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UTILIZING MATHEMATICAL MODELS FOR THE ASSESSMENT OF SOIL CALIFORNIA BEARING RATIO (CBR) ENHANCED BY PET PLASTIC WASTE

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ABSTRACT: Soil reinforcement in engineering entails enhancing soil strength through techniques like mechanical compaction and the incorporation of plastic waste materials. The adoption of alternative approaches for bolstering soil strength holds environmental benefits, particularly when it involves recycling discarded waste, such as plastic waste products. This contemporary method of soil reinforcement addresses societal challenges, curbs waste accumulation, and transforms discarded materials into valuable resources. Therefore, the utilization of waste plastic bottles to enhance soil quality presents an economically viable solution, given the limited availability of high-quality soil for construction purposes. This research paper's primary objective was to investigate the potential utilization of plastic bottle waste for stabilizing medium-compressible clayey soils. The research study systematically conducted a series of experiments to explore the application of plastic waste as a reinforcement material for soil. Diverse sizes of plastic waste and various substitution ratios were employed in the experimental procedures. A comprehensive set of tests, encompassing both index properties and mechanical properties, was carried out on soil samples collected from the Sisarma area in the Udaipur region.The results of these tests unequivocally illustrate that the incorporation of plastic waste, up to a substitution rate of 2%, positively impacts the California Bearing Ratio (CBR) properties of the soil. It's noteworthy that for optimal outcomes, it is advisable to use plastic waste with dimensions not exceeding 10mm. This research work offers valuable insights into the potential advantages and limitations of employing plastic waste for soil reinforcement.

Keywords: California Bearing Ratio (CBR), Index properties, mechanical properties, Soil reinforcement

I INTRODUCTION: - Soil with geotechnical engineering characteristics serves as a fundamental material in various engineering applications, encompassing its use in highway embankment backfill, roadbed layers, and the foundations of buildings. However, there are instances when finding suitable soils proves to be a formidable task, leading to the consideration of alternative soil types. Yet, these alternatives often come with less favorable engineering traits, such as inadequate soil grading, vulnerability to water and wind erosion, and complications in achieving proper compaction. For example, sandy soil is ill-suited for roadbed construction. Consequently, the utilization of these alternative soils demands enhancements in their geotechnical properties. This necessitates the improvement of mechanical parameters like compaction and shear strength to conform to established engineering standards. Typically, a variety of additives, including substances like silica fume, cement kiln dust, fly ash, cohesive admixtures, and treated coir fiber, are harnessed to augment the geotechnical properties of the soil.

The robustness of a structure's foundation is of paramount importance, as it heavily relies on the quality of the surrounding soil. This paper underscores the concept of soil reinforcement through the use of shredded waste plastic products, introducing an innovative approach to address this critical aspect.

II. LITERATURE REVIEW

Pal *et al.* (2018) In their experimental study, Pal et al. focused on stabilizing alluvial clayey soils near the surface by incorporating randomly distributed waste plastic bottles at various lengths and percentages relative to the soil's weight. They cut the waste plastic bottles into three different sizes: 1cm x 1cm, 1cm x 2cm, and 1cm x 3cm, and mixed them in different proportions of 0.25%, 0.5%, and 0.75% based on the dry soil weight. The research aimed to assess a range of compaction and strength properties. The findings revealed that an increase in the percentage of waste plastic bottle chips in cohesive soil led to a decrease in the maximum dry density, while the optimum moisture content increased.

K**umar et al. (2017)** conducted an experimental investigation on Black cotton soil. Their study focused on the blending of Black cotton soil with copper slag and fly-ash at varying percentages. They assessed a range of index l/and mechanical soil properties, including liquid limit, plastic limit, plasticity index, free swell, compaction test, and CBR (unsoaked).Their findings led to the conclusion that the addition of 30% copper slag and 10% fly ash, both measured by weight in relation to the soil, resulted in improved dry density and CBR values, as well as a reduction in soil swelling.

Mallikarjuna *et al.* (2016) conducted research on the stabilization of Black cotton soil using plastic waste. Their focus was on addressing challenges faced in Amravati, the capital of the newly formed Andhra Pradesh State. They undertook experimental programs to reinforce Black Cotton Soils in the Capital Region, specifically Amravati, by incorporating plastic waste as a soil reinforcement material. Various proportions of plastic strips, ranging from 0% to 8.0% by weight, were added to the Black Cotton Soil. The optimal percentage of plastic strips in the soil was determined through California Bearing Ratio (CBR) testing. In this study, plastic strips sourced from used plastic chairs, with a density of approximately 0.42 gm/cc, were employed and added to the Black Cotton Soil in quantities of 2%, 4%, 6%, and 8%. Modified Proctor tests and CBR tests were then conducted on the samples. The study concluded that the CBR value increased up to 4% plastic content, indicating improved soil properties.

Michael et al. (2016) conducted a review on the reinforcement of soil using industrial solid wastes. Their paper focused on the replacement of various materials, including red mud, copper slag, brick dust, polyvinyl waste, ceramic dust, sawdust, and fly ash. They subjected soil samples to tests, including Atterberg's limits, CBR (California Bearing Ratio), and compaction tests. The study's conclusion highlighted that nearly all industrial wastes possessed the capacity to enhance expansive soil properties, offering a cost-effective alternative to traditional soil improvement methods.

Mahali *et al.* (2015) The research conducted by the team aimed to explore the utilization of stone dust reinforced with PET strips (Polyethylene terephthalate) for enhancing subgrade soil quality. The study focused on assessing the impact of stone dust reinforced with PET strips through a series of California Bearing Ratio (CBR) tests. In this investigation, three different sizes of PET strips, measuring 10mm, 20mm, and 30mm in length, each with a consistent width of 10mm, were employed. The plastic strips were incorporated at various proportions, ranging from 0.25% to 2% concerning the dry weight of the stone dust. The study's outcomes unveiled several significant findings: An increase in the fiber content correlated with a notable rise in the maximum dry density of the stone dust mix. The inclusion of plastic fibers led to a decrease in the optimum moisture content, making the material more suitable for construction purposes. The introduction of PET strips had a strengthening effect on the overall strength and performance of the stone dust. Remarkably, the addition of PET strips, considered waste material, significantly improved the CBR value, rendering it a practical and cost-effective reinforcement technique. As the content and length of waste plastic strips increased, the reinforcement effect became increasingly pronounced. The CBR value of the reinforced system was approximately 2.79 times that of the unreinforced setup, highlighting the material's significantly enhanced load-bearing capacity. The research suggests the economic benefits of incorporating waste materials in the construction of base courses for rural roads. Furthermore, it underscores that reinforced stone dust is a highly effective and versatile material, particularly suitable for use as filling material in embankment construction, even in areas characterized by saturated clay soils.

Manuel *et al.* (2014) carried out firmness analysis of kuttanand clay fortify with polyethylene terephthalate bottle strips. In this study, they had taken Kuttanand clay spread over the Kuttanand region in the state of Kerala, India. These clays were characterized by high compressibility, low shear strength and high percentage of organic matter, which were unfavorable from the geotechnical point of view. For the study plastic strips were obtained from PET water bottle. The strips were cut into pieces of length 25 mm having average width 10 mm. It is to be noted the that the mould diameter would be at least four times the utmost strip length, which ensures the adequate space for the strip to behave freely and unrestrained of mould restraint. Strips are arbitrary assorted with soil in diversified proportion (0, 0.25, 0.5, 0.6, 0.75, and 1) by dry weight of soil. Plastic reinforced soils were prepared manually by hand mixing. Oven dried soil after passing through 4.75 mm sieve was taken and water added and mixed uniformly. For a particular percentage of fiber content, the $1/3^{rd}$ of total amount of plastic strips were distributed evenly and mixed thoroughly with wet soil. After mixing the $1/3^{rd}$ amount, another $1/3^{rd}$ amount were mixed in the same way. Lastly the rest $1/3^{rd}$ amount was mixed with the wet soil. The wet plastic-mixed soils were then used for various tests. Standard Proctor test, CBR test, unconfined compression test and Triaxial compression test were done in the laboratory. They had concluded that Analysis of foundation using PLAXIS software show that the total displacement of foundation decreases from 0.2984m (before stabilization) to 0.0935m after stabilizing soil upto 1m depth at a load of $45kN/m^2$. The maximum dry density increase with the increase in the strip content upto optimum strip content and then decreases. CBR value increases with the increase in the strip content upto optimum strip content and then decreases. The optimum strip content corresponding to maximum improvement in CBR value is found to be 0.6%. The unconfined compressive strength of the sample increase from 5 kN/m^2 (pure clay) to 24.69 kN/m^2,cohesion of the sample increase from 5 kN/m^2 (pure clay) to 17.5 kN /m^2 and the angle of internal friction (Ø) of the sample increase from 30 (pure clay) to 190.

Fauzi *et al.* (2013) investigated the utilization of High Density Polyethylene (HDPE) and Glass as material stabilizer in Kuantan clayey soil stabilization. They researched on soil engineering properties and strength test for various contents of HDPE and glass to different types of clayey soil from various sites in Kelantan. The Standard Compaction and California Bearing Ratio (CBR) were applied in soil samples to estimate the optimum mixture design. The samples were set up by mixing soil samples with various content of stabilizer at optimum water content. The variation content of stabilizer was 4%, 8% and 12% by dry total weight. The accomplishment of subgrade stabilization depends on the engineering properties of clay and characteristic of stabilizer [5, 6, 7, 8, 9, and 10]. According to the laboratory test results were shown, that the engineering properties of Kuantan Clayey soil and CBR were improved by adding Cutting HDPE and crushed Glass as stabilizer.

III. MATERIALS

3.1 Soil

Soil is a primary component used in the construction of embankments and highway subgrades, playing a critical role in the performance of pavements, particularly flexible pavements. The type and properties of the subgrade soil significantly influence the pavement's quality. In this particular study, the soil was sourced from Sisarma, which is situated approximately 10 kilometers away from Maharana Pratap University.

The soil was categorized according to IS-1498 [1970], which outlines the principles for classifying soils for engineering purposes. To conduct the testing, the soil was first sieved through a 425-micron sieve, and the portion that passed through the sieve was collected for analysis. The analysis aimed to determine the proportion of various particle sizes within a given dry soil sample through a process known as particle size analysis or mechanical analysis.

Particle size analysis involves two main phases:

1. Sieve analysis, which is primarily suited for coarse-grained soils.
2. Sedimentation analysis or Wet Mechanical analysis typically performed for fine-grained soils.

This process allows for the separation of the soil into different size fractions, enabling a comprehensive understanding of the soil's composition and characteristics, which are essential for engineering and construction purposes.

3.2 Plastic Waste

The plastic waste strips, sourced from bottles or PET waste, were collected from a local industry known as Tammana Polypet, situated in Udaipur. These plastic strips had varying aspect ratios, including both one and two. The dimensions of the plastic bottle strips used in this research encompassed a spectrum of sizes denoted as (BxL) in millimeters, ranging from 1x1, 1x2, 2x2, 2x4, 4x4, 4x8, 6x6, 6x12, 8x8, 10x10, to 12x12.In this study, these plastic strips were introduced into the soil at different weight percentages. Specifically, the study involved the inclusion of these strips in the soil at proportions of 0%, 0.5%, 1.0%, 1.5%, and 2% relative to the dry weight of the soil. This wide range of proportions facilitated a thorough investigation into the influence of these plastic waste strips on the soil's characteristics and behavior.

Fig. 1 a. Shredding Machine of Plastic waste, courtesy: Tammana Polypet, Udaipur **b. Sample of Plastic waste use for research work**

3.3 Water

Throughout the study, potable water was employed, ensuring it was devoid of impurities such as salt and organic content.

IV METHODOLOGY:

To gauge the properties of the soil and classify them appropriately, a set of index tests will be performed. The objective is to investigate the influence of plastic waste as a reinforcing material, which necessitated a comprehensive battery of mechanical tests. In these tests, varying proportions of plastic waste were introduced into a poorly graded soil. The experimentation took place at the Soil Engineering Laboratory situated at CTAE, MPUAT in Udaipur.

4.1 California Bearing Ratio test – IS 2720-16 (1987)

The laboratory test under consideration is aimed at determining the California Bearing Ratio (CBR) value through a load penetration test. This particular test method is specifically designed for assessing the subgrade strength of roads and pavements. The results generated from this test are vital in ascertaining the required pavement thickness and the characteristics of its various layers. In the realm of flexible pavement design, this method is the most commonly employed.The suite of equipment involved in the CBR test includes: A mold with a diameter of 150mm and a length of 175mm, complete with a detachable perforated base plate and a collar boasting a diameter of 50mm. A spacer disc with dimensions of 148mm in diameter and 47.7mm in length. A surcharge weight weighing 2.5Kg and featuring a central hole with a diameter of 50mm. Another slotted weight, also weighing 2.5kg.A penetration plunger with a diameter of 50mm and a length of 100mm.A loading machine with a capacity to apply load to the soil specimen through a loading frame, accommodating a maximum load of 5000Kg.A compaction rammer, invaluable for compacting the expansive soil within the mold in three distinct layers. During the compaction process, the rammer is dropped from a height of 31cm.A weighing balance machine, facilitating the measurement of the weight of the mold with or without the poorly graded soil. Notably, filter paper is placed at the base of the mold to streamline the mold preparation process after compaction.A mixing tool, playing a key role in ensuring thorough mixing of the soil. A water measuring tool, instrumental in determining the quantity of water content within the expansive soil.A proving ring, serving as the conduit for transferring the load from the frame to the specimen, in addition to measuring the applied compressive load.A strain measurement dial gauge boasting a 0.01mm graduation.Each of these pieces of equipment contributes significantly to the seamless execution of the CBR test, ultimately providing valuable insights into subgrade strength for effective pavement design.

V TEST RESULTS AND DISCUSSION:

The index properties of the soil are presented in Table 1 based on various soil tests.

Table 1. Index Properties of Soil

S.No.	Particular	Test Result
1	Soil Classification	CS
2	Liquid Limit (%)	46
3	Plastic Limit	29.17
4	Plasticity Index	17.83
5	Optimum Moisture content (%)	17.6
6	Maximum Dry density (g/cc)	19.4
7	Specific gravity	2.48

5.1 California Bearing Ratio test

Testing of California Bearing Ratio test of various sample of soil were performed as per IS 2720 part 16 - 1987. Table no. 28 and 29 shown the value maximum compressive stress (Kg/cm2) of soil at various proportions. The % CBR value of normal soil sample was obtained as 4.47 kg/cm2. The calculation of CBR value was taken at 2.5 mm and 5 mm penetration.

Fig. 2 & 3 shows that the % CBR value increases mutually upto 2 % of PET waste Size 6mm x 6mm. The maximum value of % CBR obtained as 5.640. The effect of PET waste shows 20 % increment of CBR value.

From the above results it was found that 12mm x12mm size PET waste show less CBR value compare to normal soil at 1.5 % and 2% variation. From those results it is observed that 12mm x 12 mm size PET waste not acceptable at 1.5 and 2% variation.

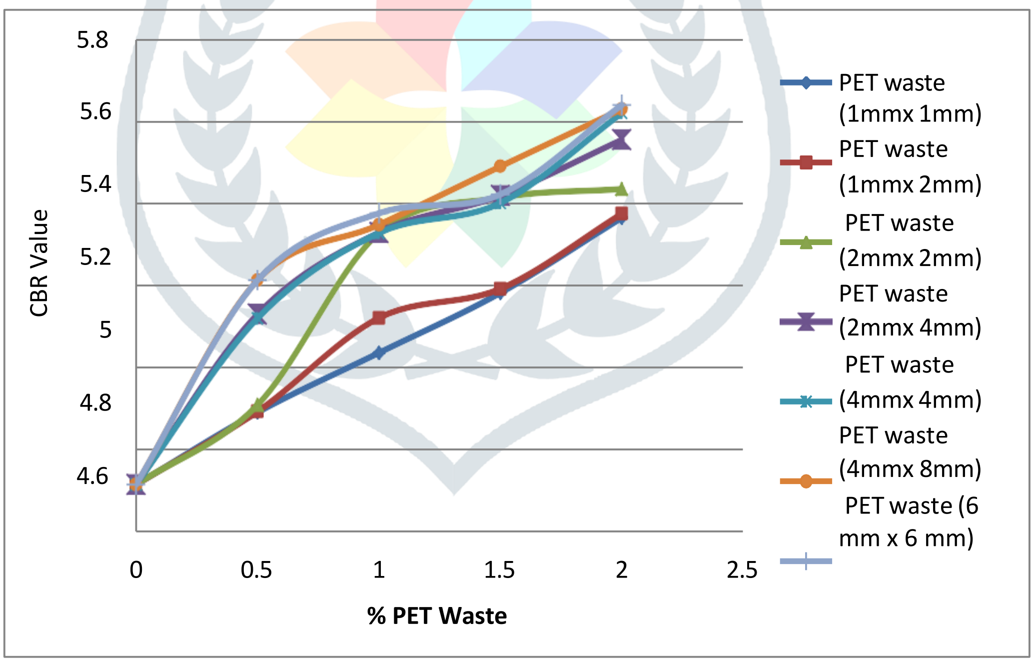


Figure 2 Variation of CBR Value for varied addition of PET waste of Size 1 mm, 2mm , 4mm, 6mm

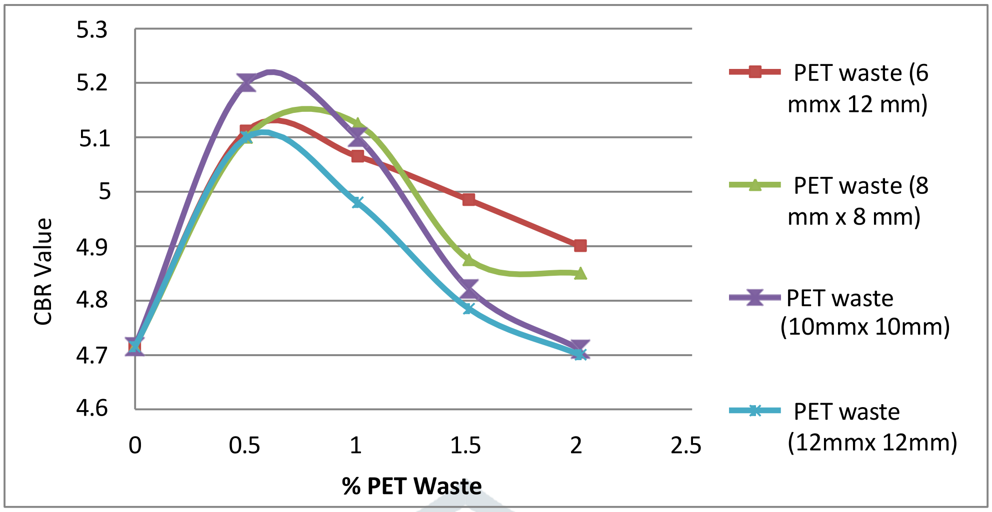
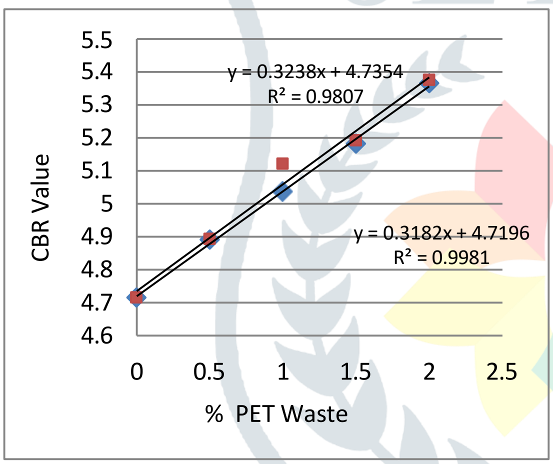
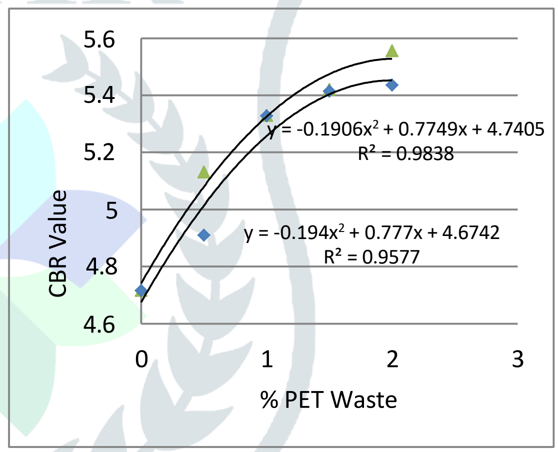


Figure 3 Variation of CBR Value for varied addition of PET waste of Size 6 mm, 8 mm, 10 mm and 12 mm

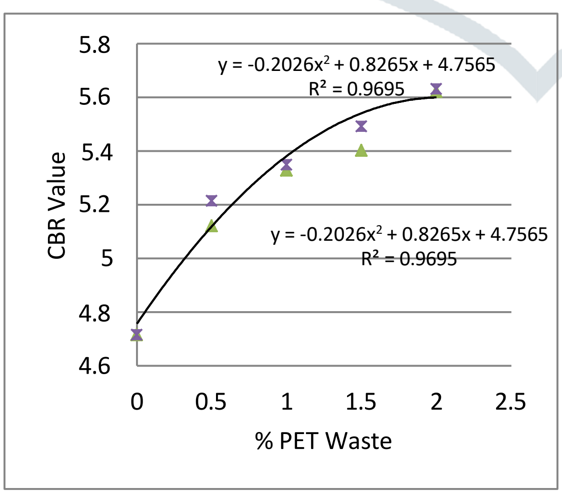
5.2 Mathematical model of the linear and nonlinear regression analysis relationship of reinforced soil for CBR value.



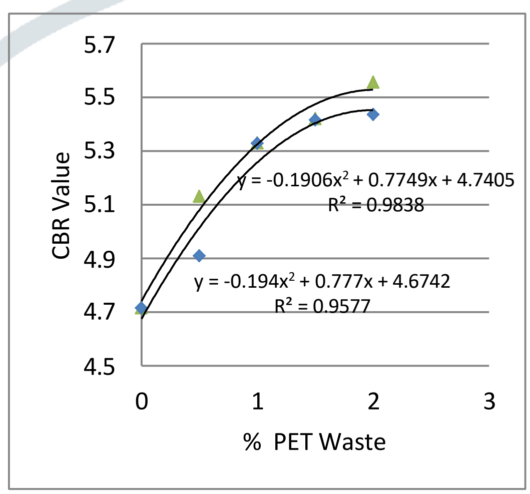
(a) PET Size 1mm



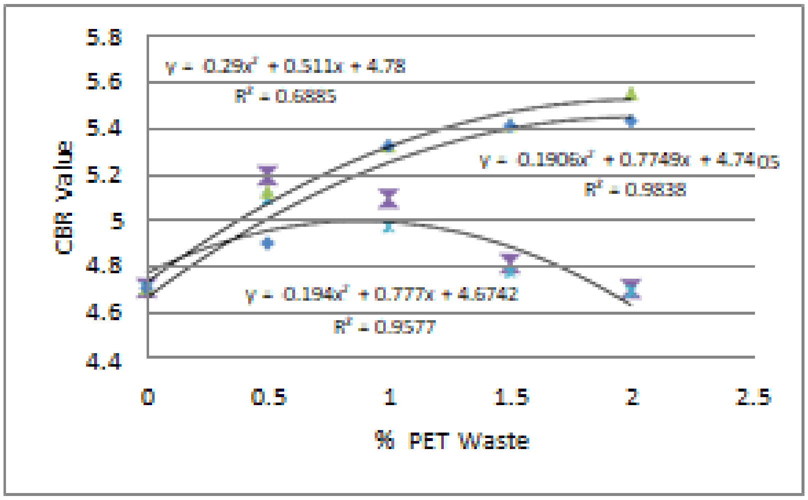
(b) PET Size 2mm



(c) PET Size 4mm



(d) PET Size 6mm



e) PET Size 8mm, 10mm & 12mm

Figure 4 Linear and Non Linear regression analysis results, variation of CBR Value for varied addition of PET waste of different size Shown in fig. (a,b,c,d,e)

CBR test results show that the relationship curve between CBR values versus percentage of PET waste of reinforced soil. From the fig 2 shows that the reinforced soil had obvious linear and nonlinear characteristics curve at inclusion of various percentages and different size of PET waste in soil mass.

From the above results the final predictable mathematical equation is:

$Y = 0.324\ X + 4.74$ (Size of PET waste ≤ 1 mm) (Eq. 1)

$Y = -\ 0.192\ X^2 + 0.775\ X + 4.\ 75$ (size of PET waste ≤2 and ≥10mm) (Eq.2)

$Y = -0.290\ X^2 + 0.511X + 4.78$ (Size of PET waste 12 mm) (Eq.3)

Where; Y = CBR Value,
X = % PET Waste ($0 \leq X \leq 2$)

Equation 1 shows that the test parameter a and b can be obtained by linear fitting when knowing the test results. Fig. 4 (a) shows the linear fitting results of size less than are equal to 1 mm. This equation predicts the approx. value of maximum CBR value in between substitution 0 to 2 % of PET waste in soil mass.

Equation 2 & 3 shows that the test parameter a, b and c can be obtained by nonlinear fitting when knowing the test results. Eq. 2 and 3 are second order polynomial equation. This equation predicts the approx. value of maximum CBR value in between substitution 0 to 2 % of PET waste in soil mass.

VI CONCLUSION AND SUMMARY

The repurposing of specific inorganic solid waste materials in civil engineering projects is increasingly gaining favor, serving the dual purpose of enhancing environmental sustainability by reducing residual waste and creating novel geotechnical materials with superior mechanical properties. A systematic research study was systematically undertaken to investigate the influence of PET waste on the mechanical characteristics of soil across different proportions. This investigation revolved around two main factors: the dimensions of PET waste with aspect ratios of 1 and 2, and the varying percentages of PET waste mixed with the soil. The soil sourced from the site exhibited characteristics indicative of poorly graded clay, as delineated in the index properties analysis.

- The inclusion of PET waste in the soil leads to an increase in the California Bearing Ratio (CBR) value, with the improvement reaching up to 2% when compared to the CBR value of standard soil.
- The highest CBR value observed in this study, reaching 20%, was obtained when using PET waste with dimensions of 6mm x 6mm.
- It's noteworthy that when 12mm x 12mm PET waste was introduced, there was an initial 1% increase in CBR value compared to the normal soil.
- Surprisingly, this initial increase was followed by a subsequent decrease, causing the CBR value to drop below that of the normal soil.

Hence, it can be summarized from the above reported conclusion that the upto 10 mm size of plastic waste with aspect ratio one show positive influence on the mechanical properties up to variation of 2% with compressible clay soil. The ideal size was considered for addition with soil is 6 mm with aspect ratio one upto 2 %. It is recommended that up to 1% variation of PET waste all samples show positive results.

VII FUTURE SCOPE

This experimental study utilizes the plastic waste (PET) as a soil reinforcement material. Optimum substitution of PET waste material has been suggested for the production of new reinforced soil. Research may be conducted in future for assessment of the various other properties in details and more precise results to provide confidence in the users of substitute PET waste reinforced soil., so as to utilize the quantity of plastic waste in construction aspects.

- Microstructure assessment of modified plastic waste soil scanning electron microscope (SEM) may be investigated.
- Further study, may be required to change the soil and type of PET waste for better outcomes.
- This study has lots of research gap due to different type of soil available in earth surface.

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