A STUDY ON CBR BEHAVIOR OF WASTE PLASTIC STRIP REINFORCED SOIL

A.K. Choudhary1, J.N. Jha2* and K.S. Gill3

1Department of Civil Engineering, National Institute of Technology, Jamshedpur, India, E-mail: drakchoudharycivil@gmail.com
2Department of Civil Engineering, Guru Nanak Dev Engineering College, Punjab, India E-mail: jha@gndec.ac.in
3Department of Civil Engineering, Guru Nanak Dev Engineering College, Punjab, India E-mail: kulbirgillkulbir@yahoo.co.in

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The performance of paved and unpaved roads is often poor after every monsoon and, in most cases; these pavements show cracking, potholes, wheel path rutting and serious differential settlement at various locations. Therefore, it is of utmost importance considering the design and construction methodology to maintain and improve the performance of such pavements. Attempts have been made in the study to demonstrate the potential of reclaimed high density polyethylene strips (HDPE) as soil reinforcement for improving engineering performance of subgrade soil. HDPE strips obtained from waste plastic were mixed randomly with the soil. A series of California Bearing Ratio (CBR) tests were carried out on randomly reinforced soil by varying percentage of HDPE strips with different lengths and proportions. Results of CBR tests demonstrated that inclusion of waste HDPE strips in soil with appropriate amounts improved strength and deformation behavior of subgrade soils substantially. The proposed technique can be used to advantage in embankment/road construction.

Keywords: High Density Polyethylene, Pavement, Reinforcement, California Bearing Ratio.

1. INTRODUCTION

Nowadays, plastic containers usually made of high density polyethylene (HDPE) are being increasingly used for storage and marketing of various liquids. Most of these containers are specifically made for spot use, having short life span and are being discarded immediately after use. Though, at many places HDPE is being collected for recycling or reuse, however; the secondary markets for reclaimed HDPE have not developed as recycling program[1]. Therefore, the quantity of HDPE that is being currently reused or recycled is only a fraction of the total volume produced every year[2]. According to the data published by Environmental Protection Agency (US Environmental Agency 1992), the solid waste produced in the US in 1988 included 14.4 million tons of plastic occupying 20% by volume of available landfill spaces. Approximately 2.2 million tons of HDPE are produced annually and only 7% are currently being recycled. The estimated municipal solid waste production in India up to the year 2000 was of the order of 39 million tons per year. This figure is most likely to touch 56 million tons per year by the end of 2010[3]. The typical percentage of plastics in the municipal solid waste produced in India is around 1%[4]. One of the main reasons cited for 2005 Mumbai city flood was choking of drains by...
plastic wastes discarded/thrown indiscriminately by the users. The best way to handle such wastes is to utilize them for engineering applications. Some of the civil engineering uses of recycled HDPE include fence line posts of guard rail posts for highways[5] and light weight reinforcing inclusions in concrete[6]. Soil reinforcement technique can be a significant secondary market for waste HDPE to improve the strength of subgrade soils. This technique has been found effective and reliable method to improve the strength of subgrade soils[7]. A treated or stronger subgrade soils shall require relatively thinner section of a flexible pavement as compared to that of an untreated and weaker sub-grade resulting in significant cost advantage. Over the years, the use of geotextiles and other polymeric reinforcements such as geogrids has increased drastically in geotechnical engineering. However, in certain cases; especially for low cost embankment/road construction, their cost becomes a prohibitive factor for their wide spread use. In comparison with systematically reinforced soil, randomly distributed fiber reinforced soils exhibit some advantages. Preparation of randomly distributed fiber-reinforced soils mimics soil stabilization by admixture. Discrete fibers are simply added and mixed with soils, much like cement, lime or other additives. Randomly distributed fibers offer strength isotropy and limit potential planes of weakness that can develop parallel to oriented reinforcement. In recent years applications of nontraditional materials either natural or waste products have been tried in road construction in many developing countries[8]. Traditional inert materials are replaced with materials, which would otherwise be ecologically burdensome. Towards this end; randomly reinforcing the soil by using high density polyethylene strips obtained from waste plastic containers may provide an easy and sometimes an economical means to improve the engineering performance of subgrade soils. On the other hand, they are otherwise considered unsuitable and if found effective can also reduce the problem of disposal of this non biodegradable waste causing environmental hazards. Prediction of pavement performance becomes difficult if unconventional materials are used as a part of pavement structure[9]. Therefore, in the present investigation an attempt has been made to demonstrate the potential of reclaimed HDPE strips as soil reinforcement for improving the subgrade soils. The paper describes a series of CBR tests carried out with varying percentage of HDPE strips mixed uniformly with the soil. The results obtained from the tests were presented and discussed. It is also important to note that the choice of the California Bearing Ratio (CBR) test apparatus as the testing platform brings some inherent problems into the experimental study. Small size of the CBR test apparatus limits the size and amount of the fiber inclusion. End effects in such a small sample size can be more pronounced than that of the other large scale model tests. When materials having maximum particle sizes are to be tested, the test method provides for modifying the gradation of the material. The modified material may have significantly different strength properties than the original material. Despite these limitations, a large experience base has been developed using the CBR test and some satisfactory design methods are in use based on the test results.

2. BACKGROUND

Soil fiber composites have been found effective in improving the CBR value as reported in the literature[10-14]. These studies indicated that stress-strain-strength properties of randomly distributed fiber reinforced soil are a function of fiber content and aspect ratio. Considerable improvement in frictional resistance of fine grained soil was also reported by roughened HDPE[15]. In addition, use of polyethylene fiber (plastic waste) improved peak and ultimate strength of both cemented and un-cemented soil[16]. Strength and load bearing capacity of soil was enhanced considerably when the soil is stabilized mechanically with short thin plastic strips of different length and content[4, 7]. The feasibility of reinforcing soil with strips of reclaimed high density polyethylene has also been investigated to a limited extent[17,19]. It has been also reported that the presence of a small fraction of HDPE fiber can increase the fracture energy of the soil. Although, a few studies on the subject of engineering behavior of HDPE reinforced soil as described earlier are available in literature but a detailed study pertaining to its use in real life problems is still quite meager. In view of the above limited studies, present study has been taken up with special reference to its feasibility for application in embankment/road construction.

3. EXPERIMENTAL WORK

A brief description of the materials and methods [as per IS-2720-Part-XVI (1987)] used in this investigation is given in the following paragraphs:

Materials

Sand: Locally available sand collected from Kharkai River, Jamshedpur, Jharkhand (India) was used in this study having specific gravity of 2.62, mean particle diameter (D₅₀) of 0.55 mm, coefficient of uniformity (Cu) of 2.40 and coefficient of curvature (Cc) of 1.67. The grain size distribution of the soil is shown in Figure 1. The sand was classified as ‘SP’ as per the Unified Classification System. The maximum and minimum dry densities of sand as determined from the relative density test were 16.5kN/m³ and 14.6kN/m³ respectively.

HDPE: The waste plastic strips used in the present study were purchased from a rag picker, who collects recycling material from the waste dump around Jamshedpur, Jharkhand (India) at a price of INR 100 per kg (approximately $2 per kg). They are made of
HDPE having a width of 12mm and a thickness of 0.40mm. These were cut into lengths of 12mm [Aspect Ratio (AR) =1], 24mm (AR=2) and 36mm (AR=3). It is important to ensure that mould diameter remains at least 4 times the maximum strip length, which will ensure that there is sufficient room for the strips to deform freely and independent of mould confinement. The waste plastic strips to be added to the soil were considered a part of the solid fraction in the void solid matrix of the soil. The content of the strip is defined herein as the ratio of weight of strips to the weight of dry sand. The tests were conducted at various strip contents of 0.0%, 0.25%, 0.50%, 1.0%, 2.0% and 4.0%. In the absence of standards for testing strips, the standard used for wide width tensile strength test (ASTM D 4885) for geosynthetics were used. The tensile strength of 100mm long waste plastic strip was determined at a deformation rate of 10mm/min in a computer controlled House field machine. The average ultimate tensile strength of this strip was 0.36kN and percent elongation at failure was 23%.

Test Procedure

The experimental study involved performing a series of laboratory CBR tests on unreinforced and randomly oriented HDPE strip reinforced sand specimen. Specimens were prepared by compacting sand in dry state in three equal layers to a dry density of 16.2kN/m³ (corresponding to a relative density of Dr=85%) in a steel CBR mould of 150 mm diameter and 175 mm high. HDPE strip reinforced sand layers were prepared at the same dry density as that of unreinforced sand. Required amount of strips as well as sand for each layer were first weighed and then the strips were randomly mixed with dry sand and due care was taken so as to have a homogeneous mix. The mix was then transferred to the mould and a surcharge base plate 148 mm in diameter and weighing 25 N was placed over it in order to avoid segregation of strips during vibration. The sand was compacted in the mould by vibrating it on a vibration table for 2 minutes. Similar procedure was adopted for compacting other two layers in the mould. The tests were performed as per procedures described in IS-2720-PartXVI-1987[20]. A surcharge plate of 2.44kPa was placed on the specimen prior to testing. The loads were carefully recorded as a function of penetration up to a total penetration of 12.5 mm. Finally, load-penetration curves were drawn for each case and corrections were applied using the standard procedure. From the load-penetration curves so obtained california bearing ratio values as well as secant modulus (defined as the ratio of load in kPa at a penetration of 5.0 mm to the penetration of 0.005m) were determined. Since for all the cases considered in the present investigation, the CBR value at 5.0 mm penetration was observed higher than that of 2.5 mm penetration even on repetition. Therefore CBR values reported in the present investigation are those of 5.0 mm penetration.

4. RESULTS AND DISCUSSION

The most important engineering parameter to evaluate a sub-grade or sub-base materials for pavement design is the CBR value. Deformation of the soil specimen being predominantly shear in nature, the CBR value can be regarded as an indirect measure of strength[21]. The load-penetration curves obtained from the CBR tests for un-reinforced and randomly reinforced system with strip contents ranged from 0.025% to 4.0% for different aspect ratios (AR=1 to 3) are shown in Figure 2 through Figure 4. It can be observed from these figures that mixing of randomly distributed HDPE strips in sand increased the piston load at a given penetration considerably. The figures further reveals that the initial slope of the load-penetration curve is significantly improved due to the incorporation of strips in sand. It is also evident from these figures that inclusion of waste plastic increased the CBR value significantly.

Increase in the CBR value due to the presence of strip content has been expressed by a dimensionless term California bearing ratio index (CBRI) and has been defined as the ratio of the CBR value of reinforced soil (CBRr) to the CBR value of unreinforced soil (CBRu).
CBRI = CBRr/CBRu  \tag{1}

The CBR value of the unreinforced sand corresponding to 2.5mm and 5.0mm penetration were found to be 14.01 % and 18.88 % respectively as shown in Figure 2, which were increased to 24.23% and 29.20% respectively when sand was reinforced with 0.25% waste plastic strips having aspect ratio equal to 1. Further increase in strip content from 0.25% to 1% without changing the aspect ratio again enhanced the CBR value to 29.78% and 32.89% respectively corresponding to 2.5mm and 5.0 mm penetration. The trend remained unchanged even when the percentage of waste plastic strip content is further increased from 1% to 2% or 4% in the soil. The maximum value of CBR at 5 mm penetration is 41.65% when 4% waste plastic strip content having aspect ratio equal to 1 was mixed with the soil. Similar results have been observed for other values of aspect ratio as shown in Figure 3 and Figure 4.

Increase in strength of soil due to the inclusion of waste plastic can also be expressed in terms of piston load. Increase in piston load due to the presence of waste plastic strip has been expressed by a dimensionless term known as piston load ratio (PLR), which is defined as ratio of maximum piston load at12mm penetration for HDPE strip reinforced sand (Lr) to the maximum piston load at same penetration for unreinforced sand(Lu).

PLR = Lr/Lu  \tag{2}

Figure 5 reveals that the CBR value for 4 % strip content having 12 mm strip length is 41.65% but this value increased to 48.85% when strip length was increased from 12mm to 24 mm without changing the strip content. When the strip length was further increased to 36 mm again without changing the strip content, the value of CBR increased further from 48.85% to 54.89%. Increase in CBRI value of a reinforced system was found approximately 2.9 times as high as that of an unreinforced system as shown in Figure 6. A similar trend was also observed for other strip content.

The variation of CBR for strip reinforced sand with different strip lengths at various strip contents is shown in Figure 5. On the other hand, Figure 6 shows the variation of CBRI with different strip contents at various aspect ratios. The increase in CBRI is noticeably attributed to strip inclusion in the soil and strip length. Figure 5 reveals that the CBR value for 4 % strip content having 12 mm strip length is 41.65% but this value increased to 48.85% when strip length was increased from 12mm to 24 mm without changing the strip content. When the strip length was further increased to 36 mm again without changing the strip content, the value of CBR increased further from 48.85% to 54.89%. Increase in CBRI value of a reinforced system was found approximately 2.9 times as high as that of an unreinforced system as shown in Figure 6. A similar trend was also observed for other strip content.

Figure 5 Variation of California Bearing Ratio (CBR) with strip length at different strip content

![Figure 5 Variation of California Bearing Ratio (CBR) with strip length at different strip content](image1)

Figure 6 Variation of California Bearing Ratio Index (CBRI) with strip content at different aspect ratio

![Figure 6 Variation of California Bearing Ratio Index (CBRI) with strip content at different aspect ratio](image2)
and strip length. It can be also observed that the piston load of reinforced system having aspect ratio 3 is almost three times as high as that of an un-reinforced system.

The variation in secant modulus of strip reinforced sand with strip length at various strip content is shown in Figure 8. As expected the increase in secant modulus is noticeably attributed to strip inclusion in soil and strip length. For example, the secant modulus of the un-reinforced sand of 395.2MPa can be increased to 611.2 MPa when 0.25% of waste plastic strip having strip length of 12mm is added. When the strip content was increased to 2% without changing the strip length, the secant modulus became 712.9MPa. Similar trend was observed when strip content was further increased to 4%. Figure 8 further reveals that secant modulus also increases with the increase in strip length even when there is no change in the strip content. For example, when the strip length was increased from 24 mm to 36 mm without change in strip content, the secant modulus at 4 % strip content was increased from 1022.5 mPa to 1149.0 Mpa. A similar trend was also observed for other strip contents.

After the completion of each test, specimens were dissected and the strips were examined. Many of the strips showed elongation, thinning and clear impression of sand particles. Apparently, as the soil sheared during penetration, strip fixed in the sand by friction elongated as the soil deformed. Generally the CBR value at 2.5mm penetration is higher. However in the present study, the CBR value of HDPE strip reinforced sand at 5.0mm penetration are found to be higher than those at 2.5mm penetration. This indicates that at higher deformation the HDPE strip reinforcement is more effective in improving the strength of sand by increasing the resistance to penetration. The resisting action of the strips can be visualized by Figure 9 (a) and (b). In situation (a) the plunger pushes down particle ‘C’ to occupy position in between particle ‘A’ and ‘B’. The strip resists the downward movement of particle ‘C’ until slippage between soil and strip occurs resulting into a development of situation (b). Thus, it is the interaction between soil and strips which causes the resistance to penetration of the plunger resulting into higher CBR values. Kumar et al. (1999) based on their laboratory investigations conducted on silty sand and pond ash specimens reinforced with randomly distributed polyester fibers, concluded that fibers increased the peak compressive strength, CBR value, peak friction angle and ductility of the specimen. Authors further reported that the optimum fiber content for both silty sand and pond ash was approximately 0.3-0.4 % of dry unit weight\[12\]. Santoni et al. (2001) based on their laboratory unconfined compression tests conducted on sand specimen reinforced with randomly oriented discrete fibers, concluded that the fibers inclusions significantly improved the unconfined compression strength of sand specimens and the maximum benefit was achieved at a fiber content rate between 0.6% and 1% of dry weight\[22\]. The disagreement among the reported results is attributed to the difference in the material properties and testing conditions.

**Figure 7 Variation of Piston Load Ratio (PLR) with strip content at different aspect ratio**

**Figure 8 Variation of secant modulus with strip length at different strip content**

After the completion of each test, specimens were dissected and the strips were examined. Many of the strips showed elongation, thinning and clear impression of sand particles. Apparently, as the soil sheared during penetration, strip fixed in the sand by friction elongated as the soil deformed. Generally the CBR value at 2.5mm penetration is higher. However in the present study, the CBR value of HDPE strip reinforced sand at 5.0mm penetration are found to be higher than those at 2.5mm penetration. This indicates that at higher deformation the HDPE strip reinforcement is more effective in improving the strength of sand by increasing the resistance to penetration. The resisting action of the strips can be visualized by Figure 9 (a) and (b). In situation (a) the plunger pushes down particle ‘C’ to occupy position in between particle ‘A’ and ‘B’. The strip resists the downward movement of particle ‘C’ until slippage between soil and strip occurs resulting into a development of situation (b). Thus, it is the interaction between soil and strips which causes the resistance to penetration of the plunger resulting into higher CBR values. Kumar et al. (1999) based on their laboratory investigations conducted on silty sand and pond ash specimens reinforced with randomly distributed polyester fibers, concluded that fibers increased the peak compressive strength, CBR value, peak friction angle and ductility of the specimen. Authors further reported that the optimum fiber content for both silty sand and pond ash was approximately 0.3-0.4 % of dry unit weight\[12\]. Santoni et al. (2001) based on their laboratory unconfined compression tests conducted on sand specimen reinforced with randomly oriented discrete fibers, concluded that the fibers inclusions significantly improved the unconfined compression strength of sand specimens and the maximum benefit was achieved at a fiber content rate between 0.6% and 1% of dry weight\[22\]. The disagreement among the reported results is attributed to the difference in the material properties and testing conditions.

**Figure 9 Schematic diagram showing position of strip (a) before and (b) after slippage between soil and strip**

**Thickness of Base Course:**

For the cost benefit analysis of the reinforcement (plastic waste as strip) function, it is necessary to evaluate the pavement thickness reduction that is achievable by use of HDPE strips. As per recommendation of IRC-37-1984, the sub-base material should have minimum CBR of 20% for cumulative traffic up to 2 million standard axle (msa) and 30% for traffic of greater than 2msa. Since the
inclusion of 4% HDPE strips with aspect ratio 3 increased the value of CBR from 18.88% to 54.89%, so it can be safely concluded that the sub-base made of sand mixed with randomly oriented HDPE strips can be used for the traffic greater than 2msa particularly for situations where good quality conventional sub base materials (gravel, moorum, kankar, brick mortar, crushed stone etc) are not available locally.

5. CONCLUSIONS

The feasibility of reinforcing soil with strips of reclaimed HDPE was investigated in this study. Strips of HDPE were mixed with local sand and tested to determine CBR values and secant modulus. The tests show that reinforcing sand with waste HDPE strips enhances its resistance to deformation and its strength. Based on the results, the following conclusions can be drawn:

1. The addition of reclaimed HDPE strips, a waste material, to local sand increases the CBR value and secant modulus.
2. The maximum improvement in CBR and secant modulus is obtained when the strip content is 4% and the aspect ratio 3.
3. The reinforcement benefit increases with an increase in waste plastic strip content and length.
4. The maximum CBR value of a reinforced system is approximately 3 times that of a unreinforced system.
5. Base course thickness can be significantly reduced if HDPE strip reinforced sand is used as sub-grade material. This suggests that the strips of appropriate size cut from reclaimed HDPE may prove beneficial as soil reinforcement in highway sub-base if mixed with locally available granular soils in appropriate quantity.

The results of this study suggest that strip cut from reclaimed HDPE may prove useful as soil reinforcement in highway application. However further study is needed: (i) to optimize the size and shape of strips and (ii) to assess the durability and aging of the strip. Large scale test is also needed to determine the boundary effects influence on test results.

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