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Review on the Study of Stress-Strain Behaviour of Cohesive Soil Mixed with Natural Fibres

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Abstract: ***The term soil reinforcement is conventional since decades ago for the stabilization of soft ground such as of clay and peat. Numerous researches have arisen in the utilization of natural fibers as the reinforcement materials. Cost reduction, increment of sustainability awareness and eco-friendly environment are some of the advantages when using natural fibers to stabilize soft ground. A research study was carried out to evaluate the strength of the soft soil when unreinforced and reinforced using natural fibers. The crushed coir fibers were added at different percentages to the dry weight of the sample. A series of an unconsolidated undrained Tri-axial test was conducted on the unreinforced and reinforced samples where the behavior of the samples were observed and compared. The results indicated that inclusion of fibers affects the soil's undrained shear strength, causes decrease in preconsolidation pressure and increase in compressibility and swelling indices. It was observed that increasing the percentage inclusion increases the undrained shear strength of the soil, up to a certain amount. Moreover, the stiffness and ductility of the soil are quite improved with the use of natural fiber.***

Keywords: Coir Fibers, Triaxial Test, Compressibility, Swelling Indices, Stiffness

1. Introduction

One of the challenges in construction on soft ground is that, problems such as insufficient bearing capacity and soil settlement may arise. These complications are generated by the low shear strength and low permeability of the soil. These effects are successfully simulated with Triaxial Tests where the stress-strain relation of undisturbed soil specimen is investigated by subjecting the soil sample to different stress levels and drainage conditions. In general, incorporating reinforcement inclusions within soil is an effective and reliable technique to improve the engineering properties of soil. Addition of natural fiber to the soil is a very good soil-reinforcement technique. Coir fiber can be effectively used to tackle many short-term stability issues in geotechnical engineering related to shear strength, permeability, etc. Coir fiber is anatural material obtained from coconut husk. The fibers are adding in various percentages to the natural cohesive soil. A random distribution of fibres also helps to develop the shear strength of the soil without having to present the weakness plane in the soil composite which eventually will help to reduce settlement.

2. Literature Review

Lawer et al. (2021) investigated the effects of coconut fiber and palm fiber on some geotechnical characteristics of a weak lateritic subgrade. It is necessary to find economically efficient ways to improve the engineering properties of these marginal lateritic soils. The lateritic soil was collected and blended with various percentages of the fibers varying between 0.1 and 1.0% by weight of dry soil. The mixed materials were then subjected to various laboratory tests including compaction, unconfined compression test and California bearing ratio test. From the results, it was observed that increasing the fiber content decreased the maximum dry density and increased the optimum moisture content. As the percentage of the fiber content increases, the UCS and CBR values also increases.

Mahdi et al. (2021) investigated the influence of natural fibers as sustainable ones including basalt (BS) and bagasse (BG) as well as synthetic polyester (PET) fibers on the strength behavior of clayey soil. . Use of environmentally friendly approaches with the purpose of strengthening soil layers along with finding correlations between the mechanical characteristics of fiber-reinforced soils such as indirect tensile strength (ITS) and California bearing ratio (CBR) and as well as the evaluation of shear strength parameters obtained from the triaxial test would be very effective at geotechnical construction sites. The results of the triaxial compression test revealed that with the addition of BS fibers, the internal friction angle increased by about 100%, and with the addition of PET fibers, the cohesion increased by about 70%.

Ayush et al. (2020) studied the difference and the end by looking at the underlying properties and the last properties after utilization of waste coconut coir fiber, glass fiber and cement sack. The utilization of coconut fiber, which is presently regularly considered as waste, as an asset to deliver ranch building material to substitute wood item, offers numerous points of interest. A progression of tests were performed with red topsoil soil utilizing coconut coir, glass fiber and cement pack as fortification at different rate substance to discover its impacts on the soil and to discover whether the specific soil support blend is valuable.

Muneerah et al. (2019) in this paper, comparative study on the consolidation characteristics of soft soil reinforced with coconut husks or coir fibers at different inclusion of lengths and crushed forms were carried out. The percentage inclusion of fibers was kept at an increment of 0.5% with a maximum of 2.0%. The consolidation behavior of these reinforced samples were observed and compared with the unreinforced sample. The results indicated that different percentage inclusion of coir fibers affects the soils'

consolidation behavior in terms of the coefficient of consolidation, cv and coefficient of permeability, k. From the conducted experimental investigation, it can be concluded that the soil samples reinforced with 20 mm length of coir fibres give the most significant effect to the soil's consolidation behaviour when it was added at 1.0%.
Suffri et al. (2019) researched to evaluate the strength of the soft soil when unreinforced and reinforced using natural fibres. Cost reduction, increment of sustainability awareness and eco-friendly environment are some of the advantages when using natural fibers to stabilize soft ground. The crushed coir fibers were added at 0.5%, 1.0%, 1.5% and 2.0% to the dry weight of the sample. A series of an unconsolidated undrained Tri-axial test was conducted on the unreinforced and reinforced samples where the behavior of the samples were observed and compared. The results indicated that inclusion of fibres affects the soil's undrained shear strength.

Muneerah et al. (2018) experimentally investigated the use of these coir fibers in soft clay with regards to its consolidation behavior were carried out. The Maximum dry density and Optimum moisture content was determined from compaction test to be used as a basis in preparing samples for the consolidation tests. The soil samples which were reinforced with various inclusions of coir that is at 1.0, 1.5, 2.0 and 2.5% and of different sizes of 10, 20 and 30 mm were tested to determine the effects on consolidation behaviour due to the inclusion of these fibres. The results were compared with that of the unreinforced soil sample and it was indicated that the coefficient of consolidation (cv) is affected by the length of coir fibres.

Mirzababaei et al. (2018) studied a series of multi-stage drained reverse direct shear tests were carried out on soft clay samples reinforced with 0.25% and 0.50% polypropylene fibers of 6 mm, 10 mm and 19 mm in length. Tests were carried out at different normal effective stresses and cumulative horizontal shear displacement of 1.17 times of the sample width. Results showed an increase of the shear strength with the increase of fiber content and length.

Sotomayor et al. (2018) evaluated the load-settlement behavior of non-reinforced and reinforced sand with coconut fibers using either a random or a layered distribution. plate load tests with both non-reinforced and reinforced sand were performed fixing the moisture content and percentage of fibers for all tests. The results show that the greatest settlement reduction is obtained with layered distribution. Conversely, random distribution provides more ductility and, consequently, the mixture can resist a highest load than layered distribution.

May et al. (2017) studied the stress-strain behavior of cohesive soil Triaxial test and direct shear test, both for unconsolidated-undrained, are carried out to compute the shear strength parameters, c and ϕ. The data from UU triaxial test are used to investigate the values of elastic modulus, E.

Yadav et al. (2017) this paper focused on the influence of inclusion of waste rubber tire fibres on some of the geotechnical properties of uncemented/cemented clay. For this investigation, three percentages of cement (0%, 3%, and 6%) and five percentages of rubber fibre (0%, 2.5%, 5%, 7.5%, and 10%) were considered. The tests namely, compaction, unconfined compressive strength, split tensile strength, California bearing ratio, swelling pressure, wet/dry cycles durability along with the scanning electron microscopy were conducted on the clay-cementrubber fibre mixtures to ascertain the suitability of rubber fibres with cement stabilized clay. The test results revealed that the incorporation of rubber fibre reduces the unconfined compressive strength and split tensile strength of cement-stabilized clay but prosperously improves the rate of loss of post-peak strength and change the brittle failure behavior of cemented clay to ductile. Based on the test results, the maximum percentage of rubber fibre content mixed with cement-stabilized clay was found to be 7.5%.

Dharmesh et al. (2016) presented the results of plate load test on square model footing resting on sand beds reinforced with coir geotextile in geocell and planar forms. It is best suited for low-cost applications in developing countries due to its availability at low prices compared to its synthetic counterparts. The results indicate that bearing characteristics clearly depend on the form in which reinforcements are applied. For the same amount of material, coir geocell reinforcement provides better performance compared to planar forms.

Omar et al. (2016) studied the effect of sawdust content on the engineering properties of clayey-silt soil. The dry soil passing sieves No.40 were mixed with the sawdust, with the amount 1, 2, 3 and 5 % from dry weight of soil, then, samples engineering properties were indicated. Effect of sawdust usage on undrained shear strength of the soil was investigated by unconfined compression test and UU triaxial test. The undrained strength were increased by 41.437% with increasing 3 % but, the undrained strength decreased with 5% of sawdust. Also the results obtained from unconfined compression test and UU triaxial test were compared and looked at compatibility of the results.

Behzad et al. (2015) in this study, the optimum fibre contents were obtained for mixtures of clay with two different types of fibre. The study showed that the inclusion of fibre at optimum fibre content can improve the dynamic properties of clay at the low shear strains used. Test results indicated that both the shear modulus and damping increased. Hence, the inclusion of fibre in clay can provide a double benefit for the dynamic response of a site by increasing the stiffness of the site and reducing its amplitude of vibration.

Botero et al. (2015) this study proposed an alternative reuse method for certain types of plastic waste in geotechnical construction projects. The principal objective of this research was to study the mechanical behavior of a silty soil that was reinforced with aleatory distributed PET fibers. To meet this objective, UU triaxial laboratory tests were performed on soil specimens with fiber contents of 0.0e1.0% of the soil dry weight.

Vishwas et al. (2015) the effect of treated coir fibres on the shear strength behaviour of clay is presented in this study. A series of consolidated undrained test were performed on soil reinforced with untreated, sodium hydroxide treated and carbon tetrachloride treated fibres. The coir fibre content was varied from 0.4% to 1.6%. The results indicated that the deviator stress at failure of the clay and clay with untreated coir fibres can be increased by treatment with carbon tetrachloride and sodium hydroxide. A significant increase was also observed in shear strength parameters of clay reinforced with coir fibers at different percentages.

Vivi (2014) investigated the tensile and compression strengths of natural and treated soft soil. The tensile strengths and compression strengths of compacted specimens of natural soil, lime and coir fiber treated soil were obtained using the indirect tensile test and unconfined compressive test. The results revealed that both tensile and compressive strengths increased with the addition of lime, coir fiber and the increasing of the curing time. From the test results, the relationship of the unconfined compressive strength of the soft soil was predicted by the correlation agreed with the indirect tensile strength.

Yankai et al. (2014) investigated the mechanical properties of silty clay reinforced with discrete, randomly distributed sisal fibers using triaxial shear tests. The sisal fibers were cut to different lengths, randomly mixed with silty clay in varying percentages, and compacted to the maximum dry density at the optimum moisture content. The results indicate that with a fiber length of 10 mm and content of 1.0%, sisal fiber-reinforced silty clay is 20% stronger than no reinforced silty clay.

Shivanand et al. (2014) this paper discussed the strength behavior of cohesive soils reinforced with coir fibers, polypropylene fibers and scrap tire rubber fibers as reported from experimental investigation, that includes triaxial, direct shear and unconfined compression tests. Triaxial test results indicate that the stress-strain behavior of soil is improved by incorporating coir fibers in the silty soil, and that the deviator stress at failure is increased up to 3.5 times over plain soil by fiber inclusion. Direct shear test results show that the shear strength of polypropylene fiber reinforced soil increases with inclusion of fibers up to 0.4%, beyond which it decreases. Unconfined compression test results indicate that the UCS of polypropylene fiber reinforced soil is greater than those of the parent soil. When tire rubber fibers are used, the optimum fiber length is 10 mm and the optimum fiber content is 2%.

Anagnostopoulos et al. (2013) investigated the influence of certain parameters (the strength properties of the fibre, the relative size of the fibres and grains, and the rate of shear) on the shear strength of polypropylene fibre reinforced cohesive soils. . A series of consolidated drained or undrained direct shear tests were conducted on unreinforced and reinforced sandy silt and silty clay specimens. The results also showed that the reinforcement effect was more pronounced under undrained shearing conditions.

Estabragh et al. (2013) presented the results of an experimental investigation into the effects of discrete palm fibers on the consolidation and shear behavior of a randomly reinforced clay soil. The results indicate that the inclusion of the fiber reinforcement within the soil causes decrease in preconsolidation pressure and increase in compressibility and swelling indices. In addition, the strength and friction angle increase considerably in terms of total and effective stresses.

Treasa et al. (2013) discussed shear strength of clay reinforced with randomly distributed coir fibers based on a series of consolidated undrained triaxial compression tests. Test results show that major principal stress at failure for clay-coir fiber matrix increases with increase in fiber content (Wf) and fiber aspect ratio (Ar). In general, the study identifies that the inclusion of discrete coir fibers in random fashion significantly improves the shear strength of clay and hence could be effectively used for the cases where in-place mixing of soil with fibers is possible.

Rakesh et al. (2012) presented the effect of treated coir fibres (15 mm in length) on the unconfined compressive strength of clay. Dry, sodium hydroxide and carbon tetrachloride–treated coir fibres were used in the study. The coir fibre content was varied from 0.4% to 1.6%. The results indicated that the unconfined compressive strength of clay and clay with dry coir fibres can be increased by treatment with carbon tetrachloride and sodium hydroxide.

Estabragh et al. (2012) investigated the behavior of cement stabilized fiber-reinforced clay with different cement and fiber contents. Unconfined compression tests (UCT) were carried out on the uncemented samples. These UCT tests were also conducted on the cement-stabilized samples with and without fiber inclusions after 3, 7, 14 and 28 days of curing time. The results indicated that the inclusion of fibers within uncemented and cement-stabilized soil caused an increase in the unconfined compressive strength and axial strain at failure, and changed the brittle behavior of the cementstabilized soil to a more ductile behavior.

Bindu et al. (2011) studied the effect of inclusion of coir fiber on the shear strength of marine clay. Reinforced soils can be obtained by either incorporating continuous reinforcement inclusions within a soil mass in a certain pattern or mixing discrete fibres randomly with a soil. Results indicate that the shear strength increases considerably by the inclusion of the coir fibers by about four times.

Dasaka et al. (2011) investigated the effect of coir fiber on the stress–strain characteristics of a reconstituted cohesive soil. Addition of natural fiber to the soil is a very good soil-reinforcement technique in the context of sustainable development. Coir fiber can be effectively used to tackle many short-term stability issues in geotechnical engineering related to shear strength, permeability, etc. Tests were carried out using fiber contents varying in the range of 0%–2% by dry weight of the soil. The stiffness and ductility of the soil are quite improved with the use of natural fiber.

Pradip et al. (2011) presented the effect of random inclusion of polypropylene fibers on strength characteristics of soil. Locally available cohesive soil (CL) is used as medium and polypropylene fibers with three aspect ratios (l/d = 75, 100 and 125) are used as reinforcement. Direct shear tests, unconfined compression tests and CBR tests were conducted on un-reinforced as well as reinforced soil to investigate the strength characteristics of fiber-reinforced soil. The test results reveal that the inclusion of randomly distributed polypropylene fibers in soil increases peak and residual shear strength, unconfined compressive strength and CBR value of soil.

Attom et al. (2009) paper presented the effect of shot, discrete, randomly oriented fibers on the mechanical properties of clayey soils. The mechanical properties investigated include peak unconfined strength, stiffness and ductility. Two types of fibers were studied i.e., nylon and palmyra fibers with aspect ratio equal to 75. The clayey soils were mixed with fibers at five different percentages by volume of solid soil. The result showed that the peak unconfined compressive strength, stiffness and ductility of the clay fiber mixture increased with fiber content. Palmyra fiber showed a higher increase in the relative unconfined compressive than nylon fiber mixed when mixed with clayey soils, for all fiber contents.

Sivakumar et al. (2008) presented the strength and stiffness behavior of soil reinforced with coir fibers. . Soil samples reinforced with coir fibers of different sizes, and made into cylindrical soil specimens were tested in triaxial shear apparatus to determine the strength and stiffness of soil response due to fiber inclusion and the results were compared with that of unreinforced soils. The results show that addition of coir 1–2%as random reinforcing material increases both strength and stiffness of clay soil considered in the study. Analysis shows that the available models are not adequate to capture the strength and stiffness response of coir fiber-reinforced soil. A nonlinear regression model for strength and stiffness response is proposed in the present study.

Lalana et al. (2007) the stiffness at small strains and non-linear stress-strain relation of compacted cement-mixed well-graded gravelly soil as well as the ageing effects were evaluated by drained triaxial compression tests on compacted moist specimen scured for different periods at isotropic and different anisotropic stress states. In all the tests, the initial stress – strain relation at small strains less than about 0.001z was essentially elastic and the initial Young's modulus, E_0, was essentially the same as the E_{eq} value evaluated by applying unloads cycles under otherwise the same conditions.

Zeynep et al. (2007) the ductility, toughness, and resistance to tensile cracking of clays can be improved with the inclusion of short fibers. The objective of this study was to evaluate the drained and undrained shear strength of mixtures of clay and tire buffings. Consolidated drained and consolidated-undrained triaxial tests were run at confining stresses ranging from 50 to 300 kPa. Results showed that the peak strength of the composite is comparable to or greater than that of clay alone when tested at confining stresses below 200– 300 kPa.

Temel Yetimoglu (2005) Laboratory California Bearing Ratio (CBR) tests were performed to investigate the load–penetration behavior of sand fills reinforced with randomly distributed discrete fibers overlying soft clay. The effect of fiber reinforcement content on bearing capacity, stiffness and ductility of the fiber-reinforced sand fill–soft clay system was determined. The test results indicated that adding fiber inclusions in sand fill resulted in an appreciable increase in the peak piston load. The reinforcement benefit increased with an increase in fiber content.

Temel et al., (2002) investigated the shear strength of sands reinforced with randomly distributed discrete fibers by carrying out direct shear tests. The effect of the fiber reinforcement content on the shear strength was investigated. The results of the tests indicated that peak shear strength and initial stiffness of the sand were not affected significantly by the fiber reinforcement.

3. Conclusion

Clay is reinforced with a large amount of short fiber and the behavior of the reinforced clay is similar to that of a composite material. The inclusion of fibers has a significant effect on the consolidation behavior of randomly reinforced clay soil. The preconsolidation pressure decreases and C_c and C_s increase with increasing the fiber content in reinforced soil. The addition of crushed coir fibers as the soil reinforcement shows a significant improvement on the strength behavior when compared to being unreinforced. The stiffness response of coir fiber-reinforced soil is better than that of un-reinforced soil. The stiffness modulus increases with increase of fiber content.

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