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ENGINEERED SOIL AND THE NEED FOR LIME-NATURAL POZZOLAN MIXTURE PERCENTAGE APPROXIMATION

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ABSTRACT: The topic, engineered soil and the need for lime-natural pozzolan mixture percentage approximation is tried to be realized with the basic objective of initiating the identification of the percentage range for lime-natural pozzolan amender mixture approximation as in lime fixation for soil stabilization. The so far accomplished research sources were taken as bases of conceptual formulation. Amending of soil by using $CaCO_3$ and the abundantly available local natural pozzolan showed a success to develop a wall making input for rural housing development. In due course, arriving at an approximate percentage fixation remained a challenge because of the lengthy time required for laboratory material characterization and the cost incurred. In here, though for a specific soil type, a possible method of range approximation is suggested based on: pre-initial lime consumption, initial lime consumption, optimum lime-natural pozzolan consumption and post-optimum lime-natural pozzolan consumption. The outcome indicated the rough range of 4.5% to 9.5% for lime-natural pozzolan mixture application as shown in the OMC and MDD vs. amender percentage line graph; reflecting a possible answer to the stated objective.

Key words/phrases: Admixture; Engineered soil; Fixation; Lime; Natural pozzolan

INTRODUCTION

Globally, numerous researches are going on to address the human habitat concern as related to accessibility, affordability, sustainability and a stewardship responsibility for the whole ecosystem. In this respect, early generations of researchers had opened a big interactive space with multidimensional efforts and findings as an invaluable contribution to the well-being of humanity. Among those, earth based structures remained major players to contribute to the alleviation of housing challenges. In the process, the weaknesses of natural soil technologies in the face of strength and durability requirements were underpinned with various amenders and related innovative construction techniques.

It is well understood that, earth is the oldest building material known, with recorded cases of the use of earth bricks dating back to Mesopotamia around 10, 000 BC. In its present sense, the use of earth as a building material was revived in early 1970s in Australia following the energy crisis (Muga and Thomas, 2013). The energy crisis was over; but the predicament of global warming due to excessive energy use and CO_2 emission is on the rise and posing insurmountable havocs to the human habitat.

The manufacture of most conventional materials requires the expenditure of non-renewable resources in various forms. Many of these manufacturing processes are detrimental to the environment. For example, steel and cement factories emit toxic gases leading to air pollution. Excessive quarrying of limestone for lime burning or cement manufacturing has disturbed the ecological balance. In addition, these conventional building materials are usually transported over great distances thus contributing to the spending of fossil fuel energy (Obonyo, *et al.*, 2010).

In this regard, a contemporary study in Ethiopia sorted out the five top most conventionally used construction materials (cement, sand, coarse aggregates, hollow concrete blocks, and reinforcement bars), which are also prime sources of waste generation during construction in the Ethiopian building sector. Then, what followed was the evaluation of the embodied energies and CO_2 emissions of these materials by focusing on a mix of five typical commercial and public buildings within the cradle-to-site lifecycle boundary only. The evaluation results demonstrated that cement, hollow concrete blocks (HCBs), and reinforcement bars (re-bars) are the major consumers of energy and CO_2 emitters.

Cumulatively, they were responsible for 94% of the embodied energy and 98% of the CO_2 emissions. The waste part of the construction materials escalated the embodied energy and the subsequent CO_2 emissions considerably (Woubishet Zewdu and Kassahun Admassu).

The remedial measure to reverse the situation is to use less energy intensive building materials. However, though earth based structures are the best future contenders, they are unfortunately prone to environmental adverse effects in terms of strength and durability. Once recognized, such weaknesses could be diagnosed with various methods of amending natural soils to improve their responses to the mentioned pressures. Recently, a method of amending soils using lime and natural pozzolans was suggested based on the improvements achieved. The attained results of the effort indicated that the designed mix proportioning of the ingredients confirmed that the products are acceptable both in compressive strength and durability terms for the intended purpose. To that effect, the blocks produced using the proposed method, are named as amended compressed earth blocks (ACEBs); (Kassahun Admassu, 2019). To establish the innovative approach on a firm ground, the main objective of this research is basically to initiate the identification of the percentage range for lime-natural pozzolan amender mixture approximation as in lime fixation for soil stabilization.

Literature Review

Lime is a general term that is used to refer to the following three types-quick lime (CaO, Calcium Oxide), slaked or hydrated-lime ($Ca(OH)_2$, Calcium Hydroxide) and carbonate lime ($CaCO_3$, Calcium Carbonate). Calcium Hydroxide is the most widely used chemical stabilizer for clay soil sub-grades. Limestone or carbonate lime is not chemically reactive enough to lead to soil stabilization. However, the addition of carbonate lime results in the improvement of soil strength through physical interaction. Soil stabilization using calcium carbonate obtained from egg shell powder resulted in the increase in the UCC strength of soil. The compounds dissolved from the clay mineral lattice react with calcium ions in pore water to form calcium silicate hydrate and calcium aluminate hydrate gels, which coat the soil particles and subsequently crystallize to bond them (Petry and Little, 2002; Transport Research Laboraotry, 2003; Lime Treated Soil Construction Manaual, 2004; Rao and Shivananda, 2005; James and Pandian, 2014).

A nominal quantity of lime (1.0-3.0%), poses significant changes in the plasticity characteristics of the soil, by altering the charge distribution on the clay surface. Nevertheless, ICL does not contribute to long-term strength development, since free calcium ions are not available to take part in the pozzolanic reaction that follows. Based on this, Nelson and Miller developed a methodology to determine ICL in terms of liquid limit and plasticity index, as the minimum percentage of lime required to modify the plasticity characteristics of a soil. Any further addition of lime beyond ICL becomes excess, and it takes part in the chemical and pozzolanic reactions to enhance permanent strength and stiffness properties (Nelson and Miller, 1997; Rogers, *et al.*, 1997; Cherian and Arnepalli, 2015).

Lime-soil mixtures are one material to which the general thought "when the density increases the strength also increases" does not always apply. It usually applies, though, if at the same lime content additional compaction effort is used to produce higher densities. Lime-soil mixtures then usually have substantially higher strengths when they are compacted to a higher density with a greater compaction effort. The chief factors affecting the strength of lime-soil mixtures are type of lime, lime content, type of soil, density and the time and type of curing. Most of these factors are interrelated. Except in specific cases, no one of these factors is a great deal more important than another. In general, the strength of lime-soil mixtures increases as the lime content in the soil is increased. Regardless of the type of lime used or the other conditions, a minimum of about 3.0% lime is needed to produce the desired results. In most clays lime can produce a cementing action which will result in a higher strength and greater durability than would occur in untreated soils (Herrin and Mitchell, 1961).

These pozzolanic reactions involve interactions between soil silica and/or alumina and lime to form various types of cementation products thus enhancing the strength. The use of natural pozzolana and its combination with lime in conjunction with soft clayey soils needs to be investigated. As the soil is good source of alumina, the effects of lime treatment can be enhanced to a great extent if the apparent shortage of silica can be adequately supplemented by the addition of natural pozzolana, which is high in reactive silica content (Harichane, *et al.,* 2010). Also, under such effort the following is manifested.

- The combination of lime–natural pozzolana substantially improved the unconfined compressive strength in grey and red clay soils. In both soils, unconfined compressive strength increases with increase in age and stabilizer content. After 90 days of curing, the grey and red soils presented an increase of 63 and 21 times compared with the untreated soils; respectively.
- The results indicate appreciable improvement of both stabilized soils. The combination lime–natural pozzolana produced higher strength values than lime or natural pozzolana alone (Harichane, *et al.*, 2012).

Al-Swaidani, *et al.* (2016) stated the following on lime-natural pozzolan treated soil.

(1) The PI of lime-treated clayey soil decreased with increasing natural pozzolana. Reduction of this index is an indicator of improvement which can be correlated with an increase in the strength and a reduction in swelling and compressibility. The use of natural pozzolana alone and 4.0% lime content transformed the studied clayey soil from CH into MH class soil. However, adding natural pozzolana to lime-stabilized clayey soil moved the studied soil to ML class soil.

(2) The MDD of lime-stabilized clayey soil was significantly affected by adding natural pozzolana. The appreciable drop in MDD obtained at 8.0% lime content has been compensated with adding 20.0% natural pozzolana. On the other hand, the OMC was also reduced when adding 20.0% natural pozzolana to 8.0% lime-stabilized clayey soil.

(3) Although linear shrinkage strains of lime-treated clayey soil samples have considerably been reduced with increasing lime content when compared to untreated soil, further reductions were noted with adding natural pozzolana.

(4) Microscopic analyses confirmed that the addition of lime or lime and natural pozzolana to the investigated clayey soil has caused marked change in morphology. The SEM and EDX results showed presence of C-S-H and C-A-S-H in both lime and natural pozzolana-lime-treated clayey soils. These cementitious phases induced significant improvements in the engineering properties of the investigated clayey soil, such as workability, compaction, strength and shrinkage.

At this point it is vital to note that, in all the above researches it is understood that the lime type used is that from a factory production line subjected to intensive energy processing. On the contrary, in the current case, it is the raw lime stone ($CaCO_3$) powder that is made use of. Thus, an increase in strength of 63 and 21 times higher or other so much inflated physical characteristic values need not be expected. However, as per international standards for earthen structures the product happened to satisfy all the set requirements. Moreover, since the technology focuses on rural low cost housing it suffices the basic need and should be supported with sustainable research and development (R&D) to standardize the product as a main stream building material.

Theoretical Basis and Method

The work of Harichane *et al.* (2010) states that, as lime is added to many soils the mixture will not develop the desired strength even after considerable curing time. These non-reactive soils, however, can usually be stabilized satisfactorily with lime when a pozzolanic material is also added to the mixture. Pozzolans are primarily siliceous materials containing certain chemical compounds that will react with lime and water at ordinary temperatures to form the necessary cementing compound.

The combination of natural pozzolana-lime can substantially improve the unconfined compressive strength. The results of tests show that the combination of lime-natural pozzolana can effectively improve the durability of clayey soils from poor to excellent. Moreover, more soils should be investigated and criteria for soil-lime-natural pozzolana durability based on residual strength may prove suitable (Herrin and Mitchell, 1961).

According to Yunus *et al*. (2014), the lime fixation point can also be referred to as the "Initial Consumption of Lime" (ICL). The addition of lime below ICL value only contributes to the improvement of a soil's workability. However, beyond the ICL value cementation commences and the lime stabilization becomes more effective. Basically, the amount of lime added is between 1.0-3.0% by dry mass of soil if only modification process is desirable. A substantial strength gain is achievable upon the addition of lime above the ICL value. In other words, the determination of ICL was mainly to optimize the modification process. Based on ASTM D6276, the lowest percentage of lime that produces soil pH of 12.4 is considered as the minimum amount of lime required for stabilization. This procedure is also called the Eades and Grim test. The Optimum Lime Content (OLC) is defined as the lime content (expressed as a percentage) beyond which any further lime increment results in a constant plastic limit and strength. As mentioned earlier, for lime contents up to the ICL, although the workability of the soil improves, there is no effect on the soil strength.

The ICL determination was conducted in accordance with BS 1924 (1990). ICL gives an indication of the minimum quantity of lime that must be added to a material to achieve a significant change in properties. During lime stabilization reactions, the highly alkali soil pH value (12.4) promotes dissolution of siliceous and aluminous compounds from the clay mineral lattice. The compounds dissolved from the clay mineral lattice react with calcium ions in pore water to form calcium silicate hydrate (C-S-H) and calcium aluminum hydrate (C-A-H) gels, which coat the soil particles and subsequently crystallize to bond them. Stabilizing the clayey soil with lime contents greater than its ICL value thus ensures occurrence of cementitious pozzolanic reactions in the clayey soil (Al-Swaidani, *et al.*, 2016).

In view of the above, taking advantage of the certainties in the application of lime and natural pozzolan to improve clayey soils' behavior for earthen construction; there is a need to go for a commensurate and yet economical use of the ingredients. Since natural soil is the bulk of the material in this method, its use depends on the architectural and engineering aspect of the design; while the focus of enhancing material fixation will be on lime and natural pozzolan mixture proper formulation and quantification for application. Though lime fixation was a customary approach for so long in earthen structures the technique could also address the inclusion of natural pozzolan application as well; to make it more economical and sustainable. Moreover, creating a method for a reasonably quick determination of lime-natural pozzolan mixture amount approximation for practical field application could be possible; if sufficient ranges of soil are investigated and well documented in the long run.

PILC, ILC, OLC and POLC Phases in Lime-natural Pozzolan Mixture Addition to Clayey Soils

The pre-initial lime consumption (PILC), initial lime consumption (ILC), optimum lime consumption (OLC) and post-optimum lime consumption (POLC) are all important milestones in the chain of reactions of lime-natural pozzolan mixture addition to clayey soils with water as a medium. From the various laboratory investigations and field applications conducted in the last few years the conclusions reached at so far have witnessed that, amending clayey soils with carbonate lime ($CaCO_3$) and natural pozzolan mixture was found to be a trust worthy alternative to modify natural soils. The two amending mixtures were used without any further treatment except grinding in the lab. The other alternative to acquire the lime was to get it from a plant which grinds limestone for agricultural soil treatment purposes. Both the lime types have proved that these admixtures do contribute to enhance the strength and durability of soils for earthen structures (Kassahun Admassu, 2019). The next step will be to refine the method by going into further details and bringing to light some of the grey areas. So far, in a previous streamlining effort the author dealt with the challenge of hydration and carbonation reaction competition effect to lay the foundation for a convenient curing regime, paving the way for a future industrial application (Kassahun Admassu, 2020).

At this stage, the challenge to be addressed is how to devise a method to approximate the range of lime-natural pozzolan mixture addition to a given soil type in a reasonable period of time as a tool for field application. The aim is to examine in detail and quantify input ingredients by understanding the consumption rate of lime and natural pozzolan mixtures focusing on the specific soil to be treated to avoid a hasty generalization on a subject of such complex magnitude. The basic soil which was dealt with in this report is a highly plastic soil (CH or OH) origin with a plasticity index (PI) of 43%; which gradually was transformed into MH or OH having a PI of 25% through the appropriate amending method and process (Table 1) (Kassahun Admassu, 2019). This specific soil was selected from among the three (cohesive non-granular soil, sandy clay soil and granular soil) for a pilot project field application following a rigorous laboratory investigation on all of these.

Table 1. Granulometric analysis and physical properties of ingredients for practical application (Kassahun Admassu, 2019)

Series Designation	Mix Ingredients	Compositions (%)			Shrinkage (%)	PI (%)	OMC (%)	MDD (KN/m³)
		Sand	Silt	Clay				
SD-1	Soil Only – S	64	20	16	10	43	35.8	21.7
SD-2	Soil + Lime (2%) - S+L	47	17	36	10	28	35.8	21.7
SD-3	Soil + Lime (3%) - S+L	44	30	26	13	36	34.0	21.3
SD-4	Soil + Pozzolan (3%) -S+P	40	27	33	9	27	34.0	21.3
SD-5	Soil + Pozzolan (4%) -S+P	48	28	24	10	32	36.3	21.6
SD-6	S+ L (1.0%) + P (3.5%)	52	20	28	9	25	34.4	21.3
SD-7	S+ L (2.5%) + P (7.0%)	40	33	27	13	25	32.0	21.0

Based on the above characterization of the selected soil and six of its amended derivatives, which are trial mixes to arrive at the appropriate proportion, compressed earth blocks and mortar were produced for the field practical application. Before the actual field implementation, the produced blocks underwent elaborate lab tests to address environmental exposure conditions, strength and durability concerns; the outcome of which is shown in Figure 1 below.

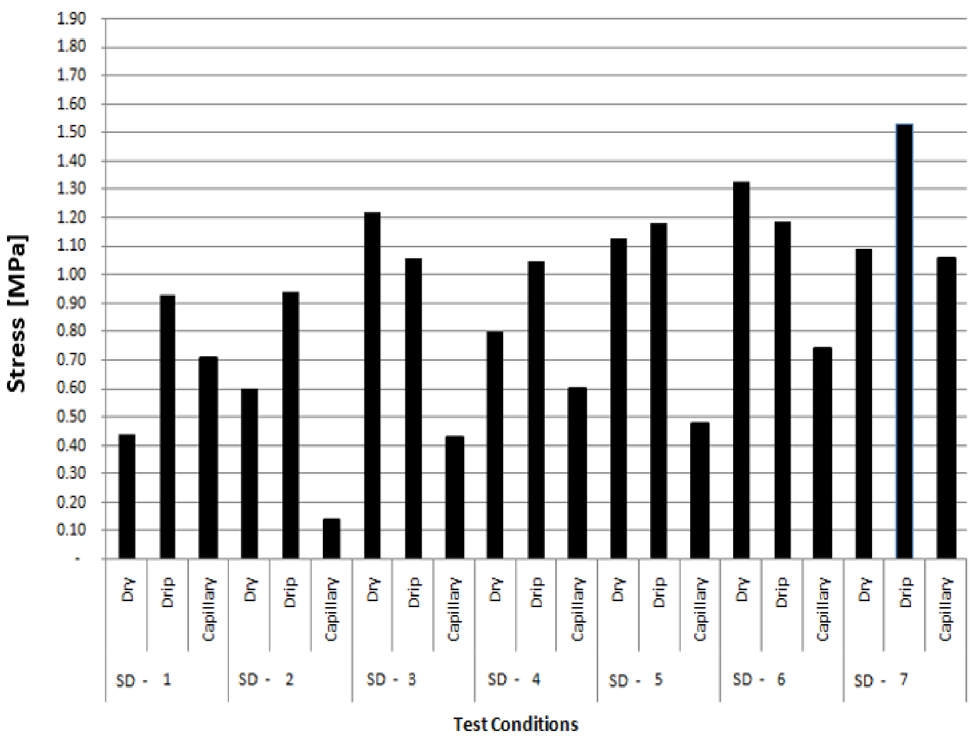

Figure 1. Compressive strength test results of CEB and ACEB units vs. various testing conditions (Kassahun Admassu, 2019)

While examining Table 1 and Figure 1 in perspective, though SD-6 and SD-7 were equally good contenders for application, it was decided to make use of amended product SD-7 for a pilot project field application. This decision has to be validated further putting emphasis on the four governing parameters of optimum moisture content (OMC), maximum dry density (MDD), plasticity index (PI) and unconfined compressive strength (UCS).

Regarding the three fundamental parameters (OMC, MDD, UCS), Harichane, et al. (2012), arrived at the following concluding remarks as their research findings on two types of clayey soils treated with lime-natural pozzolan mixture.

- Increased the maximum dry density for the grey soil and decreased that of the red soil.
- Decreased the optimum moisture content for the grey soil and increased that for the red soil.
- Substantially improved the UCS with increase in age and stabilizer content.
- Produced higher strength values than lime or natural pozzolana; alone.

Their finding indicates that, the amending technique is soil type dependent; which is an exposition of the knowledge level of understanding to efficiently exploit this material for the purpose of earthen construction.

Since the main objective of this research is basically to initiate the identification of the range for lime-natural pozzolan amender mixture approximation as in lime fixation in soil stabilization; the starting point is chosen to be the observations made in the earlier prolonged laboratory investigations. Thus, it was decided to use the optimum moisture content (OMC) and maximum dry density (MDD) parameters in relation to lime-natural pozzolan mixture percentage additions to the selected soil as a basis of discourse.

RESULTS AND DISCUSSION

The amending process started with a 2.0% lime addition (Figure 2) but no effect was observed. At a 3.0% lime addition the MDD dropped from 21.7-21.3 kN/m³ and the OMC from 35.8-34.0%. With a 3.0% natural pozzolan alone addition in SD-4, SD-3 and SD-4 preparations remained equal in their MDD value of 21.3 kN/m³ and OMC of 34.0%. In SD-5, a 4.0% natural pozzolan alone application pushed up the MDD to 21.6 kN/m³, and the OMC to 36.3%. SD-6 is where 1.0% lime and 3.5% natural pozzolan mixture (4.5%) amender was applied which brought down the MDD to 21.3 kN/m³ and the OMC was also reduced to 34.4%. The last preparation (SD-7) is composed of a 9.5% lime-natural pozzolan mixture amender (2.5% lime and 7.0% pozzolan). The MDD stood at 21.0 kN/m³ and its' OMC at 32.0%.

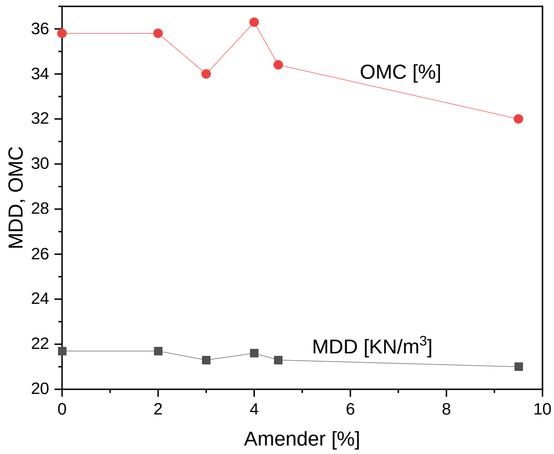

Figure 2: Amender (%) vs. MDD and OMC results

In general, though both MDD and OMC were decreasing with certain but very much limited anomalies, the obtained results coupled with a sequential PI reduction and enormous compressive strength developments have witnessed the successes of the effort (Table 1 and Figure 1).

Table 1 is taken from a previous source (Kassahun Admassu, 2019); slightly modified by the addition of the MDD column to help in making Figure 2 complete. The figure is developed to elucidate the interrelationship between lime-natural pozzolan mixture (amender), the required OMC and the achieved physicochemical change in MDD as a driver for product strength gain and durability superiority. Except the erratic situation in the amender increment range between 3.0 and 4.5% of the OMC line graph, it is a slow decrease to the point of 9.5% mixture level. As we focus on the MDD line, the amender increment is less bumpy and it is taking place in that same range of the OMC; peculiarity. Generally, traversing from 2.0-3.0% of the amender, it rather seems unquestionable and obvious in view of examining the forth coming segment (4.5-9.5%) of the line-graph; where both the OMC and MDD lines are moving in unison within their decreasing phenomenon. On the other hand, in Table 1, the consistent decrease of the PI to 25.0% (SD-6 and SD-7) from 43.0% and the recorded unconfined compressive strength (UCS) values of 0.8-1.3 MPa by SD-6 and 1.1-1.5 MPa by SD-7 is quite a remarkable achievement as compared to the 0.5-0.9 MPa of SD-1 (soil only block) under all the minor oddities observed.

Going back to the aim of defining initial lime-natural pozzolan consumption (ILPC) for optimum lime-natural pozzolan consumption (OLPC) suggestive determination, one can get a clue from the contents of Figure 2. At 2.0% amender (lime only) level in SD-2, nothing happened to the original soil's behavior. On the other hand, in SD-3 where a lime only amender is considered as a turning point to see the effect of a 3.0% lime addition as a defining moment; where inclusion of lime alone has brought about a change. At this point OMC and MDD decreased from 35.8 to 34.0% and from 21.7 to 21.3kN/m^3; respectively. SD-4 is composed of soil and 3.0% natural pozzolan only. Both OMC and MDD remained where SD-3 was; i.e., no change. At SD-5, 4% natural pozzolan alone was the admixture and the OMC went up to 36.3% and the MDD also to 21.6 kN/m^3**.** SD -6 is where a 4.5% amender was added at 1.0% lime and 3.5% natural pozzolan rates. Here, the OMC went down to 34.4% and the MDD remained at 21.6kN/m^3 as in SD-5. The last formulation (SD-7) is composed of 2.5% lime and 7.0% natural pozzolan (9.5% total). The outcome is 32.0% OMC and 21.0kN/m^3 MDD; a decrease in both the values as compared to that of SD-6.

Reviewing the whole range of the graph, the 3.0% lime is the initial lime consumption (ILC); for ILC gives an indication of the minimum quantity of lime that must be added to a material to achieve a significant change in properties (Harichane, *et al*., 2010). The addition of lime below ILC value only contributes to the improvement of a soil's workability. However, beyond the ILC value cementation commences and the lime stabilization becomes more effective (Yunus, *et al*., 2014).

The other parameter which is a good indicator of the amending effect is the decrease and then keeping the status quo of the PI at a given value. Referring to Table 1, with a fringe of anomalies the decrease was obvious and remained constant at SD-6 and SD-7; with a PI of 25.0% down from 43.0%.

In which case, under the current situation, the 2.0% lime dose could be the pre-initial lime consumption (PILC). Since the asymptotic MDD line is very gradual and stabilizes at 9.5% (2.5% lime and 7.0% natural pozzolan) amender consumption, the 4.5% admixture (1.0% lime and 3.5% natural pozzolan) is the point of optimum lime-natural pozzolan consumption (OLPC). Thereafter, the 9.5% lime-pozzolan mixture could be termed as the post-optimum lime-natural pozzolan consumption (POLPC). The outcome is obvious, for this particular soil the optimum lime-natural pozzolan mixture consumption (OLPC) is roughly established within the line segments of: PILC, ILC, OLPC and POLPC. The overall success of the formulation was based on the well-recognized theoretical background of lime fixation point in lime-soil stabilization.

Predecessors' and Current Work Corroboration

De Brito Galvão *et al*. (2004), defined the inflection point of lime content as Lime Modification Optimum (LMO). They attributed this behavior to the flocculation stage, in which the hydraulic conductivity increases. Further addition of lime results in the formation of cementitious minerals, which modifies the micro-pore network and reduces the hydraulic conductivity.

The trial least initial consumption of lime (LICL) content was adopted as 3.0%. It is documented in literature that the lime content of more than ILC results in an increase in strength of the lime-stabilized soil (Nasrizar, *et al*., 2010; Maaitah, 2012; Muhmed and Wanatowski, 2013; Saride, *et al*., 2013; Ciancio, *et al*., 2014; James and Pandian; 2014).

Eades and Grim (1966), suggested a methodology to determine OLC of a particular soil type as the lowest percentage of lime required to maintain a soil–lime–water solution pH of 12.4 (which is equivalent to pH of a saturated lime solution), and this method was later modified into American Society of Testing Materials (ASTM) standard for determining the optimal lime content (ASTM D6276-19).

Sivapullaiah *et al.* (2017), reported that, the optimum lime content for the tested soil has been identified and several methods to determine its rough value presented which have the potential to reduce testing times and the associated costs.

- An OLC of 4.0% was found for the tested soil, subsequent pH testing suggested this as lime saturation of the pore water.
- Both pH and PL testing might offer suitable alternatives to extensive and time consuming UCS testing for more rapidly determining the OLC for RE contractors.
- The durability test results exhibited a full 12 cycles of wet-dry survival performance; in addition to a residual compressive strength increase.
- Overall, the use of lime-natural pozzolan effectively transformed the clayey soil from poor to excellent.

Keeping the predecessors' efforts in mind, its' congruency with the current work could be summed up as:

- 2% lime didn't react, but 3% showed up indicating it is the initial lime consumption (ILC)
- 3% natural pozzolan alone showed no sign, but the 4% reacted.
- Once the two above are observed, the next step was to test the combination of the two which led to 1% lime + 3.5% natural pozzolan totaling 4.5%. Found effective.
- Extending the range to 2.5% lime + 7.0% natural pozzolan totaling 9.5%. Found effective.

Thus, the 4.5% could be taken as the optimum lime-natural pozzolan consumption (OLPC). The 9.5% could be termed as, post optimum lime-natural pozzolan consumption (POLPC). Out of which, the OLPC is roughly established within the line segment of PILC, ILC, OLPC and POLPC as a final outcome.

Moreover, the decrease in OMC is due to the effective stabilization of the highly plastic soil with the lime-natural pozzolan mixture addition within the environment of reduced moisture. Likewise, the diminishing aspect of the MDD is a response to the stated influence emanating from the lower specific gravity of the amending materials as compared to the plastic soil; where, the formation of cemented particles impacted the subsequent density of the amended soil. To generalize, the findings thereof are recapped as in the following section.

CONCLUSIONS

As clearly stated earlier, the main objective of this research is basically to initiate the identification of the percentage range for lime-natural pozzolan amender mixture approximation as in lime fixation for soil stabilization. To address the clearly stated objective, the paper solely focused on charting a quick and straight forward approximation of lime-natural pozzolan mixture formulation in order to make the proposed method more user-friendly, economical and instrumental for the introduction of easy to use rural housing focused popular technology. The emphasis of the wall component ingredient and product formulation is a lab supported test specimen preparation followed by compressive strength test of the samples at their 90th day; but after being exposed to various testing conditions (dry, post-drip and post-capillary effect).

In addition, to make a commensurate analysis, synthesis and discussion PI, OMC, MDD and amender percentage mixture additions were captured and plotted. The amending designs were of six types/groups, the seventh being the selected soil it-self. The intention was to evaluate the efficacy of the amending method through the determination of lime-natural pozzolan admixture dosage as in the practically accepted lime fixation point determination in soil stabilization. In order to make use of the stated parameters, the identified milestones are: pre-initial lime consumption (PILC), initial lime consumption (ILC), optimum lime-natural pozzolan consumption (OLPC) and post-optimum lime-natural pozzolan consumption (POLPC).

Thus, according to the established parameters of pH, PL and UCS to demarcate the noted milestones; though pH was not integrated into the current experimental work as a whole, the remaining two parameters PL and UCS coupled with a very much reduced PI which is finally stabilized at a given numerical figure consecutively; are considered to be valid indicators to suggest the possible milestones of lime/lime-natural pozzolan consumptions. Learning from the accumulated knowledge of the predecessors, it is arguably justifiable to conclude that the methodically deliberated upon milestones for a quick decision (fast track) of lime-natural pozzolan approximation proposal is a feasible alternative on the table for further scrutiny and responsibly focused refinement.

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