EXPERIMENTAL INVESTIGATION ON SOIL STABILIZATION USING COIR FIBER, FLY ASH, AND CALCIUM CHLORIDE

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ABSTRACT

Soil stabilization is essential for enhancing the engineering properties of weak or problematic soils to ensure safe and durable infrastructure. This study explores an eco-friendly approach to soil stabilization using a combination of coir fiber, fly ash, and calcium chloride ($CaCl_2$). Coir fiber, an agricultural byproduct, provides tensile strength and ductility, while fly ash acts as a pozzolanic material improving binding characteristics. Calcium chloride serves as a chemical stabilizer that accelerates cementation and moisture reduction. A series of laboratory tests—including Unconfined Compressive Strength (UCS), Atterberg limits, compaction, and California Bearing Ratio (CBR)—were conducted on treated and untreated soil samples. The results demonstrate significant improvements in shear strength, reduction in plasticity, and enhanced load-bearing capacity of the stabilized soil. The study confirms the synergistic effect of the selected additives and highlights the potential of this sustainable stabilization technique for geotechnical and road construction projects.

I. INTRODUCTION

1.1SOIL STABILIZATION

The performance of any civil engineering structure is highly influenced by the underlying soil properties. In many regions, weak or expansive soils pose a major challenge to construction activities due to low bearing capacity, high compressibility, or excessive plasticity. Traditionally, chemical stabilizers like lime and cement have been used to improve soil characteristics, but they come with environmental and cost concerns. Hence, there is an increasing demand for eco-friendly and cost-effective soil stabilization techniques that incorporate natural and industrial byproducts.

Coir fiber, a renewable resource derived from coconut husk, offers improved tensile strength and resistance to cracking when mixed with soil. Fly ash, a waste product from thermal power plants, contributes to the pozzolanic reaction, enhancing soil stiffness and reducing permeability. Meanwhile, calcium chloride ($CaCl_2$), a hygroscopic salt, helps in reducing moisture content and accelerating soil bonding processes.

This experimental study aims to evaluate the combined effect of coir fiber, fly ash, and $CaCl_2$ on the mechanical and physical properties of locally available subgrade soil. The primary goal is to develop a sustainable stabilization method that not only improves strength parameters but also aligns with environmental goals by utilizing agro-industrial waste. The research investigates the optimal mix proportions and examines improvements through standardized geotechnical testing procedures.

1.1.1Mechanisms of Stabilization:

The adjustment The modification framework may move for the most part from the course of action of new blends confining the better soil particles to covering atom surfaces by the additional substance to limit the soddenness affectability. Thus, a central understanding of the alteration instruments required with each additional substance is important sooner than picking a convincing stabilizer suited for a specific application.Chemical adjustment include reconciliation or infuse the dirt by artificially lively mixes, for example, Portland concrete, lime, fly fiery remains, calcium or sodium chloride or with visco flexible materials, for example, bitumen.

1.1.2Traditional Stabilizers:

Customary stabilizers all things considered rely upon pozzolanic reactions and cat molecule exchange to modify or conceivably offset. Among each and every customary stabilizer, lime likely is the most routinely used. Lime is set up by rotting limestone at lifted temperatures. Lime-soil reactions are amazing and mainly incorporate a two phase get ready. The basic reaction incorporates cat molecule exchange and flocculation/agglomeration that acknowledge quick textural and flexibility changes. The structure, in this way of flocculation of earth particles on account of cat molecule exchange and without a moment's hesitation pozzolanic reactions, realizes greater atom agglomerates and more friable and functional soils. Disregarding the way that pozzolanic reaction methodology are direct, some measure of pozzolanic quality get may occur in the midst of the basic reactions, cat molecule exchange and flocculation/agglomeration. Level of this quality get may change with soils depending upon contrasts in their mineralogical piece.

1.1.3By-Product Stabilizers

Like ordinary stabilizers, pozzolanic reactions and cat molecule exchange are the fundamental change frameworks for a significant parcel of the by-thing stabilizers. Lime broiler clean (LKD) and bond heater clean (CKD) are by-aftereffects of the formation of lime and Portland concrete, separately. Lime broiler clean (LKD) commonly contains between around 30-40 % lime.

The lime may be free lime or joined by pozzolans in the stove. The wellspring by such pozzolans is no doubt the fuel used to give the imperativeness source. LKDs may be to some degree pozzolanically responsive by virtue of the closeness of pozzolans or they may be absolute non open since of the nonattendance of pozzolans or the low idea of the pozzolans constrained in the LKD. Solid heater clean (CKD) is the consequence of the age of Portland bond. The fines got in the exhaust gasses of the formation of Portland concrete are more likely (than LKD) to contain responsive pozzolans and thusly, to reinforce some level of pozzolanic reactivity. CKD all things considered contains between around 30 and 40 percent CaO and around 20 to 25 percent pozzolanic material.

1.1.4Non Traditional Stabilizers:

The instrument of adjustment for non-customary stabilizers shifts enormously among the stabilizers. Black-top might possibly be gathered as a conventional stabilizer relying upon point of view. Black-top is not a "concoction" stabilizer as in it doesn't respond synthetically with the dirt to create an item that changes surface science of the dirt particles or that ties particles together.

1.2Methods of Soil Reinforcement:

1.2.1Geo-synthetic reinforcement:

This procedure involves dividing the earth in compacted layers and fortifying each layer with geo-synthetics. The synthetics are used as a piece of two courses in the midst of grade stronghold. The essential approach is to give extended sidelong confinement at the slope stand up to by putting constrained strips at the edge of the inclination. This abstains from sloughing and abatements crumbling. In solid soils one of a kind geo-materials with great leakage capacities consider brisk pore weight dispersal. The second approach is to implant bits of the built oppositely to the common tension plane. As far as possible and presentation of the layers that cross the slip surface addition the contradicting minute occurring here. Central purposes of this methodology are that the material contemplates awesome filtration and waste, it is uncommonly versatile, and its fake properties gives the designed a long strength. Its strength has been figured in the region of 500 and 5000 years, regardless of the way that its quality characteristics must be adjusted at times. These properties contemplate this method to be associated in an extensive variety of soil. Regardless, the materials are not instantly available to poor gatherings, plants can't create through them, the use has typical costs and its execution in gigantic slanted areas is marvelous.

1.2.2Randomly mix fibers into the soil

This methodology includes self-assertively mixing strands into the earth to grow its shear quality. The fibers augment the connection among the soil particles. Similarly the collaboration of the fibers among themselves and the strands' flexibility influences them to bear on as an essential work that holds the soil together extending the earth helper uprightness.

II. LITERATURE REVIEW

Ghavami et al. (1999)found that consolidation of 4% sisal, or coconut fiber, gave noteworthy malleability and fairly extended the compressive quality. It was furthermore discovered that introduction of bitumen emulsion did not upgrade the holding between the earth and strands; anyway did basically improve soil strength.

Prabakar and Siridihar (2002) used 0.25%, 0.5%, 0.75% and 1% of sisal fibers by weight of rough soil with four exceptional lengths of 10, 15, 20 and 25 mm to strengthen an area risky soil. They assumed that sisal fibers decrease the dry thickness of the earth. The development in the fiber length and fiber content furthermore diminishes the dry thickness of the earth. Likewise it was discovered that the shear pressure is extended non-specifically with increase long of fiber up to 20mm and past, where a development long diminishes the shear extend. The rate of fiber substance moreover improves the shear quality. In any case, past 0.75% fiber content, the shear push lessens with increase in fiber content.

Ravishankar and Raghavan (2004)affirmed that for coir-offset lateritic soils, the most outrageous dry thickness (MDD) of the earth decreases with development of coir and the estimation of perfect clamminess content (OMC) of the earth increases with an extension in rate of coir. The compressive nature of the composite soil increases up to 1%of coir content and further augmentation in coir sum achieves the decreasing of the characteristics. The rate of water ingestion increases with a development in the rate of coir. Unbending nature of coir strengthened soil (stove dry examples) increases with an extension in the rate of coir.

III. RESOURCES USED AND ITS PROPERTIES

This part manages the physical and concoction properties of different materials utilized as a part of the adjustment of the delicate sub review soil/Embankment soil by utilizing CaCl2 arrangement, Fly cinder and fortifying with Coir fiber.

3.1SOIL

The expansive soil used in the experimental work was brought from P.Kotha Kota Village near Pakala Mandal, Chittoor District, Andhra Pradesh.

Physical Characteristics of Expansive Soils.

Table no.3.1:

S.NO	PROPERTIES	TEST VALUES
1	Specific Gravity	2.1
2	Liquid Limit	45%
3	Plastic Limit	20.68%
4	Plasticity Index	24.32%
5	Maximum Dry Density	1.943
6	California Bearing Ratio	2.09%
7	Un Confined Compression Strength	2.085

3.2COIR FIBER:

The outside covering of stringy material of a created coconut, named coconut husk, is the reject of coconut natural item. The strands are ordinarily 50– 350 mm long and include generally of lignin, tannin, cellulose, gelatin and other water dissolvable substances.(Hejazi,et.al,2012) Coconut palms are fundamentally created in the tropical locale of the world and the thing from the palm is associated in sustenance and non-sustenance things, which deals with the job of people wherever all through the globe. The coconut palm contains a white meat which has a total percent by weight of 28 incorporated by a protective shell and husk which has a total percent by weight of12 and 35 independently. The husk from the coconut palm incorporates 30% weight of fiber and 70% weight of pith material. The fiber are expelled from the husk by a couple of procedures, for instance, retting, which is a standard way, decortications, using organisms and parasites, mechanical and invention plan , for the production of building and packaging materials, ropes and yarns, brushes and padding of resting cushions accordingly on.(Pillai,2003)Coir or coconut fiber has a place with the social occasion of hard fundamental strands. The coir fiber is adequately adaptable to bend without breaking and it holds a turn as though forever waved. The consolidation of fibers affected the outlining behavior of soil-coir mixes. The development of self-assertively appropriated polypropylene fibers achieved liberally reducing the association settlement of the earth soil. Length of fibers inconsequential influences this earth trademark, however fiber substance exhibited all the more intense and convincing. Development of fiber realized decrease in flexibility and addition in water controlled conductivity. In this way there has been a creating excitement for soil/fiber stronghold. The work has been done on quality winding behavior of fiber fortified soil and it has been set up sure that extension of fiber in soil upgrades the general building execution of soil.

Fig1: general building execution of soil

3.2.1PHYSICAL PROPERTIES OF COIR FIBER

Table no.3.2.1

Length in inches	6-8
Density(g/cc)	1.4
Tenacity(g/tex)	10
Breaking elongation %	30
Diameter in mm	0.1-0.5
Rigidity of modulus	1.8924dyne/cm2

3.2.2HEMICAL PROPERTIES OF COIR FIBER:

Table no.3.2.2

Lignin	45.84%
Cellulose	43.44%
Hemi-cellulose	0.25%
Pectin's and related Compound	3%
Water soluble	5.25%
Ash	2.22%

3.3Fly Ash

The fly ash by the stabilization course should have a best values of Calcium composition and that is old as a stuffing material. Class F fly ash worn here as a filler manager since of attendance of good value of Calcium percentage.A class-F Fly ash having (CaO - 0.17%, Al2O3 - 22.26%, SiO2-75.39%, Fe2O3 - 0.51%) available in Nellore, India is used in the experimental program.

3.4 Calcium Chloride ($CaCl_2$)

Calcium chloride is utilized for various purposes at various fixations relying upon its utilization. This exploration utilized its most elevated rate calcium chloride items. The compound and physical investigation of CaCl2 is given in Tables and Water was added to accomplish the coveted focus levels.

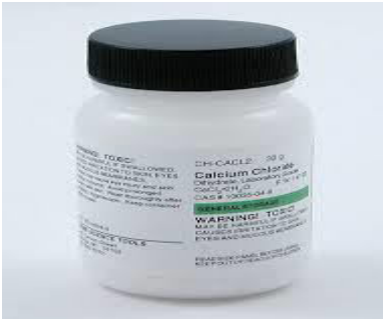


Fig no2. Calcium Chloride ($CaCl_2$)

IV. EXPERIMENTAL INVESTIGATION

A few examinations were accounted for the utilization of filaments in soil. As a piece of the present examination, every one of the fixings utilized as a part of the venture for making the balanced out soil lattice are tried for appropriateness in the light of significant necessities of details of Bureau of Indian Standards.

4.1 LIQUID LIMIT TEST

Liquid boundary is the h2o % at which the firm has small or no shear power and when it now begins to flow.

4.1.1EQUIPMENTS AND TOOL REQUIRED:

1. Liquid limit Device (Casagrande's).

2. Standard Grooving Tool (ASTM).
3. Weighing Balance.
4. Drying Oven
5. Graduated Jar.
6. Spatula etc.,

4.2PLASTIC LIMIT

Plastic cutoff means the limit plastic and semi-strong conditions of a dirt, at which the dirt can be formed into any shape. In particular, it is the water content at which the dirt tends to break when moved into the strings of around 3mm measurement.

4.2.1EQUIPMENTS AND TOOL REQUIRED

1. Porcelain Evaporating Dish.
2. Metallic rod(3mm dia and 100 long).
3. Glass plate.
4. Drying Oven.
5. Weighing Balance.
6. Containers of Moisture content determination.

4.3CALIFORNIA BEARING RATIO:

It is the relation of power per unit region necessary to go through a soil mass with standard circular piston at the speed of 1.25 mm/min. to required for the matching dispersion of a normal material. IS 2720- Part xvi (2002) is used for this test.

C.B.R. $= TestLoad\ (\ ) / StandardLoad\ (k\ ) \times 100$

The next table give the normal loads adopted for different penetrations for the normal material with a C.B.R. value of 100%

Standard Loads adopted for different Penetrations

Table no.4.3.1

Preparation of plunger(mm)	Standard Load
2.5	1370
5	2055
7.5	2630
10	3180
12.5	3600

4.3.1PREPARATION OF TEST SPECIMEN

1. Take around 4.5 to 5.5 kg of earth and blend completely with the necessary water.
2. Settle the augmentation neckline plus the bottom plate to the form. Embed the spacer find the base. Put the channel paper on the highest point of the spacer plate.
3. Conservative the blend earth in the form utilizing .also light compaction or overwhelming compaction. For light compaction, smaller the dirt in 3 breaks even with layers, each layer being given 55 passes up the 2.6 kg rammer. For substantial compaction minimal the dirt in 5 layers, 56 hits to each coating by the 4.89 kg rammer.
4. Evacuate the neckline and trim off soil.
5. Flip around the shape and evacuate the bottom plate and the misplacer circle.
6. Measure the shape with compacted soil and decide the mass thickness and dry thickness.

7. Put channel paper on the highest point of the compacted soil (neckline side) and clip the punctured construct plate in light of to it.

4.4UNCONFINED COMPRESSION TEST

An Unconfined weight test is generally called uni essential weight tests, is uncommon occasion of a tri center point test, where limiting weight is zero. UC test does not require the progressed tri significant setup and is less troublesome and speedier test to execute when stood out from tri center point test. In this test, a barrel of soil without even help is attempted to frustration in essential weight, at a predictable rate of strain. The compressive load per unit domain required to crash and burn the case as called un confined compressive nature of the earth.

Fig6: Unconfined Compression Testing Machine

4.5DIRECT SHEAR TEST

The direct shear device is used to determine failure envelopes for soils. The device is not suitable for determination of stress-strain properties of soils.

4.5.1EQUIPMENTS USED

1) Direct shear apparatus and Loading frame.
2) Dial gauge, Proving ring, Balance to Weight Up to 200g.
3) Tamper, Straight edge, Aluminium container, Spatula.

Fig7: Direct Shear Test Apparatus

V. RESULTS

This Chapter shows the various test results which are conducted on the normal soil, as well as the stabilized soil with Coir fiber and $CaCl_2$ in different proportions.

5.1TESTS ON NORMAL SOIL

5.1.1FREE SWELL INDEX TEST:

Initially Free Swell Index test conducted to the soil sample, based on this selling index value the value of optimum chemical value can find easily. IS: 2720 Part(40) - 1970

Formulas to be used

Free Swelling Index Value = $[V_d - V_k] / V_k \times 100\%$

Where, V_d = Volume of soil specimen read from the graduated cylinder containing distilled water.

V_k = Volume of soil specimen read from the graduated cylinder containing kerosene.

5.1.2 IDENTIFICATION & CLASSIFICATION OF SWELLING SOIL

Table no.5.1.1:

IS CLASSIFICATION SYSTEM (IS 1498- 1972)

Free Swell	Liquid Limit	Plasticity index	Degree of Expansion	Degree of Severity
<50	20-30	<12	Low	Non-Critical
50-100	30-50	12-13	Medium	Marginal
100-200	50-70	23-32	High	Critical
>200	70-90	>32	Very High	Severe

Table : Classification of swelling soil

5.1.3Result (for Normal Soil)

V_d = Volume of soil specimen read from the graduated cylinder containing distilled water =28

V_k = Volume of soil specimen read from the graduated cylinder containing kerosene = 12.9

Free Swelling Index Reading = {(28-12.9)/12.9}X100 = 117.03%

Hence,FSI for Normal soils = 117.03%

(As, From Table - Degree of severity is high)

5.2ATTERBERG LIMITS:

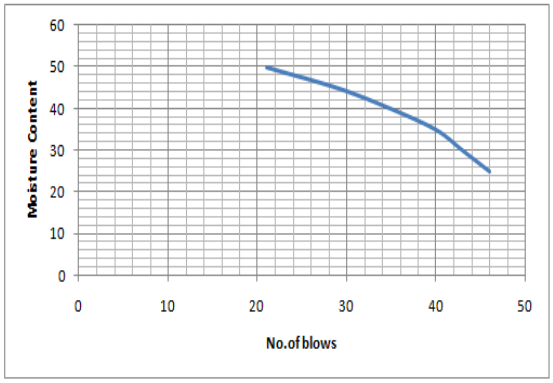
All the tests are conducted based on IS: 2720 Part (V) -1965.

5.2.1LIQUID LIMIT TEST:

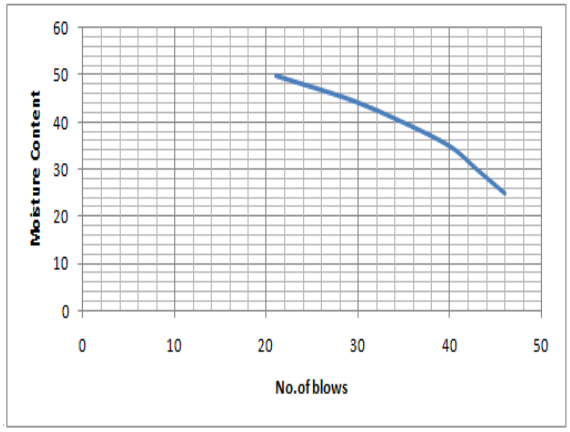
Results

S.NO	Weight of soil taken (gms)	Water added (%)	No. of blows
1	100	25	46
2	100	30	43
3	100	35	40
4	100	40	35
5	100	45	29
6	100	50	21

Table no.5.2.1: Liquid limit test results for normal soil



But, as per Indian Standards, IS 1498-1972 the soil sample contains **High degree of severity**



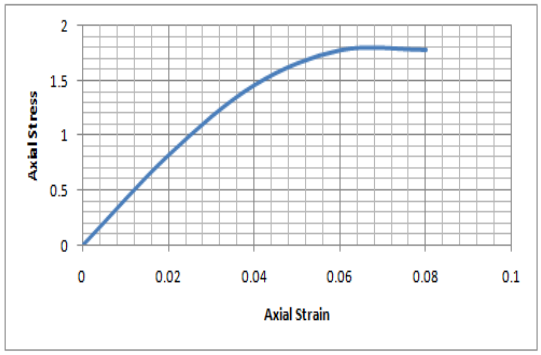


Fig 7: Axial stress Vs Axial strain

Maximum Axial stress q_u = 2.085 kg/mm^2

Maximum shear stress of Normal soil = (q_u / 2) = 2.085 / 2 = 1.042 kg /mm^2

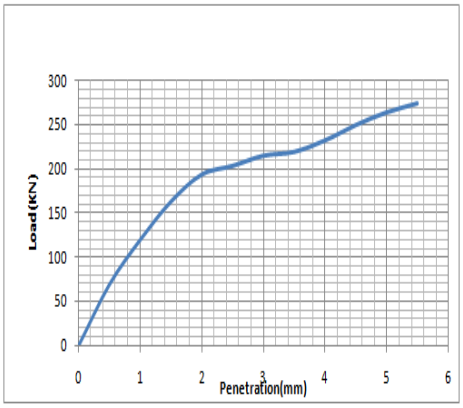


Table no.5.8.5: CBR @ 5% of fiber

VI. CONCLUSION

The results of the study clearly indicate that the combined use of coir fiber, fly ash, and calcium chloride significantly enhances the engineering properties of weak soil. The treated samples exhibited increased unconfined compressive strength, higher CBR values, reduced plasticity index, and better compaction characteristics compared to untreated soil. The coir fiber improved tensile and shear resistance, while fly ash and $CaCl_2$ contributed to cementitious bonding and moisture reduction.

This synergy between natural fibers and industrial byproducts offers a sustainable, economical, and effective solution for soil stabilization. Moreover, the approach supports waste utilization and reduces reliance on conventional stabilizers with high carbon footprints.

In conclusion, the proposed method shows strong potential for road subgrade enhancement, embankment stability, and other geotechnical applications in infrastructure development. Future research can explore the long-term durability and field-scale implementation of this stabilization

technique under various climatic and loading conditions.

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