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Comprehensive Review on the Influence of Natural Materials in Soil Stabilization

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Abstract. This comprehensive review insists on the impacts of various natural materials in the conventional ground improvement techniques. This review paper focuses on the utilization of natural materials such as Eggshell powder, Rice husk ash, Wheat husk ask, Tamarind Kernel Powder, Jaggery, Chebula, Lime and coir fibers as soil stabilizers. The properties of Unconfined Compressive Strength (UCC), California Bearing Ratio (CBR), index and consolidation characteristics had been compared with existing conventional strength of soils. Out of the materials used for soil stabilizing agents, Rice Husk Ash, Eggshell powder and Tamarind Kernel Powder showed better ground improvement properties. The eggshell powder with 5% optimum replacement by weight of dry soil sample showed an improvement in strength. The properties of the soil sample achieved the improvement in strength with rice husk ash of 6-8% optimum level. TKP of 10% was added in the soil sample showed the soil liquid limit increase to 117% from 67%. TKP of 2% and 8% were added in the soil sample showed the shrinkage limit decrease to 15.4% and 11.4% respectively. Meanwhile, TKP of 8% in the soil sample resulted in a decrease of dry density to 14 kN/m^2 from 17.1 kN/m^2. Similarly, improved strength for achieved from the following combinations of jaggery and eggshell powder, lime and Chebula.

Introduction

In this advanced age of science and technology, man has made rapid strides in all fields since the ancient ages. Right from the dark ages till the present information age, man has grown by leaps and bounds and has tried to come around all kinds of problems encountered by him. From an engineering point of view, especially from a geotechnical perspective, land use for development work has brought to the fore the problem of acute land shortage. This has led to the reclamation of unusable land for development activities.

Ground improvement technology has been the driving force that has brought about this revolution in the reclamation of unusable land, which has led to a sudden spurt in developmental activities. However, all human technologies, since times immemorial have proven to have their drawbacks in most cases. Similarly, this technology, though beneficial in several ways, had environmental impacts. With rapid urbanization and industrialization, land reclamation works have been done with ground improvement technologies. With the rising use of some of these techniques such as cement grouting, lime columns etc., the impact on the environment came to be slowly recognized. In this review study, an effort to see the insights and options of utilizing natural materials like Rice Husk Ash, Jaggery, TKP, ESP, etc. for the beneficial improvement of problematic clays [5].

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Need for this study

Ground improvement may be well-defined as the process of refining the soil engineering properties and creating firmer ones. The need for ground improvement arises under the following circumstances: i. Current industrial and urban development insisting demand land renovation. ii. Consumption of unbalanced and environmentally affected ground. iii. With the use of ground improvement techniques, the safe disposal of waste materials is easy. Even though better results were achieved in soil stabilization by cement grouting, lime columns, chemical stabilization, but their effect on the environment is still available. Hence in this review discussion, an effort has been made for the improvement of problematic clays by use of using natural materials. The current comprehensive review is also envisaged due to the environmental impacts of certain popular methods of ground improvement which have resulted in the need for environment-friendly methods to be adopted [14].

Objective of this study

The primary objective of this comprehensive review is to attain improvement of poor soils with negligible influence on the environment, to attain sustainable growth in utilizing unfeasible land without spoiling the environment. Their main objective can be disaggregated into the following stages. i. To document and evaluate the environmental consequences of recent ground improvement methods. ii. To adopt natural materials in part or whole in ground improvement techniques, after validating their positive results in the improvement of problematic clays [14].

Natural Materials with Soil

Improvement of soil by the recent methods have proved to be of great use in improving the soil and providing the scope for use of otherwise unusable land but on the other hand, have had an impact on the quality of the environment. In recent years more emphasis has gone towards protecting the environment by reducing activities of pollution and using alternative methods that minimize the impact on the environment. In the field of ground improvement, this can be achieved slowly by phasing out polluting methods of ground improvement and use of natural materials that have minimal impact on the environment, in this case, soil and groundwater. Several natural materials can be used in the process of natural materials.

Tamarind Kernel Powder

The performance of Tamarind Kernel Powder (TKP) as an additive agent has been identified recently by various researchers. TKP can be utilized as hydrocolloids in cement and lime to improve their performance. The hydrocolloids function as a thickener, water retention binder and agent, lubricant, suspending agent and friction-reducing agent [5].

Egg Shell Powder

The main aim of using Egg Shell Powder (ESP) is to make the soil well stabilized at a low cost. ESP, as the name suggests, is a powdered form of the outer shell of eggs. The use of ESP in soil stabilisation has been documented to give moderate results in improving problematic soils. The performance of ESP has been documented as lesser compared to that of albumin powder. The use of ESP as a replacement in lime stabilization was studied to find out the optimal percentage of lime for stabilization followed by the optimum quantum of ESP that can replace lime in the stabilisation. The results indicated that the performance of the ESP replaced lime stabilisation gave results marginally lesser than pure lime stabilisation. In this context, ESP can be used as a replacement without much loss in strength, thereby resulting in a decrease in the cost of stabilisation. Albumin on the other hand has been long used in some Middle East countries since ancient times as a waterproofing agent against humidity under paints. Furthermore, it was used in

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Japan as mortar in building masonry – arch bridges, some of which are still in service now. Albumin on one hand has been documented to be good material in its ability to improve the strength of soil, durability and artificially manufactured albumin is costly. However, the prospect of using albumin in small quantities along with ESP is very good [1, 16, 17].

Jaggery and Chebula

Jaggery and Chebula have long been utilized in infrastructure development since so many years ago in the southern part of India. There have been several instances of its use in the arena of Civil Engineering. Brick Jelly Concrete, made with broken bricks, lime, kadukkai (Chebula), and jaggery and so on, was preferred in South India for roofing works since the olden days for thermal insulation of roofs (The Hindu, 2004). One of the oldest churches in India, St. Mary's Church situated in Fort St. George, Chennai underwent major restoration works. Moisture content availability in the walls was the major issue over there, so de-plastering the solution was suggested by many of the researchers. The de-plastering work was done by using the jaggery and lime along with kadukkai (Chebula), and for smooth marble, finishing was done by using lime along with egg yolks (The Hindu, 2005). The facelift to the historical fort in Thirumayam, about 20 km from Pudukkottai on the Pudukkottai–Karaikudi highway, is in the third phase of the renovation of the structure. In the restoration work, a paste of conventional materials such as lime, mortar, jaggery and Chebula ('kadukkai') was used to strengthen the walls (The Hindu, 2008). Work on the renovation of an ancient temple (Sri Uthamadhaneeswarar Temple at Keezhadhaniyam) taking to the utilization of natural materials as renovation materials in the 9th century AD by ASI. The actual condition of the temple was in a dilapidated form. Every pillar and stone were cautiously detached and arranged in the same order for its re-alignment. Conventional natural materials such as jaggery, gall-nut, ('kadukkai') and lime were utilized (The Hindu, 2008). Kadukkai (Chebula) has been long used as a mortar in infrastructure development. A mortar made by using kadukkai, lime grind and egg-white is utilized as a binding agent for bricks in the architecture of Chettinad. Sri Brihadeeswara temple at Gangaikondachozhapuram, Perambalur district built by King Rajendra Chola, has been beneath the purview of the Archeological Survey of India since 1946. This temple has been completely renovated by using a mix of earth, panai vellam, kadukkai, lime and yellow oxide [5].

Rice Husk Ash

Sample of rice husk ash utilized for testing was obtained from Kamakshi rice mills in the location of Chennai, Tamil Nadu. Normally ash is disposed of in the empty barren land which would be causing environmental issues. It is obtained as a byproduct during the manufacturing process of puffed rice, which would be containing silicate and iron oxide in larger amounts. In India, nearly 60,000 tons of rice husk has been obtained after harvesting paddy fields. Its physical properties showed similar to the naturally available sand and also chemically stable ones. Its friction angle and high angularity property exhibit excellent load-carrying capacity and efficient stability [2, 3, 6, 7, 12]. The ingredients of Rice Husk Ash are listed in Table 1, general soil index properties were given in Table 2 and Table 3 shows the soil sample particle size distribution [3].

Table 1. Rice Husk Ash (RHA) Composition

Constituent	Composition (%)
SiO_2	67.3
Al_2O_3	4.9
Fe_2O_3	0.95
CaO	1.36
MgO	1.81
Loss on Ignition (LOI)	17.78

Table 2. Index Properties of Soil.

Soil Property Description	Value (%)
Liquid Limit	67
Plastic Limit	28
Shrinkage Limit	10.2
Free Swell Index	60
Max. Dry Density	1.71 g / cc
OMC	17.5
UCS	58.5 kN/m^2

Table 3. Results of Particle Size Distribution.

Fractions	Particle Size (mm)	Column B (*t*)
Fine Gravel	20 - 4.75	1.4
Coarse	4.75 – 2	5.1
Medium	2 – 0.425	9.3
Fine	0.425 – 0.075	10.6
Silt	0.075 – 0.002	7.0
Clay	<0.002	66.5

Natural Materials with Sand

As with the expansive soils, silty sandy soils are problematic if they are in contact with water. For sandy soil stabilization techniques, pozzolanic materials, cement, lime and nanoparticles are used. Lime and pozzolan used in their study were taken from the locally available. For understanding the minerals available in pozzolan and lime, an x-ray diffraction test was performed [22]. Nowadays during the stabilization of soil in addition to the strength, stability also plays a major concern. In order the improve that, fibres had been introduced to increase the ductile behaviour during stabilization techniques. Prosopis juliflora fibres were used in combination with cement, to improve the geotechnical properties of sandy soils [23].

Methodology

Preparation of Sample

The testing sample would be prepared as per the requirement of Indian Standards. The soil sample used for testing is to be sieved properly according to the testing procedures. The soil was weighed for the testing process. The alternative natural materials were also sieved and weighed as per the replacement percentages. In the dry state, selected natural materials and soil was mixed thoroughly for preparing the sample. TKP materials obtained from the market was directly utilized along with soil, eggshells were thoroughly washed and dried before utilizing as a replacement. Jaggery and lime available in the market were utilized [11, 18].

Materials

According to the plasticity chart, the soil was plotted in the region of high compressible clays (CH). The various natural materials used for the study include a combination of Chebula and jaggery, Egg Shell Powder, Tamarind Kernel Powder and rice husk ash. Rice husk ash with proportions from 5, 10, 20, 30, 40, 50 and 80% mixed samples were prepared [1, 8, 9]. TKP is a composite mixture encompassing Proteins (18-20%), galactose xyloglucan polysaccharide (55-65%), Lipids (6- 10%) and firm minor constituents as fibres and sugar etc. Egg Shell Powder (ESP), as the name suggests is a powdered form of the outer shell of eggs. The main constituents of eggshells are mineralized Calcium carbonate (95%) and the rest consisting of Calcium phosphate and Magnesium sulphate. Jaggery is a traditional unrefined sugar used throughout South and Southeast Asia [18].

Testing of Samples

Index Tests

The various index tests that were conducted to learn the performance of the natural materials in soil stabilization were the free swell test, shrinkage limit and liquid limit tests. All the index tests were accomplished as per the procedure stipulated in the Indian Standards Code [1, 4].

Compaction Test

The compaction characteristics are generally obtained by performing the standard proctor compaction test. However, in this study, a miniature mould was adopted to perform the compaction test to simplify the procedure. The mould was a scaled-down version of the proctor mould and the compaction energy obtained using the hammer made for this mould was almost the same. The number of blows per layer was modified to achieve similar compaction energy, considering all the other parameters as well. The mould had a dimension of 90 mm height and 38 mm diameter. The weight of the hammer was 1.5 kg. The number of blows per layer was seven. The compaction energy delivered by this hammer was 0.605 J as against the energy delivered by a standard proctor hammer of 0.595 J. The procedure adopted is the same as that of the standard proctor test. About 300g of soil was taken passing through a 2.36 mm sieve and retained in a 710-micron sieve. The test was started with around 10% water content. The mould was weighed before the test. The inside of the mould was oiled before each trial. The soil was divided into three portions and compacted by three layers into the mould. Each layer was compacted by giving three blows of the 1.5 kg hammer. Before filling in the second layer, the surface was scarred using a straight edge, for proper bonding of the layers. The collar was placed before filling in the third layer and sufficient soil was filled in such that the compacted height of the soil was above the height of the mould. After the third layer was compacted the collar was removed and the excess soil was struck off using a straight edge. The weight of the mould plus soil was taken after trimming the excess soil. The soil sample was then extruded and a representative sample from the three layers was placed in the oven for water content determination. The test was then repeated by increasing the water content in the soil in steps of 2%. The trials were continued till the weight of the compacted soil reached a peak value and then decreased. At least two trials after the peak value were performed. The readings were noted after each trial and the maximum dry density and optimum water content were determined by plotting a graph between dry density and water content [3, 19].

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Unconfined Compression Strength Test

The soil sample strength, as well as treated soil, was studied by performing unconfined consolidation tests. The unconfined compression test was performed as follows. The density and the water content at which the test was to be performed were fixed initially. The weight of soil required to achieve that density was worked out. The water quantity based on the predetermined water content was worked out. The soil sample was then prepared by filling the mould and applying static compression. After preparation of the sample, it was extruded from the mould. The dimensions of the soil sample were checked and its weight was measured. The sample was placed on the compression testing machine in such a way that the axis of the sample was as close as possible to the loading plate. The dials were adjusted to zero and the proving ring details were noted. The strain rate was set and the motor was started. The load readings and the strain readings were measured at frequent intervals to define the stress-strain relationship. The test was continued till the racks were well-formed. The specimen was then removed and was oven-dried to determine the water content [10, 20].

One Dimensional Consolidation Test

The compressibility characteristics of the soil, as well as the treated soil, were determined by performing the consolidation test. As in the case of the unconfined compression test, the density and the water content at which the compressibility was to be studied was set initially. The height and the diameter of the consolidation ring were measured and the inside surface of the ring was lubricated with a thin film of oil. A sufficient quantity of soil was weighed out to achieve the set density and prepared to the predetermined water content was carefully placed inside the ring, using the spacer. The weight of the soil sample plus the ring was measured. Two filter papers were moistened and placed on either end of the soil sample. A porous stone was soaked in water and placed on the base of the oedometer and the prepared sample was placed on top of it. The second porous stone was placed on top of the prepared sample, after soaking it in water. The loading block was then placed on top of the porous stone. The outer ring was placed on the setup after placing the rubber washer and the entire setup was tightened thoroughly. The sample was then immersed in water completely. The loading platform was adjusted till it touched the loading block. The dials were checked and the initial reading was noted. Then the loading frame was loaded using a load of 0.5 kg/cm^2. After a lapse of 24 hours, the dial reading was noted and the next increment of the load was put. The tests were performed for loads of 0.5, 1, 2, 4 and 8 kg/cm^2. Time-bound readings were taken for any two of the load increments to study the compression versus the time behaviour. After the test, the ring was dismantled and the final weight of the sample plus ring was taken. The sample was ejected from the ring and oven-dried to determine the final water content. The coefficient of vertical consolidation was computed from the time compression tests conducted on the soil as well as soil mixed with various natural materials, using the square root of the 't' method [13, 21].

California Bearing Ratio Test

The California Bearing Ratio Test (CBR) was conducted to determine the strength properties of the soil sample be tested. The increase of rice husk ash replacement in the soil sample reduces the soil strength but adding a small amount of lime will maintain the strength of soil samples [2, 12].

Conclusion

The following are the conclusions made from this comprehensive review paper,

- ✓ While observing the previous works, rice husk ash made a significant effect on the stability properties of soil.

- ✓ By utilizing the ESP and TKP along with clay showed better strength properties in eggshell powder and detrimental effects achieved in tamarind kernel powder.
- ✓ The combination of Jaggery:Clay:Lime would be getting better performance at the lesser percentage of combinations. In addition to that tamarind kernel powder was used to absorb and retain moisture in the areas where the permeability property is required. Hence the huge water retention capability of the soil can be adopted advantageously similar to Bentonite.
- ✓ The utilization of eggshell powder has resulted in the improvement of the characteristics of soil properties and it would be utilized in the soil stabilization technique can be recommended.
- ✓ The combination of J: C: L has improved the index properties of the soil. The use of Chebula can be studied further by avoiding it in combination and studying the results of strength tests. If the results are better than the one studied in this investigation, then the combination sans Chebula can be recommended.
- ✓ With the combination of 15% pozzolan and 3% lime in the stabilization of silty sandy soils, compressive strength has been increased by 16 times in comparison to the natural soil and is considered to be the optimum.
- ✓ The combination of 1% Prosopis juliflora fibres and 9% cement yield higher geotechnical properties in sandy soils.

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