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Use of Waste Plastics for the Enhancement of Soil Properties : A Recent Advancement in Geotechnical Engineering

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***Abstract* - Waste plastic is commonly used for shopping bags, storage and marketing for various purposes due to its most advantage character of less volume and weight. Most of these plastic are specifically made for spot use, having short life span and are being discarded immediately after use. Though, at many places waste plastics are being collected for recycling or reuse, however; the secondary markets for reclaimed plastics have not developed as recycling program. Therefore, the quantity of plastics that is being currently reused or recycled is only a fraction of the total volume produced every year. The estimated municipal solid waste production in India up to the year 2000 was of the order of 39 million tons per year. From this plastics constitute around 4 % of the total waste. With the few reasons cited above, it is very important that we find ways to re-utilize these plastic wastes. Therefore, the investigation and attempt has been made to demonstrate the potential of reclaimed plastic wastes as soil reinforcement for improving the sub grade soils and maintain the stability of embankments. The study will describe series of tests carried out to initially understand the types of soil and its properties. Then various test were carried out with varying percentage of plastic strips mixed uniformly with the soil .The results obtained from the tests will be presented and discussed.**

1. INTRODUCTION

Soil stabilization is undertaken for a wide range of ground improvement schemes in geotechnical engineering applications that include backfill for earth retaining structures, repair of failed slopes, landfill liners and covers, stabilization of thin layers of soil and sub-grades for footings and pavements. The objective of ground improvement using soil reinforcement is to make up for the inability of soil to absorb generated shear stresses by introducing reinforcement elements which reduce the loads that might otherwise cause the soil to fail in shear or due to excessive deformation. The stability and reliability of geotechnical structures may be achieved by reinforcing the soil by randomly distributing throughout the soil mass. This concept can be traced back to ancient times when natural materials such as reeds, ropes, straws and timber were used as reinforcing elements by mixing them with soil used for construction of more stable structures. The mechanism of these reinforcing elements can be compared to the behaviour of plant and tree roots in providing strength and stability to soil layers. The techniques of soil reinforcement are broadly categorised into macro-reinforcement and micro-reinforcement (Gregory and Chill, 1998; Morel and Gourc, 1997). Woven and nonwoven polymeric materials referred to as geosynthetics widely used in the construction industry today are considered as macro-reinforcement material. Micro-reinforcement, on the other hand, involves randomly incorporating small reinforcing elements into the soil mass with uniform distribution to produce a three-dimensional reinforcement system (Al-Refeai, 1991; Falorca and Pinto, 2011; Gray and Maher 1989; Ibraim and Fourmont, 2006,). Studies into the polypropylene fibres for micro-reinforcement have reported increases in peak shear strengths and reductions of post peak losses in soils (Consoli et al, 2007; Zornberg, 2002,). These fibres have also been found to improve compressive strength and ductility of soils (Maher and Ho 1994; Miller and Rifai, 2004; Santoni et al 2001). In field applications, fibre reinforced soil consisting of polypropylene fibres of lengths up to 70 mm have been successfully utilised on embankment slopes in the US (Gregory and Chill, 1998). Jones (1996) maintains that the attributes of soil reinforcement of particular advantage in civil engineering include reduction in project costs and ease of construction. Therefore, as the demand for more economical methods to improve soil continues to increase attention has been turned to reusable municipal waste as a potential source of materials for soil reinforcement. This is underscored by research efforts focused on exploring the reuse of waste materials for soil stabilization. All these waste materials are abundant but are by and large destined for disposal or incineration and yet their unique properties can once again be beneficial in a sustainable geotechnical materials stream. The need to find alternative uses for the plastic waste resource coupled with the need to identify more affordable, easily accessible reinforcing material for soils in geotechnical engineering formed the basis of this study. The research specifically explores the possibility of reusing waste PET bottles made as soil reinforcement material by undertaking a laboratory testing program to investigate the effect of random inclusions of plastic in the form of strips on the engineering strength properties of the soils.

Soil fiber composites have been found effective in improving the CBR value of soil. The 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 reinforcement with plastic waste. In addition, use of plastic waste improved peak and ultimate strength of soil. 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. The feasibility of reinforcing soil with strips of plastic has also been investigated to a limited extent. It has been also found that the presence of a small fraction of plastic fiber can increase the fracture energy of the soil.

2. LITERATURE REVIEW

Plastic is a material consisting of any of a wide range of synthetic or semi synthetic organics that are malleable and can be moulded into solid objects of diverse shapes. Plastic has higher ductility and is impervious to movement of flow. Plastics also possess high tensile strength. Due to their relative low cost , ease of manufacture , versatility, imperviousness to water and high tensile strength , plastic strips are used for stabilization of soil. Excessive plastic waste production causes plastic pollution which adversely effects on lands, water ways and living organisms . Thus, plastic reduction efforts have occurred in some areas in attempts to reduce plastic consumption and pollution and promote plastic recycling. Plastic-waste materials are produced plentifully such as polyethylene terephthalate (PET) plastic bottles, polypropylene (PP) of plastic sack, and polypropylene (PP) of carpet. But such materials have been used little for engineering purposes, and the overwhelming majority of them have been placed in storage or disposal sites. The bottled water is the fastest growing beverage industry in the world. According to the international bottled water association (IBWA), sales of bottled water have increased by 500 percent over the last decade and 1.5 million tons of plastic are used to bottle water every year. The general survey shows that 1500 bottles are dumped as garbage every second. PET is reported as one of the most abundant plastics in solid urban waste. Fig.2 shows the plastic bottles present in garbage. Waste Recovery Program, WRP (2005) indicates that the reduction of waste benefits the natural environment with indubitable economical advantages, since waste represents a large loss of resources and raw materials that could be recovered, recycled or considered for other uses. In 2007, it was reported a world's annual consumption of PET bottles is approximately 10 million tons and this number grows about up to 15% every year. On the other hand, the number of recycled or returned bottles is very low. On an average, an Indian uses one kilogram (kg) of plastics per year and the world annual average is an alarming 18 kg. It is estimated that approximately 4-5% post-consumer plastics waste by weight of Municipal Solid Waste (MSW) is generated in India and the plastics waste generation is more i.e. 6-9 % in USA, Europe and other developed countries. As per data available on MSW, approximately, 4000- 5000 tonnes per day post consumer plastics waste are generated. Chen et al (2010) indicates that reuse of plastic waste is an important step in the development of clean energy and in conjunction with the promotion of new waste plastics recycling programs could contribute to additional reductions in GHG emissions and fossil fuel consumption. Hence, there needs to be concerted efforts in the reuse of plastic waste from water bottles and this study is in this direction. Plastic bottle recycling has not kept pace with the dramatic increase in virgin resin polyethylene terephthalate (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.

The plastic wastes can be cut into pieces and mixed with soil and the response of the plastic waste mixed soil can be examined using the framework of fibre reinforced soil. Preliminary experiments show that addition of plastic waste pieces lead to an improvement in strength response and there is a need to do detailed studies in this direction.

Figure 1 :- Dumped plastic water bottles

3 EXPERIMENTAL ANALYSIS

The basic properties of the clayey soil were determined. The experiments were conducted by using soil without plastic and with plastic strips in varying percentage. The percentages of plastic were taken as 0.5%, 1%, 1.5% and 2%. The results were compared among themselves. Various experimental tests conducted to reflect the behavior of plastic reinforced soil are given below:

3.1 Proctor's Compaction Test

This project uses the Standard Proctor's test to determine the dry density of the soil sample. In the Standard Proctor Test, a standard volume (944cc) is filled up with soil in three layers. Each layer is compacted by 25 blows of a standard hammer of weight of 2.495 kg (5.51lb), falling through 304.8mm (12").Knowing the wet weight of the compacted soil and its water content, the dry unit weight of the soil can be calculated.

3.2.Direct Shear Test

The experimental study involved performing a series of laboratory direct shear tests
on the soil with different percentages of plastic strips. The rate of strain is (1.25 mm/min); all specimens are prepared with a size of (60 *60 *20) mm.

Figure 2:- Specimen (Direct Shear Test)

3.3 California Bearing Ratio (CBR) Test

The California bearing ratio (CBR) is a penetration test for evaluation of the mechanical strength of road sub grades and base courses. It was developed by the California Department of Transportation. CBR is defined as the ratio of force per unit area required to penetrate a soil mass with a circular plunger of 50mm diameter at the rate of 1.25mm/min to that required for corresponding penetration of a standard material. The ratio is usually determined for penetrations of 2.5mm and 5mm. When the ration of 5mm is consistently higher than at 2.5mm, the ratio at 5mm is used.

Table 1:- Standard load for different penetrations

Penetration of plunger (mm)	Standard load (kg)
2.5	1370
5	2055
7.5	2630
10	3180
12.5	3600

Standard load is defined as the load obtained from the test on crushed stone which has a CBR value = 100%.The following table (Table 3.6) gives the standard loads adopted for different penetrations for the standard material with a C.B.R. value of 100%. Generally the CBR value at 2.5mm penetration will be greater than that at 5.0mm penetration. In such cases, the CBR 2.5mm is selected for design. If CBR5mm> CBR2.5mm, the test is repeated. If the identical results follow, the bearing ratio at 5mm penetration is taken for the design.

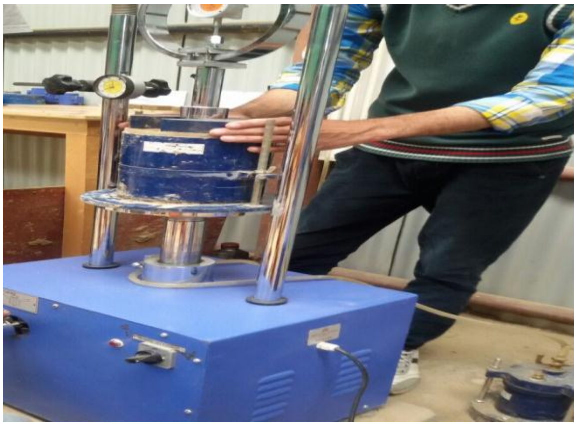

Figure 3 :-CBR Test Apparatus

3.4 Unconfined Compression test

The maximum load carrying capacity of subsoil is determined by its shear strength. The shear strength is usually determined with compression tests in which an axial load is applied to the specimen and increased till the specimen fails. The unconfined compression test gives the undrained shear strength of the soil in a sample and quick way. In unconfined compression test the specimen is not subjected to any lateral pressure during the test.

Figure 4:-UCT Apparatus

4. RESULTS AND INTERPRETATION

4.1 Proctor's Compaction Test

The optimum moisture content (OMC) and the maximum dry density (MDD) of the soil sample without reinforcement was determined by performing the Standard Proctor's test. The dry density was determined and plotted against the corresponding water content to find the optimum moisture content and the corresponding maximum dry density as 18 % and 1.69 g/cm^3 respectively.

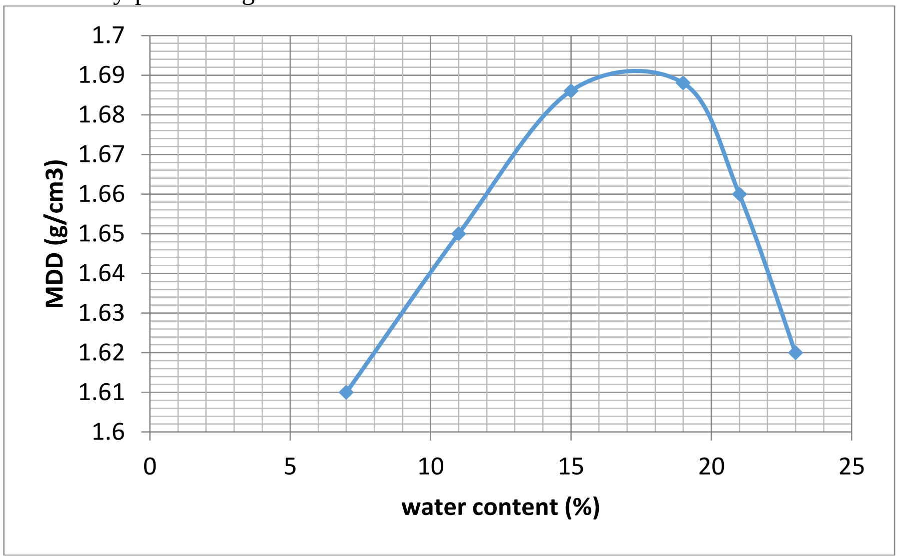

Figure 5:- Compaction curve

Then the various percentages of plastic strips (0.5%, 1.0%, 1.5%and 2.0%) were added on dry weight of the soil. Optimum moisture content (OMC) of reinforced soil is constant (18 %) for all percentages of plastic strips. As plastic fiber does not absorb water, OMC is independent of fibers content.

Table 2:- Values of MDD and OMC for various % of plastic

% of plastic strips	OMC (%)	MDD (g/cm^3)
0.0	18	1.69
0.5	18	1.71
1.0	18	1.68
1.5	18	1.66
2.0	18	1.62

It is observed that MDD increases with increase of percentage of plastic strips up to 0.5% and beyond that, the MDD decreases. Therefore the optimum percentage of plastic strips is 0.5 %. The variation of maximum dry density by changing percentage of plastic strips is shown in figure below:

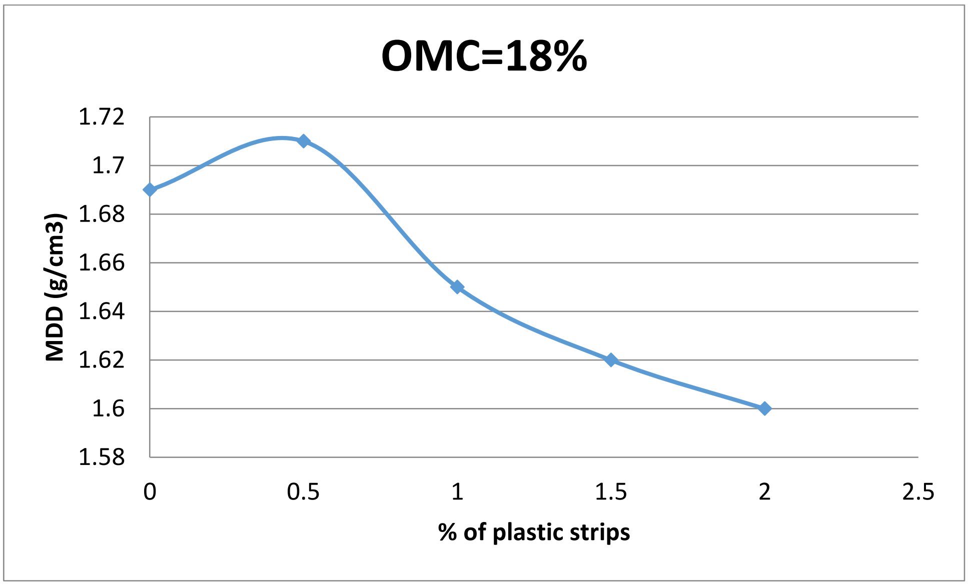

Figure 6:- MDD vs % of plastic strips

Optimum moisture content (OMC) and maximum dry density (MDD) relations from standard proctor compaction tests for soil alone and soil mixed with waste plastic fibres are summarized in the above Table . From these results it is clear that as the applied compaction energy was identical, the change of the maximum dry density of reinforced soil was the result of changing fiber content in soil. For given compaction energy, the presence of the reinforcement provides higher resistance to the compaction and so a less dense packing (low MDD) is obtained once the quantity of fibre is increased. With the increase of the fibre content in soil, energy absorption capacity of reinforced soil is increased. Due to extremely low moisture absorption characteristic of plastic strips, optimum moisture content (OMC) of every soil-plastic mix remains constant as optimum moisture content (OMC) of soil without plastic strips.

4.2 California Bearing Ratio (CBR) Test Results

The CBR tests were performed under unsoaked condition. Separate tests were performed for various percentages of plastic waste. CBR is a basic penetration test to determine the shear resistance of soil. The effect of plastic waste reinforcement was done both by comparing the CBR values, as well as the load displacement curves under unsoaked conditions.

Load-Displacement Curves

The CBR tests were performed sequentially for various percentages of plastic waste under unsoaked conditions. The load-displacement response for this condition is summarised in the plots shown below.

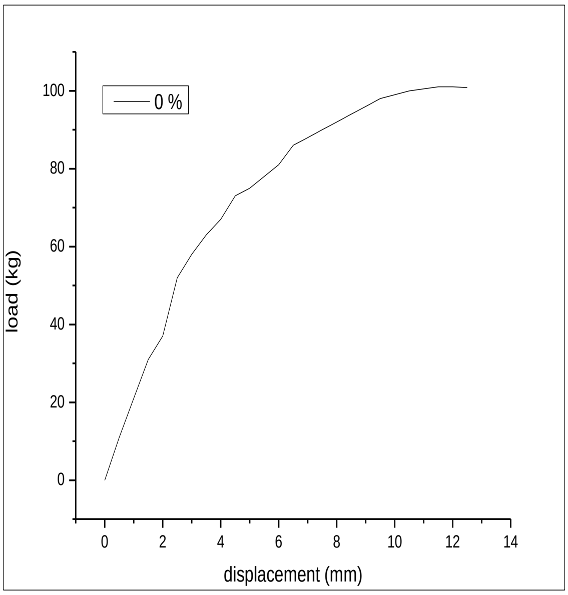

Figure 7:-load-displacement curve at 0% plastic strips (CBR)

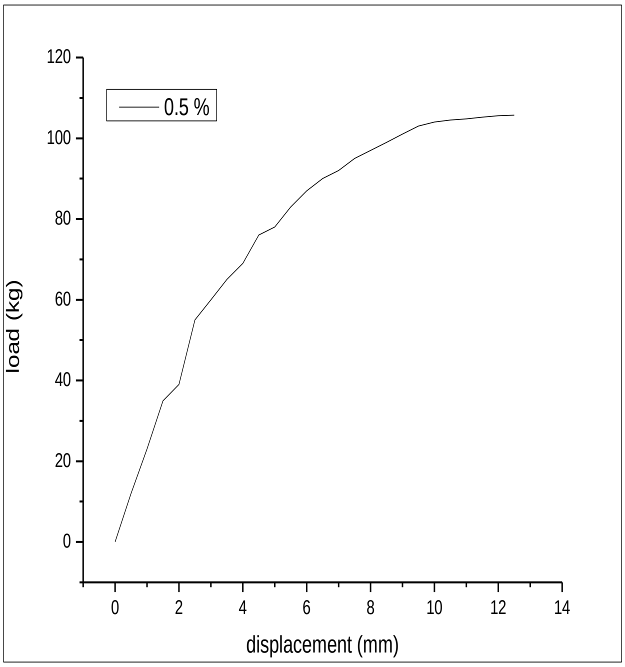

Figure 8:-load-displacement curve at 0.5% plastic strips (CBR)

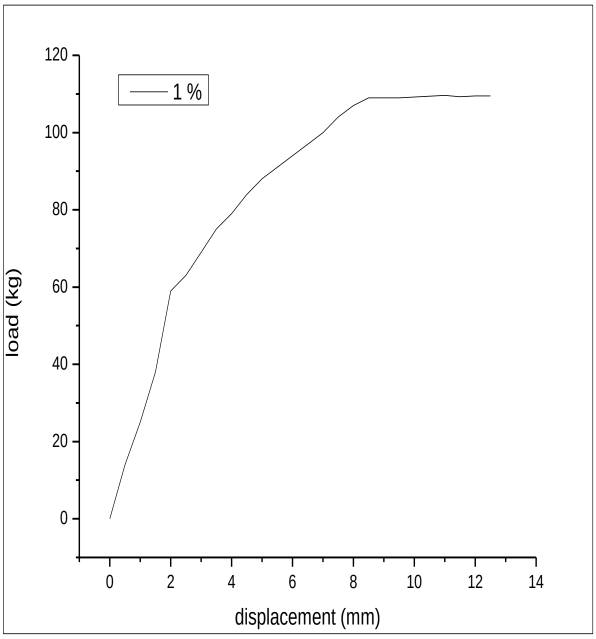

Figure 9:-load-displacement curve at 1% plastic strips (CBR)

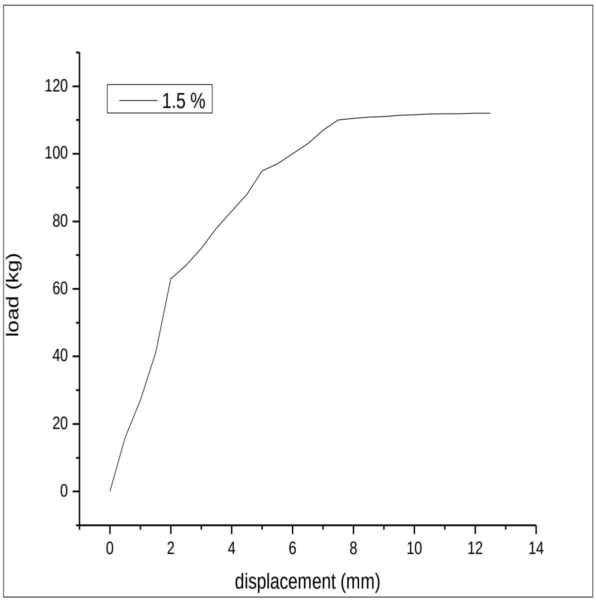

Figure 10:-load-displacement curve at 1.5% plastic strips (CBR)

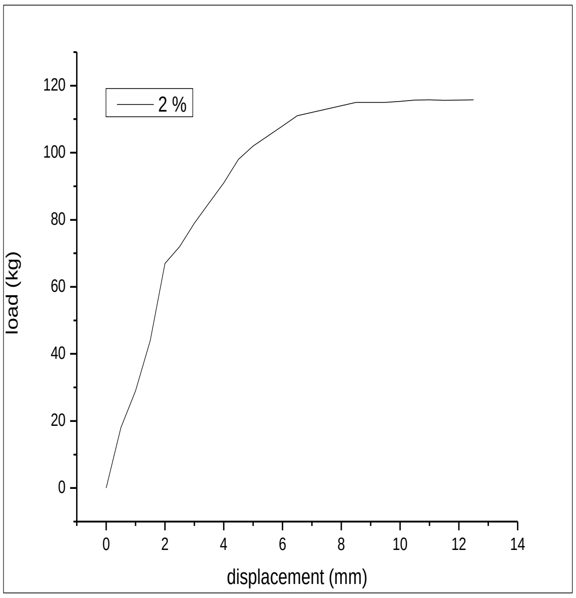

Figure 11:-load-displacement curve at 2% plastic strips (CBR)

From the load displacement curves ,it is clear that the penetration resistance of soil increases substantially on addition of plastic wastes. The increase in resistance was observed to be greater for higher percentage of plastic waste. the CBR of clayey soil was found to be 3.8, which increased to 4.2 for 0.5% plastic waste, 4.6 for 1% and 4.9 for 1.5% and 5.3 for 2%.

4.3 Unconfined Compression (UCC) Test Results

The improvement in the unconfined compressive strength (UCS) of soil by the inclusion of plastic waste is discussed in this section

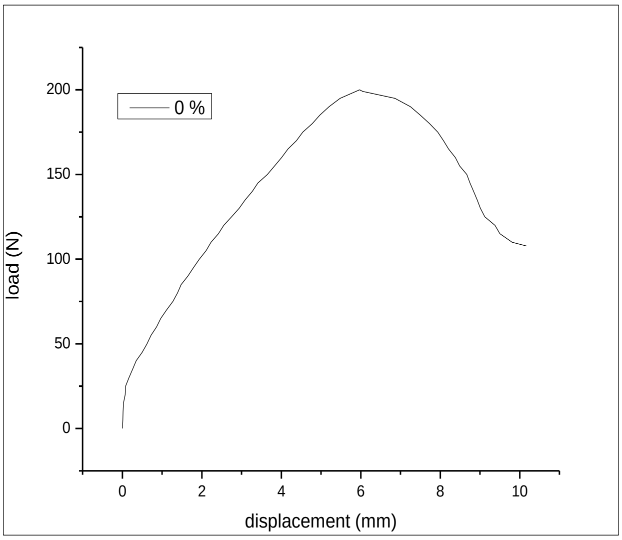

Figure 12:-load-displacement curve at 0% plastic strips (UCT)

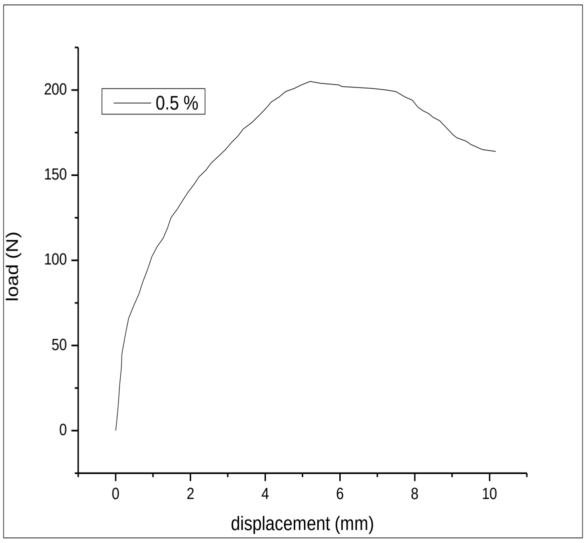

Figure 13:-load-displacement curve at 0.5% plastic strips (UCT)

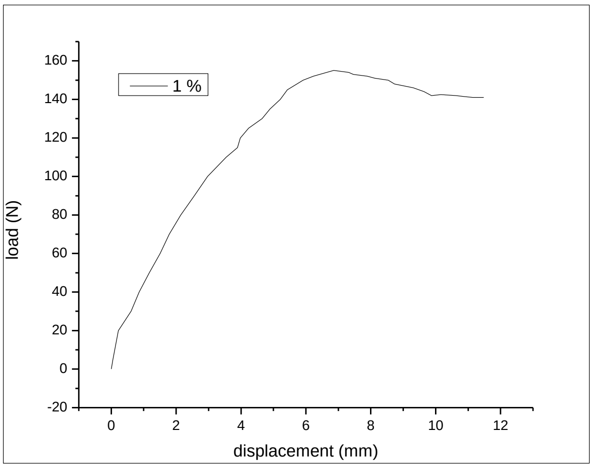

Figure 14:-load-displacement curve at 1% plastic strips (UCT)

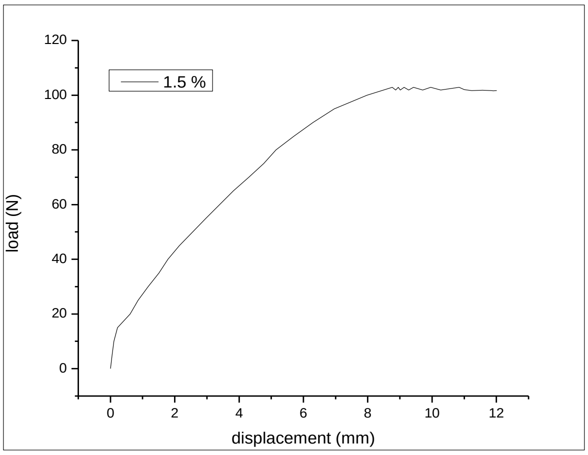

Figure 15:-load-displacement curve at 1.5% plastic strips (UCT)

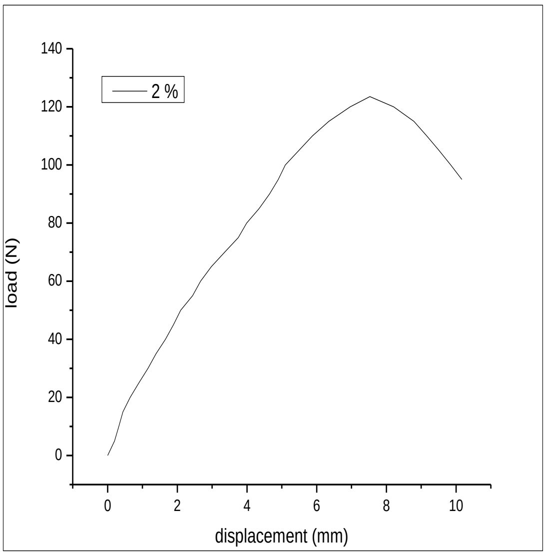

Figure 16:-load-displacement curve at 2% plastic strips (UCT)

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Thus it is clear from above load-displacement curves that unconfined compressive strength increases upto 0.5% plastic strips. However, decreases beyond 0.5%. Thus, the optimum percentage for unconfined compressive strength is 0.5%. From above curves , unconfined compressive strength is used to calculate cohesive intercept and angle of friction for each sample as given below:

Table 3:- C and ϕ at different %age of plastic strips (UCT)

% of plastic strips	Cohesion intercept	Angle of internal friction
0	64.4	10
0.5	67.23	14
1	45.6	16
1.5	33.49	12
2	42.9	8

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4.4 Direct Shear Test Results

The test was conducted on the soil sample with various percentage of plastic strips (0%,0.25%,0.5% and 0.75%).

Table 4:-Normal stress and shear stress at different %age of plastic strips

Normal stress (kpa)	Shear stress (kpa) 0% plastic	Shear stress (kpa) 0.5% plastic	Shear stress (kpa) 1% plastic	Shear stress (kpa) 1.5% plastic	Shear stress (kpa) 2% plastic
6.9	33.06	36.9	39.16	41.66	40.23
13.8	35.56	39.3	42.47	46.5	44.4
20.8	38.35	42.7	47.1	52.44	49.45

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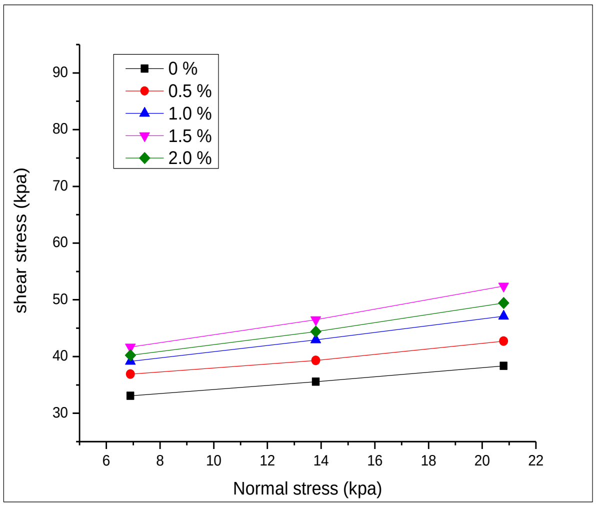

Figure 17:-shear stress vs normal stress (DST)

The values of cohesion and angles of internal friction for various percentage of plastic are tabulated in table.

Table 5:- C and ϕ at different %age of plastic strips (DST)

% of plastic added	Cohesion, c (kpa)	Angle of internal friction (degrees)
0	30.4	21
0.5	34.10	23
1	35.33	29
1.5	31.18	37
2	35.65	33

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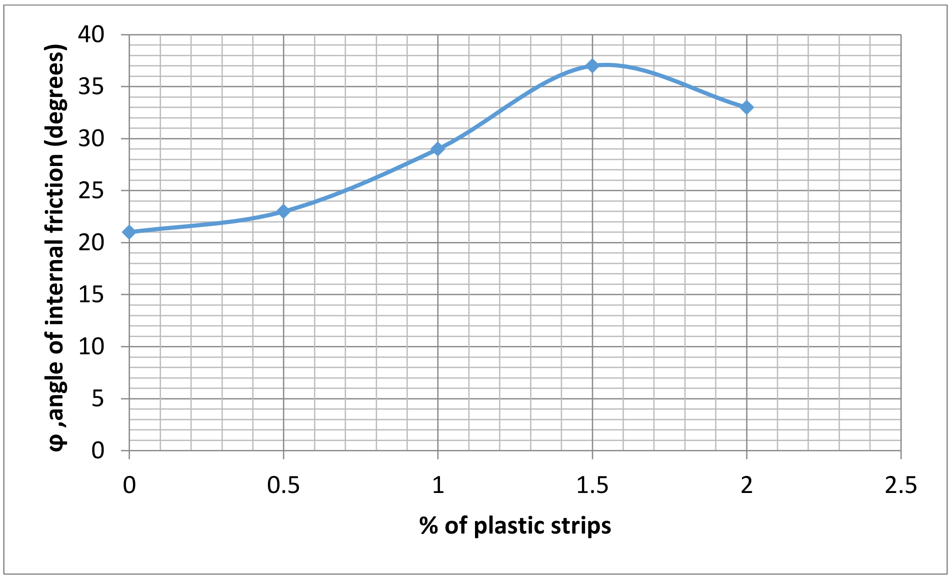

Figure 18:- ϕ vs %age of plastic strips

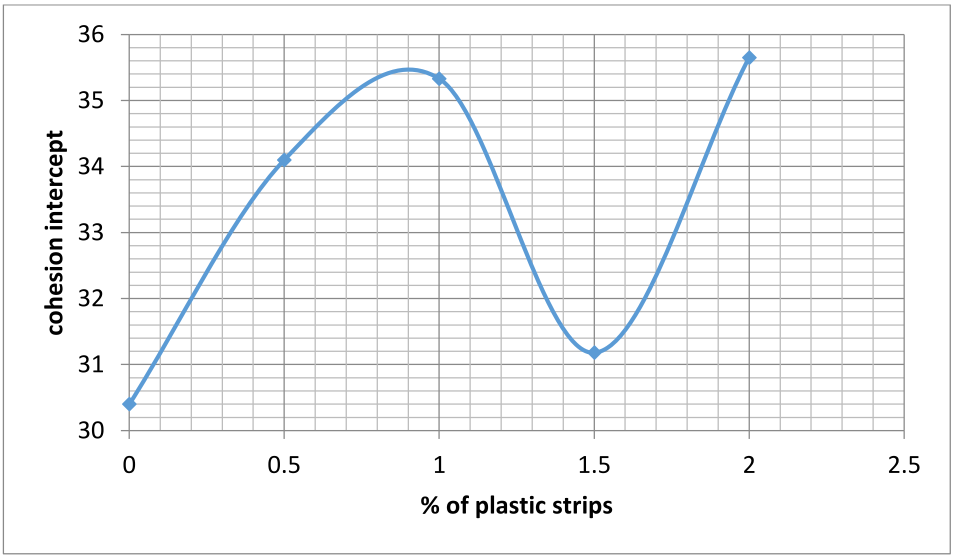

Figure 19:- "C" vs %age of plastic strips

4 CONCLUSION AND RECOMMENDATIONS

Plastic is considered as one of the major pollutant of environment as it would not decay or cannot be destroyed, so implementing this for the purpose of soil stabilization helps to reduce its harmful effects too. Stabilization by plastic strips is an economic method as these are cheaply available. By the addition of plastic strips, the engineering properties of soil get improved like compressive strength, tensile strength and shear strength.

Soil stabilization is assisted by increasing the CBR value of soil with the aid of plastic materials and hence can be used in pavements. Use of plastic strips help in pavement stabilization by preventing cracks, potholes and wheel path rutting. It also improves frictional resistance and ductility and hence can be used for stabilizing slopes and embankments. Plastic strips assist in improving compressive strength and reducing settlement. Hence it can be used under foundations.

Therefore plastic can be one of the material which can be used as a soil stabilizing agent but the proper proportion of this must be there-plastic content must not exceed 5%. This all implies that benefits of reinforcement increases to certain level and after that it will decrease the strength, so it should be used in right proportion.

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