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An Analytical Review on Comparative Analysis of Ground Improvement Using Various Admixtures

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Abstract

Soil improvement in the most sustainable way is the need of the hour and prime importance for the modern construction industry. Most of the time, it has been observed that the soil below the foundation is not mechanically capable of withstanding the load from the structure, and it might cause the failure/collapse of the structure. To prevent it, various significant soil improvement techniques have been introduced, such as mechanical stabilisation, thermal methods, use of admixtures etc. Ground improvement using admixtures involves the addition of various chemical alternatives to the subsoil to enhance its load-bearing capacity. These procedures also give long-term sustainability regarding the soil's bearing capacity. Various potential scholarly works on ground improvement have been done, i.e., the addition of bentonite, kaolinite, bitumen, rice husk ash, pond ash, lime, and cement into the soil, which has been intensely reviewed. From the combined observed experimental results of several researchers presented in this paper, it can be identified how much improvement of a particular soil property can be made by adding several types of admixtures. A clear idea can be generated as to which type of admixture is most suitable for the improvement of a particular type of soil and which soil properties can be improved by the addition of that admixture.

Keywords: *Bearing Capacity, Bentonite, Bitumen, Ground Improvement, Kaolinite, Rice Husk Ash*

1.0 Introduction

The load transferred to the soil from the superstructure does not always fall within the limit of the safe bearing capacity of the soil. As a result, shear failure of soil occurs which causes tremendousdamage to the structure. However certain ground improvement methods can be implemented to improve the subsoil characteristics which involve either chemical or mechanical stabilization of soil or both.

It is essentially done to make the soil sustain the load from various structures. It increases the efficiency of soil characteristics such as dry density, shear strength, swelling - shrinkage and bearing capacity. It also enhances the subsoil surface characteristics and is applicable for both cohesive and cohesionless soils. Research in ground improvement techniques has been carried out for decades to evolve several methods of soil stabilization and to find new better ways.

The ground improvement techniques can be broadly classified in two ways, i.e., mechanical stabilization and chemical stabilization by the addition of several admixtures to the soil. The methods of mechanical stabilization are dropping the hammer, dynamic consolidation, stone columns, and application of sand drains, sand wicks and prefabricated vertical drains. However, the major disadvantages of these methods are that only a certain depth of soil from ground level can

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be improved, these methods do not provide long-term stabilization of soil and the effectiveness of these methods is less concerning cost.

On the contrary chemical stabilization involves the addition of several admixtures i.e., addition of cement, pond ash, rice husk ash, bitumen, lime, bentonite, and kaolinite to the soil. The depth of soil to be improved problem can be solved with the help of making slurries by adding admixtures with water or any solvent and it can be applied to the ground by inserting these slurries by jet pumping in a steel pipe having a nozzle tip at the bottom for any amount of depth to the ground. After inserting these slurries, the admixtures get inserted into the soil and the voids between soil particles get filled by admixtures which reduces the permeability of the soil and also increases the shear strength of the soil by a significant amount, which not only improves the ground condition for sustain a large amount of loads coming from the superstructure to the soil, also this chemical stabilization method solves the seepage problem of the soil on which the foundation rests.

2.0 Objective

A geotechnical engineer mostly faces difficulty when construction work starts and the supporting soil on which the foundation of the rests becomes weaker or does not possess sufficient load-carrying capacity and the structure undergoes differential or total settlement. In this regard determination of the allowable and safe bearing capacity of the supporting soil (by both laboratory and field test) is very much essential. Most of the soil where the construction work is to be done is either cohesive soil or a combination of cohesive and cohesionless soil (c-φ) soil. If it has been found that the supporting soil does not have sufficient load-carrying capacity, then the ground improvement of that soil will become essential before starting the construction process. In this review paper, various works of ground improvement using several admixtures such as pond ash, rice husk ash, bitumen, lime, cement, bentonite, and kaolinite have been studied,and the experimental results of several researchers have been analyzed and compared based on ground improvement statistics. The advantages and disadvantages have been studied,and their applicability to several types of soil and ground conditions has been commented on.

3.0 Literature Review

A detailed study of the previous research works by several researchers has been summarized in this portion.

3.1 Ground Improvement Using Bentonite

The product of the weathering effect on volcanic ash (pyroclastic tuffs and tuffites)[1] is usually in the presence of water which binds water molecules well andshows low permeability to water. Three types, mainly found in nature based on cation content- calcium bentonite, sodium bentonite and potassium bentonite[2] have characteristics as shown in Table 1[3].

Sodium bentonite is mixed with soil to make the porous soil water-tight due to its ability to reduce the permeability of soil. Calcium bentonite can be used to

Table 1. Comparison of properties of calcium and sodium bentonite[3]

Characteristics of Bentonite	Sodium	Calcium
Water absorption	Large	Small
Ability to swell	Very large	Small
Heat resistance	Bigger	Smaller
Casting properties	Good	Weak
Rheological properties	Good	Weak
Waterproofing	Good	Medium
The ability to create thixotropic gel	Large	Small

improve the water-retaining capability by bonding with the particles of both cohesive and cohesionless soil[4].

3.1.1 Improvement of Cohesionless Soil

Tests on sandy soil were performed from Toro District and Mbale District, Uganda, mixed with Ca-bentonite[5]. Water content increased and became stable at 10% to 15% bentonite. Tests on bentonite have been conducted in Ramgarh, Jaisalmer, mixed with dune sand, Jodhpur, India[6]. Unconfined Compressive Strength (UCS) of dune sand has been increased and stabilized at 15% bentonite content, curing environment prominently influenced results. Bentonite has been mixed with Yamuna sand, to study the effect on compaction and shear strength properties[7]. Light compaction tests, direct shear tests and unconsolidated undrained tri-axial tests were performed. Optimum Moisture Content (OMC) and Maximum Dry Density (MDD) increased when mixed at 20% and 15% respectively, Cohesion increased to a certain limit of 20%. Bentonite has been used to improve sandy soil properties[8]. Modified Proctor test and Direct Shear Tests were performed. Maximum cohesion and plasticity for poorly graded sandy soil were obtained at 7.5% bentonite. The effect of sodium bentonite on Itanagar cohesionless soil, Arunachal Pradesh was experimented with in 2016[9]. A falling head permeability test, proctor test, and direct shear test were performed. Permeability of soil reduced, max at 20% bentonite content. OMC increased, and MDD decreased with increased bentonite content up to a certain limit.

3.2 Ground Improvement Using Kaolinite

A subgroup of clayey materials has polytypic namely nacrite, dickite and a polymorph called halloysite shows plasticity[10]. White and soft clay, composed of fine grain and plate-like particles, alternate forms of feldspar-rich rocks and anhydrous aluminate silicates shows properties of natural pozzolana enable clay to form cementitious bonds with secondary material particles[11].

3.2.1 Improvement of Cohesive Soil

Peat soil obtained from Selangor, Malaysia has been mixed with local kaolinite and an unconfined compression test and permeability test were performed[12]. 10% kaolin content showed maximum unconfined compression strength. The test specimen with a binder dosage of 300kgm^{-3} showed the highest unconfined compression strength of 485 kPa. The effect of kaolinite from Sina, Egypt was studied on the geotechnical behaviour of calcareous soil from Badr village, Egypt[4]. Compaction and CBR tests were performed. An increase in MDD and a decrease in OMC were observed, stabilized at 9% kaolinite. The best compaction was achieved for 6% kaolinite.

3.2.2 Improvement of Cohesionless Soil

To study the shear strength behaviour of mining sand, it has been treated with clay and hydrated lime and has been mixed with 5% clay and kaolinite[13]. A monotonic undrained triaxial compression test has been conducted. Clay content between 30-50 % has increased the strength of the soil sample.

3.2 Ground Improvement Using Bitumen

Bitumen is a thick, sticky, black or dark brown substance that is a form of petroleum. It is a highly viscous and waterproof material composed mainly of heavy hydrocarbons. Bitumen is commonly known as asphalt in its solid or semi-solid state. It remains solid at room temperature but can become more fluid when heated. Soil bitumen mixture has been used to make cohesive soil water resistant[14]. Fine-grained materials mixed with small percentages of lime allow penetration and mixing of bitumen into sandy soil. Bitumen-stabilized soil shows increased frost and water resistance, bearing capacity, stability, and flexibility[15].

3.3.1 Improvement of Cohesive Soil

To study the effect of bitumen emulsion on lateritesoil obtained from Anandhapuram Village (Visakhapatnam) specific gravity test, sieve analysis, Atterberg limit test and standard proctor test were performed[16]. Bitumen emulsion significantly improved the CBR of the soil. It has been found that the CBR value increased by 50% in the virgin soil. Improvement in the shear strength of bitumen emulsion has been observed when it was mixed with laterite soil[15]. Specific gravity test, Atterberg test, standard proctor test, unconfined compression test, direct shear test and California Bearing Ratio (CBR) tests were performed. Soil strength increased to 10% bitumen emulsion content. To study the effect of bitumen emulsion in black soil collected from Chittorgarh, Rajasthan, specific gravity test, Atterberg test, sieve analysis test, compaction test and CBR test have been performed on specimens with varying Bitumen content[17]. CBR of the soil increased considerably with the addition of bitumen emulsion and it showed the best results 4 hours after mixing. MDD of the soil has also increased in this experimental procedure.

3.3.2 Improvement of Cohesionless Soil

Bitumen-stabilized granular soil obtained from Ekiti state, Nigeria has been investigated and the California bearing test has been performed on specimens prepared by varying bitumen content[18]. MDD and CBR increased with bitumen content, and it has achieved maximum value at 4%. Kumar and Bansal (2017) studied the Behavior of sandy soil from Kurukshetra with cutback bitumen have been studied and proctor tests and unconfined compression tests have been performed on 9 specimens[19]. MDD increased and maxed at 12% cutback bitumen. Maximum UCS value obtained at 12% bitumen content. Max CBR value obtainedat 10% stabilizing agent.

3.4 Ground Improvement Using Pond Ash

Pond Ash is a byproduct of coal-based thermal power production plants which is disposed of in a pond in the form of slurry. It is composed of silica, alumina, iron oxide, calcium oxide, magnesium oxide, sulphur[20,21].

3.4.1 Improvement of Cohesive Soil

Black cotton soil collected from Mantur Road was stabilized when it was mixed with pond ash collected from the thermal power plant in Raichur, India[22]. The Atterberg test and compaction test were performed on specimens. The optimum dosage was observed to be 18%. MDD was found to be 1.55 gm/cc and OMC 24%. UCS attained maximum value at 18% pond ash content. To understand the change in strength characteristics of black cotton soil, the black cotton soil obtained from Palakkad has been prepared by mixing fly ash and pond ash[11]. A compaction test, unconfined compressive test and CBR were performed. Sixty per cent of pond ash was found optimum for stabilization. With increasing pond ash content, MDD decreased, and OMC increased. The stabilization of expansive soil collected from Nashik; Maharashtra has been studied thoroughly[23]. Sieve analysis, specific gravity, Atterberg's limits, compaction, unconfined compression strength, direct shear test, and CBR tests were performed, and it has been observed that the soil properties have been improved. To study the improvement of the subgrade with pond ash, clayey soil collected from Mohali, Chandigarh was mixed with pond ash collected from the thermal power plant at Ropar[24]. The addition of Pond ash showed decreased MDD and increased OMC. The improvement of the subgrade with pond ash has been studied at the same time[24]. Silty soil collected from CCET, Chandigarh, has been mixed with Pond Ash collected from the thermal power plant Ropar. The addition of Pond ash has shown a decrease in MDD and an increase in OMC for silty soil. The stabilization of tropical peat soil collected from Matang, Sarawak, with class F pond ash collected from Sejingkat Thermal Power Plant, Kuching, and Sarawak has been studied[25]. Standard proctor test and unconfined compressive strength test were performed on the sun-dried specimen. MDD for the stabilized peat has been increased and OMC was decreased with an increase in pond ash content.

3.5 Ground Improvement Using Rice Husk Ash

Rice Husk Ash (RHA) is a byproduct of the burning of rice husks, which are the outer covering of rice grains. When rice is processed, the husks are separated from the rice grains. Instead of being discarded as waste, these husks can be burned to produce rice husk ash. The use of rice husk ash provides an environmentally friendly way to utilize a byproduct that might otherwise be considered waste.

3.5.1 Improvement of Cohesive Soil

The improvement of clayey soil characteristics obtained from the Baladroz site; Baghdad mixed with RHA has been studied thoroughly[26]. Liquid limit, plastic limit, specific gravity, compaction, unconfined compression test, and swelling tests were done. Liquid limit, plasticity index and MDD have been decreased and OMC has been increased with an increase in RHA content. UCS has been increased very well and it has reached the maximum of 6-8 % RHA content. An extensive study has been done on the stabilization of alluvial soil obtained from Thungachatram, Chennai mixed with RHA[27]. Liquid and shrinkage limit, compaction characteristics, shear strength, free sell indexand CBR values were tested. Liquid limit, free swell index, OMC, and undrained cohesion value decreased and shrinkage limit, MDD, angle of internal friction, and CBR increased with increasing RHA content. It has been studied the change in geotechnical properties of cohesive soil combined with RHA on silty clayey soil collected from Khulna, Bangladesh[28]. Compaction tests, unconfined compressive tests, and consolidation tests have been performed. RHA-treated soil showedimprovement in all geotechnical properties. MDD, shrinkage limit decreased, OMC, liquid limit, and plastic limit increased. 10% RHA content showed the highest unconfined compression strength. Experimental research has been done to find the effect of rice husk ash on laterite soil properties obtained from Enugu estate, Nigeria[29]. Compaction, consistency, and shear strength characteristics have been tested. MDD decreased and OMC, volume stability, and CBR have been increased with an increase in rice husk content. The optimum content of RHA in laterite soil was found to be 10%.

3.6 Ground Improvement Using Lime

Calcium cations from hydrated lime may replace the cations present in natural soil and it can increaseits pH. The properties of the clay altered such that plasticity and moisture capacity reduced and it has led to increased stability.

3.6.1 Improvement of Cohesive Soil

To find the properties of lime stabilized subbase an experimental study has been performed[30]. Optimum moisture content and dry density improved. The suitabilityof lime for soil stabilization has been studied in laboratory[31]. Atterberg's limit, compaction factor test, and CBR were performed. 10% lime is optimum for the stabilization of clay soil. The effect of lime on clayey soil obtained from Baliapur, Near BIT Sindri, Dhanbad has been studied[32]. It was observed that OMC, Specific gravity, CBR and UCS values have been increased while MDD, Liquid content, plasticity, and permeability have been decreased. UCS increased with increased curing time. Lime was mixed with black cotton soil obtained from Utnal village near Vijayapur (Karnataka) in various proportions and sieve analysis, specific gravity test, liquid limit test, plastic limit test, standard proctor test, modified proctor test has been performed[33]. Liquid limit and plastic limit decreased with an increase in fly ash. The optimum value of MDD was obtained for 25% lime. UCS increased with increased curing time. Black cotton soil has been stabilized with lime[34]. 4% and 6% lime added to black cotton soil and liquid limit, plastic limit, MDD, OMC, CBR test, bulk density, dry density, grain size analysis and swelling pressure tests have been performed. Liquid limit, MDD, and swelling pressure have been decreased and CBR value has been increased with added lime. The effect of lime on lateritic soil obtained from Niquelândia, Goiás state, Brazil has been studied[35]. The strength and local bearing capacity of thesoil increased and curing time positively affected the shear strength properties of soil. It has been experimented to stabilize black cotton soil with lime and brick dust[3]. Maximum improvement in engineering properties was achieved at 35% brick dust and 5% lime.

3.6.2 Improvement of Cohesionless Soil

An experimental study has been done to find the effect of lime on sandy soil[36]. Modified procter test, unconfined compressive test, and plasticity index test have been performed. It has been found that the OMC value has been increased and MDD was decreased with an increase in lime content. Soil stabilized with 6% lime content showed maximum UC strength.

3.7 Ground Improvement Using Cement

Hydration reaction of cement with water produces Calcium Silicate Hydrate (CSH) gel whichfills up the empty pores between the soil particles and stabilizes the soil. The crystals formed because of a hydration reaction interlocking the particle due to the formation of CSH gel. Hence any type of soil can be stabilized.

3.7.1 Improvement of Cohesive Soil

Portland cement has been mixed with sandy-silty clay for experimental analysis[37]. The treated soil acted as soft rock and showed brittle behaviour. The optimum moisture content was found to be 12%. A greater compressive of the soaked sample was observed. It has experimented to stabilize soil with rice husk and cement[38]. MDD, OMC, CBR and UCS tests have been performed on high-plastic clay mixed with cement. OMD and shear strength have been increased and showed maximum values at 10% RHA and 6% cement content. Cement has been mixed with silty sand soil type and Grain Size Analysis, Atterberg's Limits, Proctor Compaction Test, Direct Shear test and California Bearing Ratio Test have been performed[39]. Liquid limit, plastic limit, and plasticity index, OMC, cohesion value have been decreased and maximum dry density,angle of internal friction and CBR value have been increased with the increase in cement content. Later the stabilization of black cotton soil mixed with Portland pozzolano cement has been studied[40]. The liquid limit fluctuated; the plastic limit was increased with an increase in cement content.

4.0 Methodologies Proposed by Several Researchers

Several types of geotechnical laboratory tests have been performed by previous researchers to get to know and identify how much amount of which type of soil gets improved by adding several admixtures to the soil. Based on the works done by the researchers and the brief reviews by them[41] the most important methods to determine the improvement of physical properties of soil are the proctor test (to determine MDD and OMC), unconfined compression strength test (to determine UCS value) and static triaxial test (to determine shear strength values of soil) mixed with several admixtures.

A detailed design guide of the ground improvement techniques and methodologies to identify ground improvement characteristics of soil mixed with admixtures has been proposed by Euro Soil Stab[42]. The researchers have performed those laboratory tests by either taking a particular type of soil by adding several admixtures to them or they have studied the usefulness of a particular admixture in several types of soil and identifying which type of admixture is best suitable for a particular type of soil.

The usefulness of these test methods, their applicability, the experimental results of the previous researchers and their significant contributions to ground improvementtechniques have been provided in the next section. The observed experimental results by using those methodologies described previously have been summarized and graphical representations have been given in the following section.

5.0 Results and Discussion of Experimental Results

Improvement in the sand, bentonite, black cotton, laterite, and sandy silty soil stabilized with bentonite, kaolinite, bitumen, pond ash, rice husk ash, lime and cement were studied. Changes in mechanical characteristics- MDD, UCS, OMC and shear strength (from triaxial test) were observed, and graphical representations have been prepared from the available data to compare the stabilizing properties.

5.1 Cohesionless Soil

In Figure 1, the increased percentage of bitumen and kaolinite increased the MDD of the soil. Lime decreased

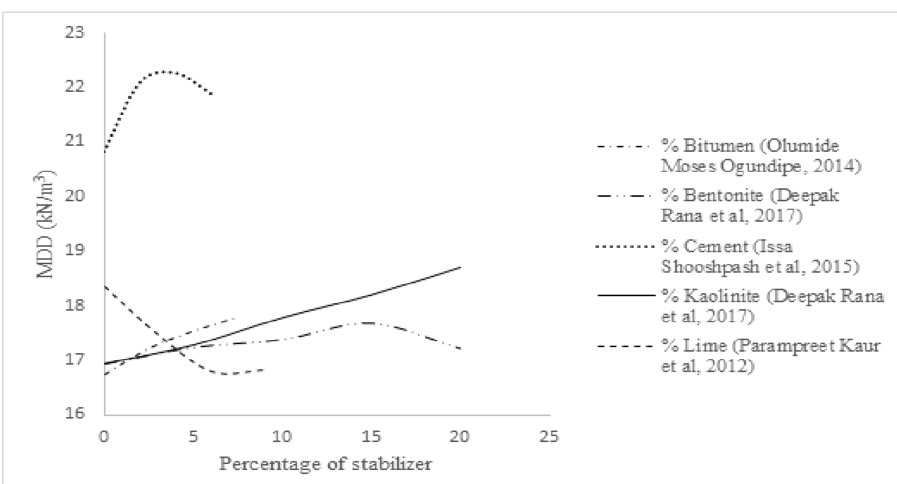

Figure 1. Change in MDD with change in percentage of stabilizer.

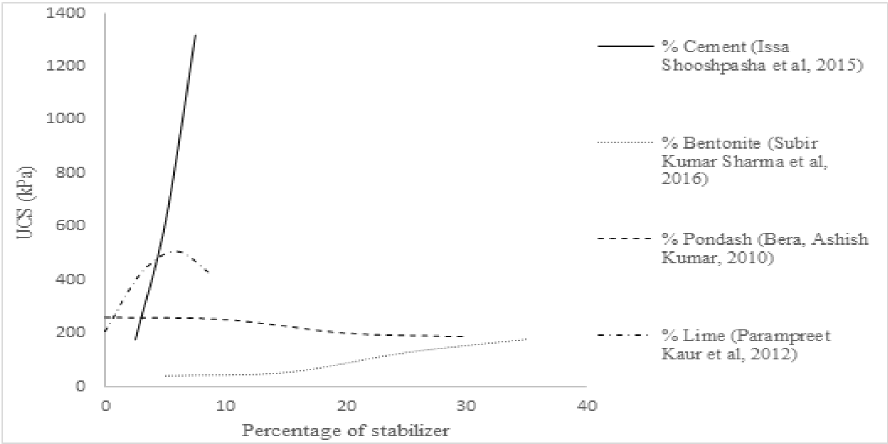

Figure 2. Change in UCS with change in percentage of stabilizer.

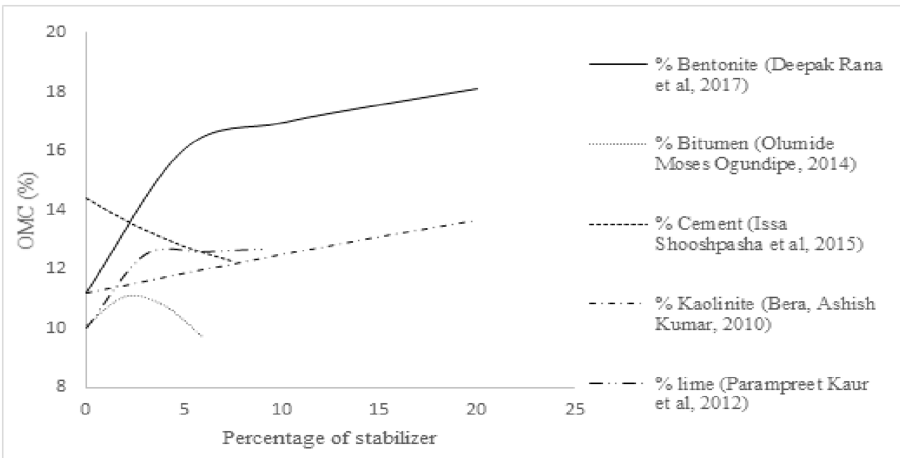

Figure 3. Change in OMC with change in percentage of stabilizer.

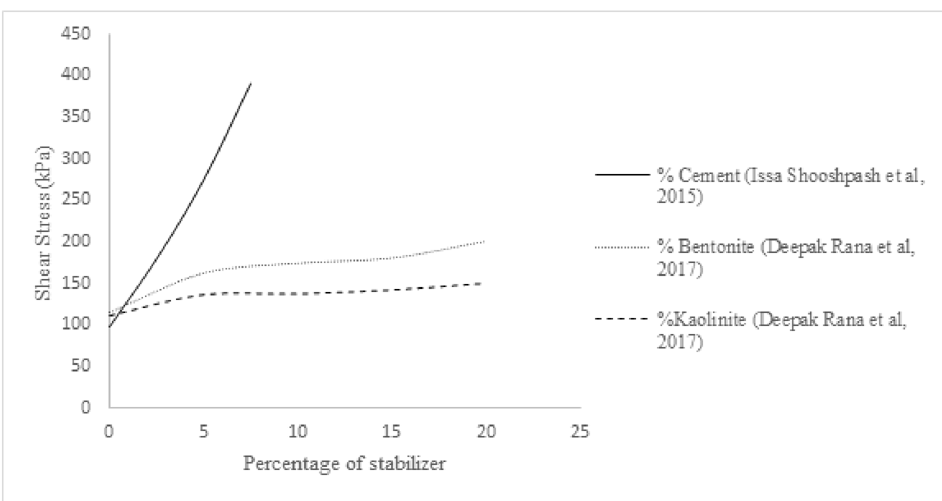

Figure 4. Change in shear stress with change in percentage of stabilizer.

the density and cement, and bentonite affected the parameter variably, at first increasing and then decreasing the density. Overall kaolinite-improved soil showed the bestimprovement in MDD.

In Figure 2, it has been found that increased bentonite and cement improved the unconfined compressive strength of the specimen, while lime and pond ash at first improved, then decreased UCS. Overall Cement stabilized soil showed the best improvement.

In Figure 3, it has been observed that increased cement content improved granular soil and showed a steady decrease in OMC. Lime and bitumen stabilized soil showed varied behaviour. It can be concluded that bentonite and kaolinite deteriorated the soil condition.

In Figure 4, it has been seen that cement-stabilized soil showed the best improvement in the direct shear strength of soil. Bentonite and kaolinite showed small improvement.

5.2 Black Cotton Soil

In Figure 5, cement-stabilized soil showed a steady increase in MDD, however, lime-stabilized soil after

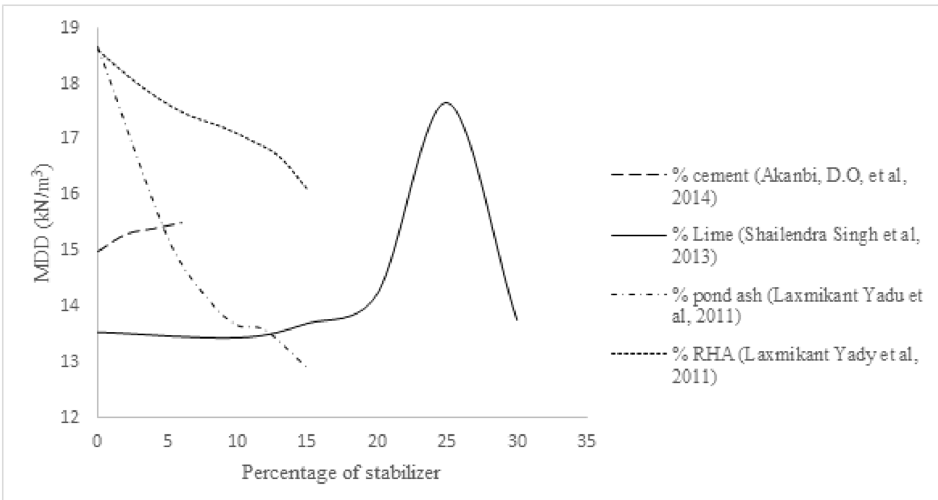

Figure 5. Change in MDD with change in percentage of stabilizer.

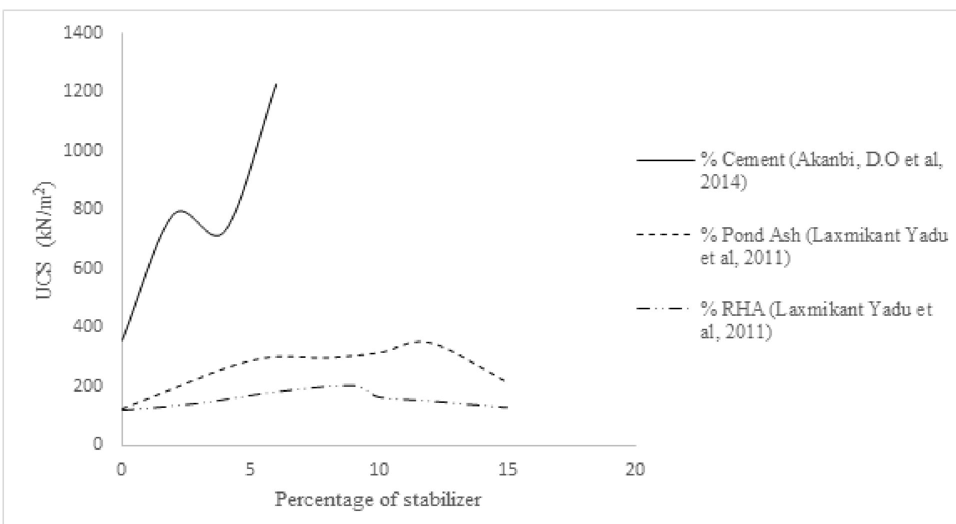

Figure 6. Change in UCS with change in percentage of stabilizer.

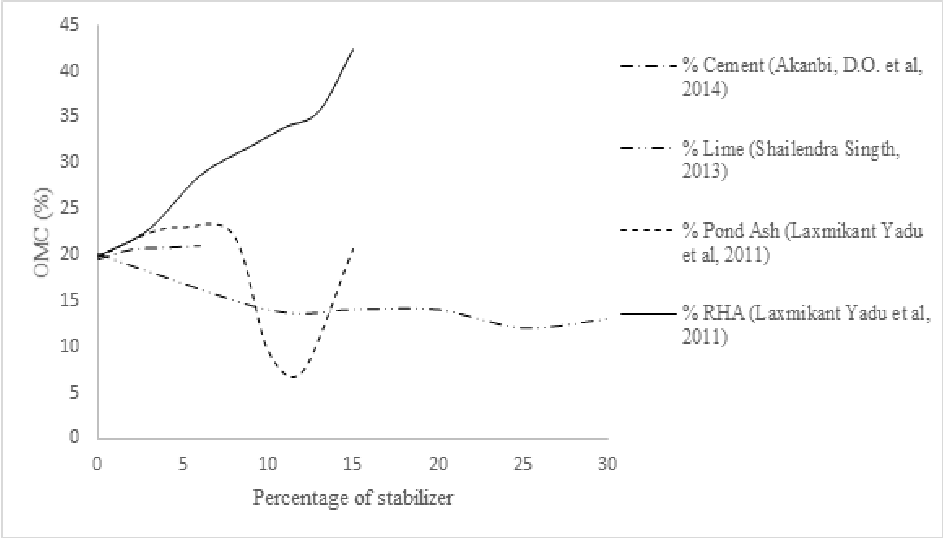

Figure 7. Change in OMC with change in percentage of stabilizer.

initial declination showed good improvement and maxed at 25% followed by declination. RHA and pond ash stabilized showed steady declination in MDD and cannot be used.

From Figure 6, in comparison to RHA and pond ash cement stabilized soil showed the best improvement of black cotton soil.

In Figure 7, pond ash and Lime stabilized soil showed decreased OMC percentage in blackcotton soil. Cement-stabilized soil showed steady OMC while RHA deteriorated the black cotton soil.

5.3 Clayey Soil

In Figure 8, bentonite-stabilized clayey soil showed a steady increase in MDD with an increased percentage of stabilizer and showed maximum improvement. Pond ash, lime and RHA-stabilized soil showed decreased MDD.

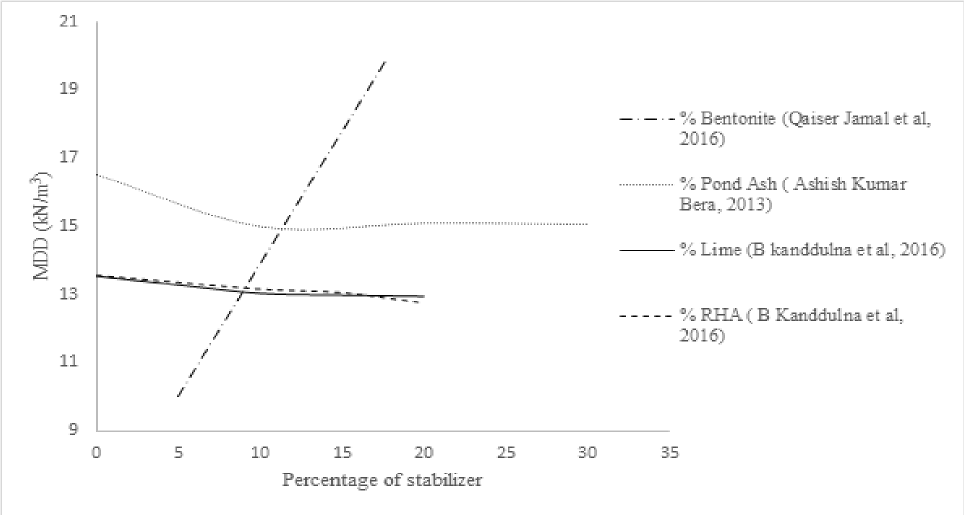

Figure 8. Change in OMC with change in percentage of stabilizer.

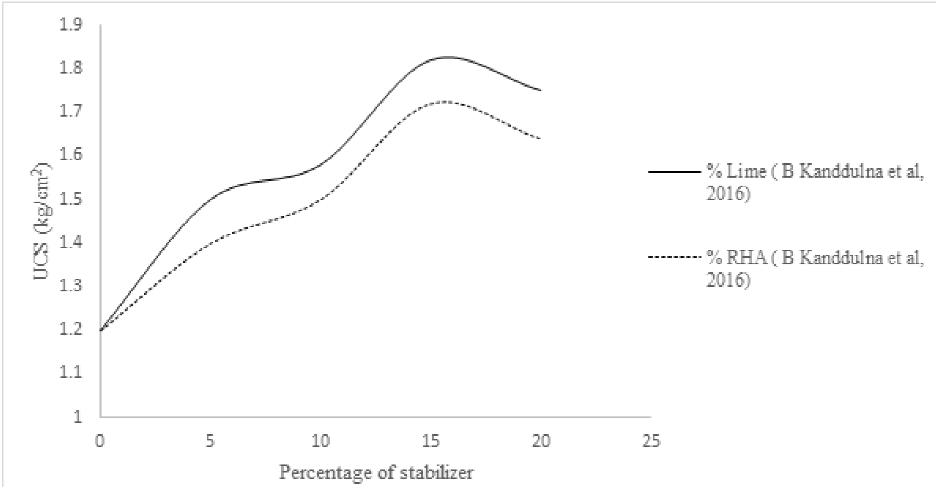

Figure 9. Change in UCS with change in percentage of stabilizer.

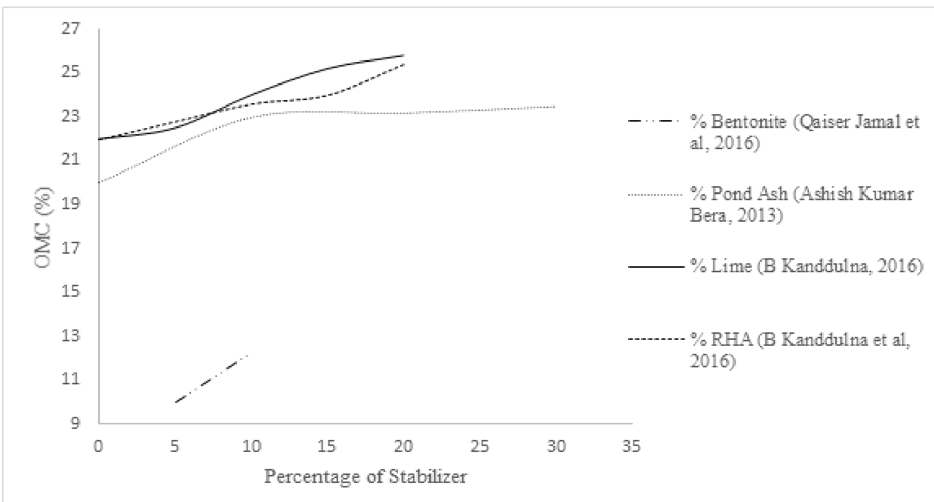

Figure 10. Change in OMC with change in percentage of stabilizer.

In Figure 9, Lime and RHA stabilized soil showed varied results with varied percentages of stabilizer. In comparison to RHA, lime showed better performance in clayey soil.

In Figure 10, it has been observed that all the stabilizers deteriorated in the virgin soil condition.

5.4 Laterite Soil

In Figure 11, the RHA stabilized specimen showed a small improvement in MDD for laterite soil. Lime and bentonite decreased the MDD as compared to virgin soil. Cement-stabilized soil showed almost stabilized MDD in laterite soil.

In Figure 12, it has been observed that lime deteriorated the soil condition, while bitumen and RHA showed good performance. RHA stabilized soil showed a rapid fall in OMC. Cement and bentonite stabilized the OMC of the laterite soil.

In Figure 13, it has been observed that lime and cement improved the UCS of the virgin soil. Cement-stabilized soil showed a steady increase with an increased percentage of stabilizer, Lime stabilized soil showed a steady increase

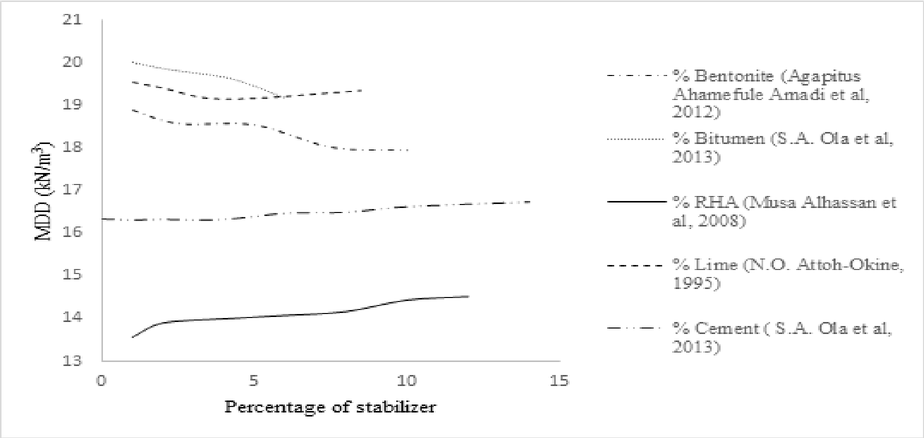

Figure 11. Change in MDD with change in percentage of stabilizer.

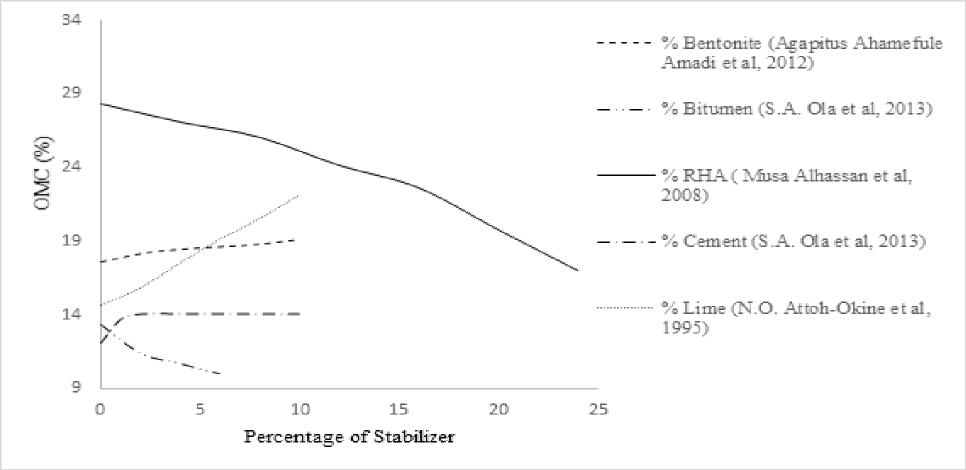

Figure 12. Change in OMC with change in percentage of stabilizer.

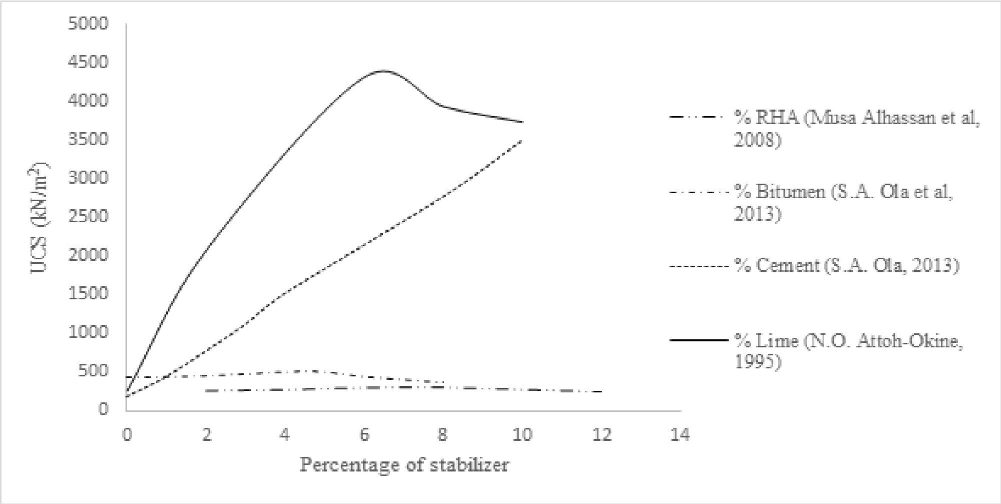

Figure 13. Change in UCS with change in percentage of stabilizer.

in UCS and it has been maxed 7% stabilizer and declined after that. Bitumen and RHA stabilized didn't show any significant change.

5.5 Sandy Silty Soil

In Figure 14, it has been found that both RHA and Cement deteriorated virgin soil conditions as the value of MDD has been reduced in both cases.

In Figure 15, RHA-stabilized soil showed better improvement of sandy silty soils in UCS as compared to cement-stabilized soil.

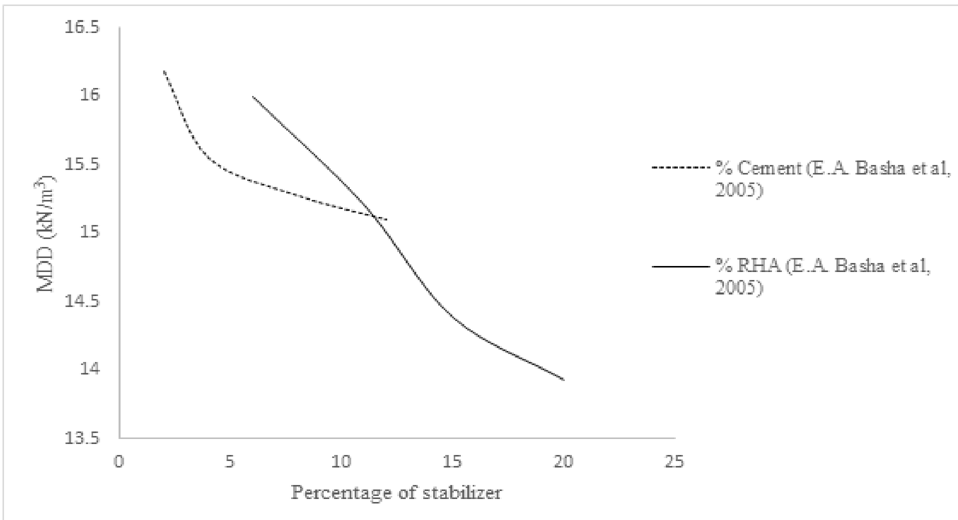

Figure 14. Change in MDD with change in percentage of stabilizer.

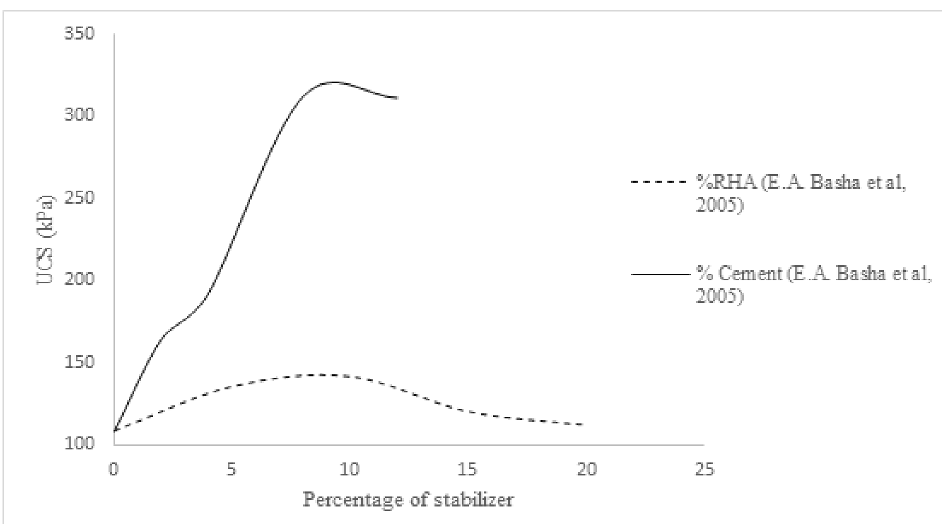

Figure 15. Change in UCS with change in percentage of stabilizer.

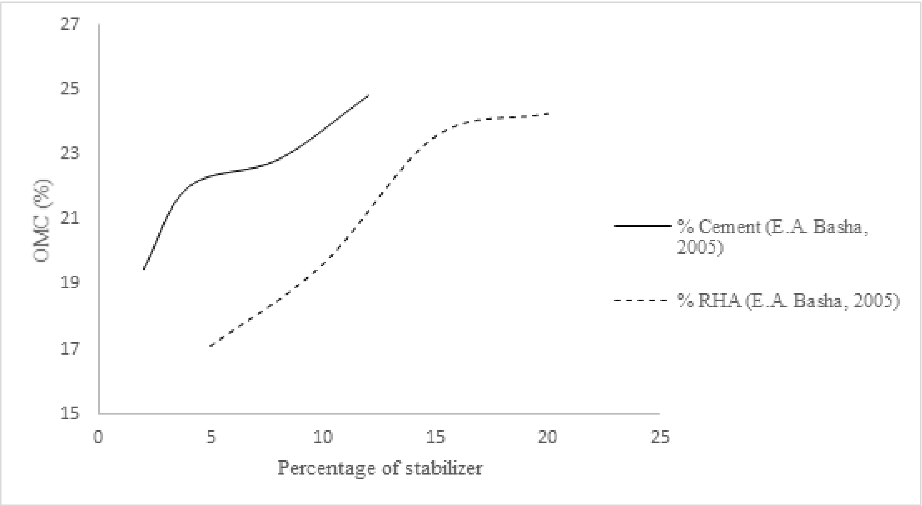

Figure 16. Change in OMC with change in percentage of stabilizer.

In Figure 16, it has been observed that both Cement and RHA deteriorated at the virgin soilconditions.

6.0 Summary and Conclusion

In this review paper, the test results of several admixtures of soil have been represented, and the trends of the graphs have been analyzed. Trend or tendency of improvement or deterioration of the properties of a particular typed soil by increasing percentage of their addition has been shown in graphical form. From the merged and combined observed experimental results from several researchers, it can be easily identified how much improvement of a particular soil property can be made by adding several types of admixtures to that soil. It can also be easily identified which type of admixtureis suitable for a particular type of soil and which soil properties can be improved by the addition of that admixture.

From the experimental results of several researchers and their experimental works for ground improvement techniques, it has been observed that cement is a better stabilising agentfor sand. Though kaolinite may also be used in cohesionless soil, kaolinite (29%) stabilized soil showed a 10.38% increase in maximum dry density and cement (7.5%) stabilized soil showed a 64.4% increase in unconfined compression strength to the virgin soil. Lime improves Black cotton soil very well. Lime (25%) showed a 35% increase in maximum dry density, and cement (6%) showed a 93% increase in unconfined compression strength to that of the virgin cohesive soil. Rice husk ash and pond ash deteriorated the soil condition and cannot be used for ground improvement. Clayey soil can be stabilized with bentonite (10%), which showed a 13% increase in maximum dry density; further research is needed about bentonite. Laterite soil is better stabilized with lime (6%) which showed a 15.92% increase in unconfined compression strength. Lime and bentonite cannot be used as a stabilizer for laterite soil.

7.0 References

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