²</td>
</tr>
<tr>
<td>4</td>
<td>Density</td>
<td>ASTM D792</td>
<td>1.38</td>
<td>g/cc</td>
</tr>
<tr>
<td>5</td>
<td>Water absorption</td>
<td>Absorption</td>
<td>nil</td>
<td>%</td>
</tr>
</tbody>
</table>

**Testing**

All the specimens were tested in a conventional triaxial apparatus under different confining pressures (ranging from 50KPa to 150KPa) in undrained condition. Load was applied at a controlled rate 1.2mm/minute until the specimen failed/strain of 20%, whichever was earlier. A total number of 117 tests were carried out for various confining pressures on unreinforced and reinforced samples at the fiber contents and the aspect ratios.

**RESULTS AND DISCUSSION**

**Variation of shear strength parameters with % plastic strips**

Both the shear strength parameters C and φ have been considered to study the alteration of shear strength of soil due to addition of plastic fiber mixes.

Variation of C with % of plastic strips have been presented in Fig. 1 for soils of three varieties of sample. Similarly variation of φ with % of plastic strips have been shown in Fig. 2 for soils of three varieties of sample. It was observed that shear strength(C) increases with increase of percentage of plastic strips upto1%. But beyond addition of 1% of plastic fiber, C decreases for aspect ratio 1 and 2. For aspect ratio 3, there was gradual reduction in value of C. Angle of internal friction (φ) increases with increase of percentage of plastic strips up to 1% of plastic strips. After addition of 1% of plastic strips, angle of internal friction decrease for aspect ratio 1, 2 and 3.

Optimum value occurs at aspect ratio 2 for shear strength. At aspect ratio of 3, φ increases up to 1% of plastic strips but there was an appreciable reduction in C, effectively the shear strength was reducing. Hence optimum value occurs at aspect ratio 2. (Fig. 3 to Fig. 6)

**Fig. 1**: % of plastic strip clayey soil with cohesion in Kg/cm²
Fig. 2: % of plastic strips clayey soil with 10% sand cohesion in Kg/cm²

Fig. 3: % of plastic strip clayey soil with 20% sand in cohesion in Kg/cm²

Fig. 4: % of plastic strips clayey soil with angle of internal friction
Fig 5: % of plastic strips clayey soil with 10% sand in angle of internal friction

As it can be seen from Fig.7, for every aspect ratio, as the percentage sand is increasing, the maximum shear strength is also increasing. This response is in accordance with the established fact that, Sand being a mechanically stable material, its addition to the cohesive soil viz., clay enhances its shear strength by way of contributing structural as well as frictional resistances. The Fig. 7, depicts the fact that, for the materials used in this study, the aspect ratio of 2.0 is found to be optimum in mobilization of the maximum shear strength. The aspect ratio influences the anchorage required for the reinforcement function that is responsible for the improvement in shear strength. The anchorage at an aspect ratio of 2.0 is found to be ideal than that of 1.0 and 3.0. It can be seen from Fig. 7, that the maximum shear strength is higher for higher percentage of sand admixed with clay, at every fiber content. This is coinciding with the mechanism observed for variation in aspect ratio. On the whole, the increase in sand content is contributing to an increase in Shear strength at every reinforcement level.

Fig. 6: % of plastic strips clayey soil with 20% sand in angle of internal friction
Interestingly, as it can be seen from Fig. 8 for every sand content, the maximum improvement in shear strength is found when the fiber reinforcement is 1.0 %. The lower percentage may have mobilized correspondingly lower level of reinforcement function. The higher percentage may have increased the fiber to fiber interaction than fiber to soil interaction leading to a drop in improvement level.

**CONCLUSION**

In this paper, an approach for the recycling of plastic waste from PET bottles as reinforcing material in geotechnical and civil engineering applications is proposed. To investigate the effects of plastic waste mixed in soil, series of triaxial compression (UU) tests have been performed with different percentages of plastic waste. The experimental results are presented in the form of $C$ and $\phi$. The experimental results show that there is appreciable improvement in the strength of soil with inclusion of plastic waste. This increase in strength of soil is due to increase in friction between soil and plastic waste and development of tensile stresses in the plastic waste. The optimum fiber content corresponding to maximum improvement in cohesion value is found to be 1% of plastic strips.
and optimum value comes at aspect ratio 2. At aspect ratio of 3, $\phi$ increases up to 1% plastic strips but there is an appreciable reduction in C, effectively the shear strength is reducing. Hence optimum value occurs at aspect ratio 2. The present study indicates that PET bottle strips may be used in case of preparation of subgrade for improvement of its strength but up to addition of 1% of plastic strips by weight and also up to aspect ratio of 2 within the ranges of soil considered in the study.

REFERENCES