

Enhancing Geotechnical Properties of Clayey Soil with Nano Silica and Fly Ash

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Abstract - For civil engineering projects including foundations, embankments, bridges, tunnels, canals, and roads, clay soil is a challenge for all civil engineers and must be stabilized. All engineering requirements cannot be met by expansive soil, nor can it support the weight that the foundation transports to the ground. Soil should be of high quality, have a high bearing capacity value, be durable against water, and have a low permeability factor. The four primary sources of waste materials utilized to stabilize expansive clay soil are industrial, agricultural, mineral, and home. The investigation conducted to determine whether adding fly ash and nano silica to clayey soil improved its characteristics is described in this article. To get the ideal percentage of admixture needed for soil stability, different amounts of fly ash and nano silica are mixed with unaltered soil. Laboratory testing, including Atterberg's limit, compaction, CBR, and UCS tests, were performed on both modified and unmodified clayey soil in this comparative study. These stabilization methods are also inexpensive and readily available waste materials. In this experiment, fly ash and nano silica were used to stabilize clayey soil. After fly ash was set at 15%, nano silica was adjusted to 04%, 06%, and 08%.

Key Words: Compaction test, CBR, UCS, Nano Silica, Fly Ash

1. INTRODUCTION

Just like other construction materials soil also has its own chemical and physical characteristics with regard its abilities on dealing with the loadings and other external forces. From all the other civil engineering fields soil engineering and soil mechanics is most complex field when it comes to factor of safety in design of sub-structures e.g. foundations, piles and other soil based constructions like sub-grade for pavements, embankments etc, requires a significantly a higher factor of safety in comparison of other

construction materials. That's why the uncertainty in soil analysis and foundations designs is higher.

Therefore the geotechnical properties of the soil are analysed before any major construction work, so as to ensure its stability against the load of the desired structures. The soil normally consists of rock particles, the air and the water are located in the empty spaces (called voids). It is essential to determine the geological properties of the soil that are influenced by the size of the particles, distribution of the grain size, form of the minerals present in the particles and the amount of that minerals. The engineering properties of the soil are generally are considered for carrying out the analysis of the site conditions and design of structures are the bulk unit weight, saturated unit weight, dry unit weight, permeability and porosity. Several laboratory tests are also conducted to check the suitability of the soil, including permeability, relative density, soil compaction characteristics and water content.

2. Literature Review

Shalaby et al. (2024)

This study aims to assess and compare the efficiency of nano-white cement in enhancing the mechanical properties of kaolin alone and kaolin mixed with nano-silica. The results of the compaction tests of the kaolin soil treated with different percentages of nano-white cement revealed a decrement in the maximum dry density, the plasticity index, and the workability. While they had elevated the optimum moisture content, plastic limit, Liquid limit, and unconfined compressive strength. The tested samples treated only with nano-silica reached their maximum strength properties with a concentration of 0.9% nano-silica then declined. The samples treated with the lowest percent of nano-silica and the different percentages of nano-white cement recorded higher readings in the unconfined compressive strength compared with the result of the sample treated

with the highest percent of nano-white cement individually. Furthermore, the SEM images of treated samples represented the physical and chemical bonds between soil particles, nano-white cement, and nano-silica. In conclusion, the nano-white cement and nano-silica additive mixtures have a powerful improving effect on the mechanical properties of kaolin soil than the nano-white cement additive only. From the results, the nano-additive (nano-silica) in tested clay blended with nano-white cement had a significant positive effect on the behavior of clay soil. So, using additives and activators on a nanoscale has economic feedback with a positive ecological effect.

Bhavsar et al. (2022) - The engineering properties of Soil are the most important factor in any type of structure construction. The most critical problem faced by the civil engineers is construction on expansive soil (black cotton soil). 51.8 million Hectar land of India is covered by Black cotton soil. This expansive soil can prove to be a substantial hazard to engineering construction due to its ability to swell or shrink with seasonal changes in moisture content. On the other hand, millions of tons of waste material are produced by thermal power industries known as fly Ash. Nowadays a major problem is "How to utilize the industrial waste product." This research deals with how to improve the geotechnical characteristics (liquid limit, plastic limit, plasticity index, MDD, and OMC) of Expansive soil by adding a different percentage of Fly Ash (0%, 10%, 20% & 30%).

Pawar et al. (2022) Using steel slag for soil stabilization is a modern application of steel slag. In this study the main approach is to investigate the effect of steel slag on the strength characteristics of clayey soil. Steel slag is blended with clayey soil in amounts of 10%, 15%, 20%, 25%, and 30% of dry weight. In our study, the optimum content of steel slag was determined by considering the maximum unconfined compressive strength. A series of further laboratory tests have been performed on this optimum mix to evaluate its suitability as a stabilizer material. The test was also conducted with conventional stabilizing material such as 10% fly ash and 5% cement with clayey soil and the obtained optimum mix was determined. Then the results are compared accordingly. In the above study, it has been observed that the addition of steel slag results in significant improvement in strength parameter as compared to fly ash but less strength in case of cement.

Nagapure et al. (2021)

In this study fly ash and lime sludge were mixed with black cotton soil to investigate the relative strength gain in terms of CBR and compaction. The effect of fly ash and lime on the geotechnical characteristics of clay-fly ash and clay-lime mixtures was investigated by conducting standard proctor compaction tests were performed as per Indian standard specifications. The black cotton soil used for these experiments was brought from the site, near bamni. The physical properties of soil were determined as per IS specification. Fly ash was brought from the CSTPS chandrapur. Its finely divided residue resulting from the combustion of coal from electric generating plants. It has high water absorption capacity.

P. Kulanthaivel et al (2021)

In order to improve the shear strength and compaction properties of problematic clayey soil, the current work reports a laboratory inquiry on the application of nano-silica (0.2, 0.4, 0.8, and 1.0%) and polypropylene fiber (0.25, 0.50, 0.75, and 1.0%). The diameter of the nanoparticles employed in this investigation was found to be between 10 and 20 nm based on the Transmission Electron Microscopy (TEM) research.

Nair et al. (2020)

One strategy to achieve the goal is to alter the mechanical properties of the soil through the methods known as soil improvement technique Nano silica are added in varying percentages like 0.2, 0.4, 0.6 and 0.8% to the soil samples. From compaction test, maximum dry density (MDD) and optimum moisture content (OMC) are to be determined for kaolinite soil. Strength parameters for clayey soil are obtained from unconfined compressive strength. Increasing ratios led to a reduction in the plasticity index due to increase in plastic limit and decrease in liquid limit.

Safi et al. (2020)

Expansive soil cannot fulfil all engineering properties and cannot stand on load which is carried by foundation to the earth. Soil should has good quality and high bearing capacity value, soil must has good compressibility and durability against water and must reduce its permeability factor as well. There are different waste materials that are used for stabilization of expansive clay soil and have four main sources such as industrial, agriculture, mineral and domestic based waste

material origin. Among all paper which has reviewed Nano-Silica and nano-Silica+white cement are most sound and eco friend waste materials for clay soil stabilization. This type of stabilization techniques are also economic and easy found waste materials.

Rajput et al. (2019)

The subgrade is an important part of highway Development. But in some areas of expansive soil or black cotton soil it is very much difficult to get selected soil. Hence need for soil improvement by using stone dust and fly ash. Now a day due to rapid urbanization and industrialization the demand of power supply has been grown up, these results in setting up of a numerous number of thermal power plants. These thermal power plants utilize the coal to produce the electricity and thereafter the coal is burnt, whatever the mineral residue is remained is called as Fly Ashes (FA). These fly ashes are collected from the Electro static precipitator (ESPs) of the plants.

Singh et al. (2019)

The primary goal of this study is to find the best way to combine clay soil with nano-silica and polypropylene fiber. Additionally, to comprehend the microstructural change toward the mixing of Nano-SiO₂ and PPF. In integration with polypropylene fiber, four distinct combinations of nano-silica at varying percentages—1%, 3%, 5%, and 7%—are utilized in varying percentages, including 0.1%, 0.4%, 0.7%, 1%, and 1.3%.

Suresh et al. (2018) This review paper presents an investigation of behavior of clayey soil stabilized with varying percentages (0.5-10%) of coir fiber and Nano silica, by carrying out the index and engineering properties of soils. Coir is a natural biodegradable material abundantly available in some parts of south and coastal regions of India. Nano silica is small filler size materials increase ductility with no decrease of strength. The induced of the nano silica acted as a hydraulic binder with lesser swelling potential. The combination of coir fiber and Nano silica are used in expansive soils for sustainable development purpose.

Anil Kumar Sharma et al., (2016)

By mixing of fly ash and Ground Granulate Blast Furnace slag binder was formed. In the beginning the initial strength test was done on different ratios of fly ash and GGBS mixture. It was observed that 70:30 mix

of fly ash and GGBS given the higher strength than individual fly ash or GGBS, even in the lack of any chemical activators. The mixing of binder without lime indicated the decrease in both liquid limit and plasticity index. When the binder content increases, the OMC decreases while MDD increases. In order to achieve the strength characteristics of every combination of soil binder samples, the tests were done on different curing periods that is 7,14 and 28 days. From this it can be found that strength increases up to 20% of the binder content and thereafter it decreases.

Tiwari et al. (2016)

They studied the stabilization of black cotton soil using fly ash and nylon fibre. In their study, they used different combinations of fly ash as 10%,20%, 30% & 40%. 20% was their optimum value. After which they calculated the optimum value of nylon fibre from various values as 0.25%, 0.50%, 0.75%, 1%, 1.5%. From which 0.75% nylon fibre comes to be the optimum. The CBR value of soil+20% fly ash+0.75% fibre was maximum of all other readings. And the MDD was also maximum of this mix proportion.

3. Materials

3.1 SOIL

Source of soil

The total weight of soil that was gathered was around 120 kg. Before the tests begin, every soil sample is sieved through a 4.75mm sieve. To remove any moisture from the soil, it is oven-dried for a full day before usage. Virgin soil is first examined for its qualities and strength value without any admixtures. It is then tested with different amounts of Nano silica and Fly Ash added. The various properties of untreated soil that is used are:

Table no. 1 Properties of soil used in the study

S.No.	Properties	Result
1.	Liquid limit (%)	42
2.	Plastic limit (%)	27
3.	Plasticity Index (%)	15
4.	Specific Gravity	2.61

5.	Maximum Dry Density (KN/m ³)	18.20
6.	Optimum Moisture Content (%)	13.70
7.	Soil Classification	CI (Intermediate Compressive Clay)
8.	CBR (%) (soaked)	2.8
9.	CBR (%) (Unsoaked)	4.2
10.	UCS (kN/m ²)	190

3.2 Nano Silica

Source of Nano Silica

Adding nano-silica to soil can improve its characteristics, decrease hydraulic conductivity, and increase its strength. It can improve clayey soil's unconfined compressive and shear strengths and strengthen soils treated with fiber, cement, and lime. Tables 2 and 3 provide a list of Nano Silica's characteristics.

Table 2: Physical Properties of Nano Silica

Physical properties	Value
Diameter (nm)	20 – 30
Surface volume ratio (m ² /g)	193
Density (g/cm ³)	1.7
Purity (%)	>99

Table 3: Chemical Properties of Nano Silica

Sr. No.	Compound	Value (%)
1	Silicon Oxide(SiO ₂)	99.88
2	Al ₂ O ₃	0.05

3	Iron Oxide (Fe ₂ O ₃)	0.01
4	Carbon content	0.06
5	Chloride content	0.09

3.3 Fly Ash

Fly Ash that is used in this project is Known as Gujcon-CRF and is manufactured by Gujrat state fertilizers and chemicals limited which was collected from their warehouse in New Delhi.

The Classification of this Fly Ash is shown in table

Table 4 Classification of fly ash

S. No	Compound	Class F Fly ash	Class C Fly ash
1.	Silica(SiO ₂)	54.8	39.8
2.	Alumina (Al ₂ O ₃)	25.9	16.9
3.	Calcium oxide (CaO)	8.6	24.2
4.	Iron oxide (Fe ₂ O ₃)	6.9	5.8
5.	Magnesium oxide (MgO)	1.9	4.7
6.	Sulphur (S)	0.5	3.2

3.4 OBJECTIVES

The objectives of the research work are:

- To determine Atterberg's limit of the virgin soil.
- To Study the effect of Standard Proctor test and find out Maximum Dry Density (MDD) & Optimum Moisture Content (OMC) of virgin soil and the different proportions of mix.

- To Study the influence of Nano Silica and Fly Ash on California Bearing Ratio.
- To Study the influence of Nano Silica and Fly Ash on Unconfined Compression strength test.

77:08:15	16.20	15.30
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3.5 METHODOLOGY

The present project can serve as an effective method to utilize industrial wastes Nano silica and Fly Ash in the construction of low cost rural roads and stabilize the subgrade of pavements where the soil is expansive in nature. These various tests needs to be carried out on samples selected for study:

1. Liquid Limit test and plastic limit test needed to be performed with the help of Cassegrande’s Apparatus first on virgin soil and then the various proportions of the mix. The Plasticity Index of the Optimum Mix should be always less than that of virgin soil.
2. Standard Proctor Test is carried out to calculate Optimum Moisture Content (OMC) and Maximum Dry Density (MDD) of virgin soil which is then compared to MDD of mix proportions. The MDD of the optimum mix should always be higher than pure soil.
3. California bearing ratio test is conducted to calculate CBR Values at different proportions with material.
4. Unconfined compression strength test is conducted to calculate UCS Values at different proportions with material.

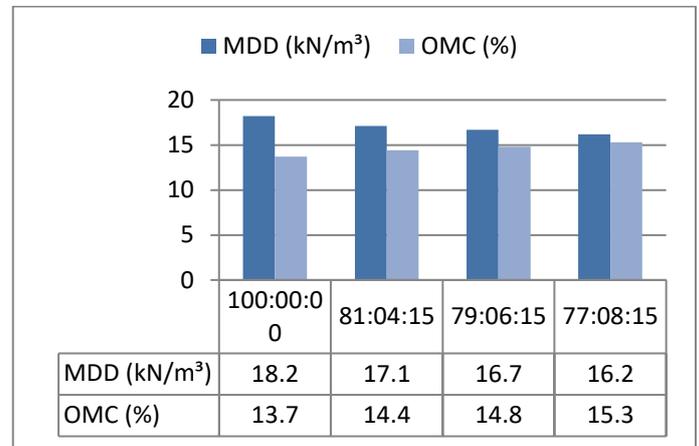
4. EXPERIMENTAL RESULTS

4.1 STANDARD PROCTOR TEST

Table no. 5: Results of OMC and MDD for mix proportions of Soil, Nano Silica and Fly Ash

SOIL:NS:FA	MDD (kN/m ³)	OMC (%)
100:00:00	18.20	13.70
81:04:15	17.10	14.40
79:06:15	16.70	14.80

Fig:-1 variations b/w MDD and OMC of Nano Silica, Fly Ash & soil with different percentages

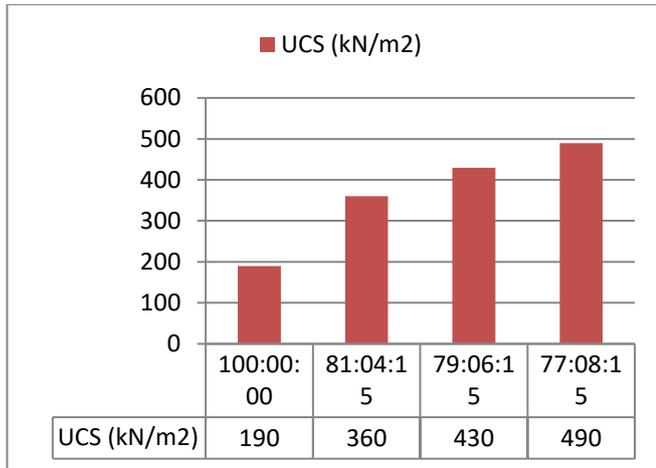


- There is an increase of OMC from 13.70 to 15.30% and decrease of MDD from 18.20 to 16.20% when the percentages of Nano Silica vary from 04, 06 and 08% and Fly Ash is fixed at 15%.

Table 6: Results of UCS of Nano Silica and Fly Ash Mix with Soil

SOIL:NS:FA	Curing Period (Days)	UCS (kN/m ²)
100:00:00	7	190
81:04:15	7	360
79:06:15	7	430
77:08:15	7	490

Fig:-2 Variations of UCS Values of Clayey soil, Nano Silica and Fly Ash

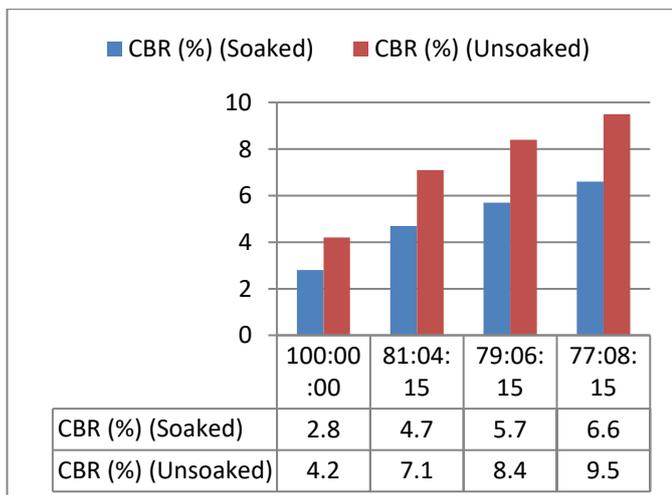


- The UCS value of soil also improves considerably with expansion of Nano Silica 08% and Fly Ash 15% with 7 days curing period. The value increases from 190kN/m² to 490kN/m² with addition of Nano Silica and Fly Ash.

Table 7: Results of CBR of Nano Silica and Fly Ash Mix with Soil

SOIL:NS:FA	CBR (%) (Soaked)	CBR (%) (Unsoaked)
100:00:00	2.8	4.2
81:04:15	4.7	7.1
79:06:15	5.7	8.4
77:08:15	6.6	9.5

Fig:-3 Variations of CBR Values of Clayey soil, Nano Silica and Fly Ash



- The increase in CBR value from 2.8 to 6.6 when Fly Ash is fixed at 15% and Nano Silica added at different ratios i.e. 04, 06, 08.
- The CBR value of soil is 2.8 and it increases to 2.35 times with addition of Fly Ash 15% and Copper Slag 08% when observed in soaked conditions.

5. DISCUSSIONS

5.1 STANDARD PROCTOR TEST:

- An increase of OMC from 13.70 to 15.20% and decrease of M.D.D. from 18.20 to 16.60% when the percentages of Nano Silica are used as 05%, 07% and 09% respectively.
- There is an also increase of OMC from 13.70 to 14.40% and decrease of MDD from 18.20 to 16.80% when the percentages of Fly Ash are used as 10%, 15% and 20% respectively.
- There is an also decrease of MDD from 18.20 to 16.20% and increase of OMC from 13.70 to 15.30% when the percentages of Nano Silica vary from 04%, 06% and 08% and Fly Ash is fixed at 15%.
- There is a decrease in MDD of modified soil with increase in percentage of Fly ash, due to the lower specific gravity of Fly ash as compared to the unmodified soil and OMC of modified soil is increase as the percentages of Fly ash increases, due to the increase in cohesive property of soil.
- With Fly Ash kept constant at 15% MDD increases with an addition of Nano Silica content in soil and Fly Ash mix. The reason behind of such behavior is high percentages of reduction in voids affect the density of soil+ Nano Silica mixes.

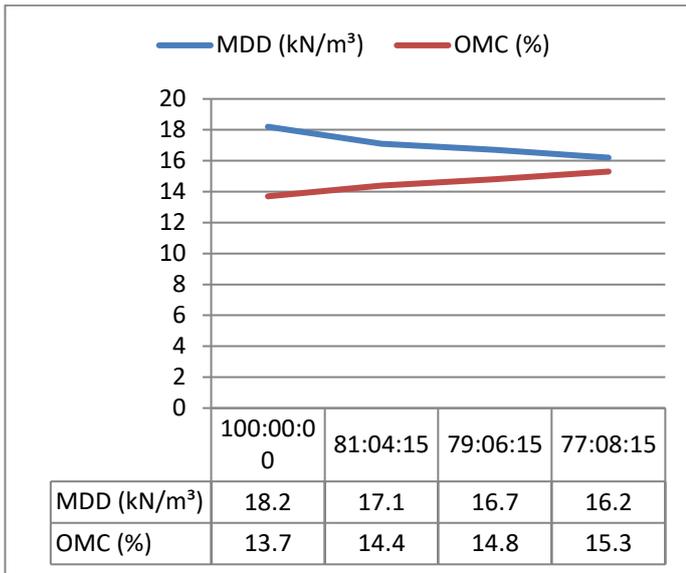


Fig:-4 Variations b/w MDD and OMC values of Nano Silica mix with Fly Ash

4.8.2 CBR TEST:

- The CBR value of untreated soil is 2.8 and when 9% Nano Silica is added, it rises to 1.68 times when the soil is soaked.
- Untreated soil has a CBR value of 2.8 adding 8% Nano Silica and 15% Fly Ash increases this value to 2.36 times. The slow development of hydration compounds in the soil as a result of the stabilizers' reaction with the soil's important particles could be the source of this increase in CBR.

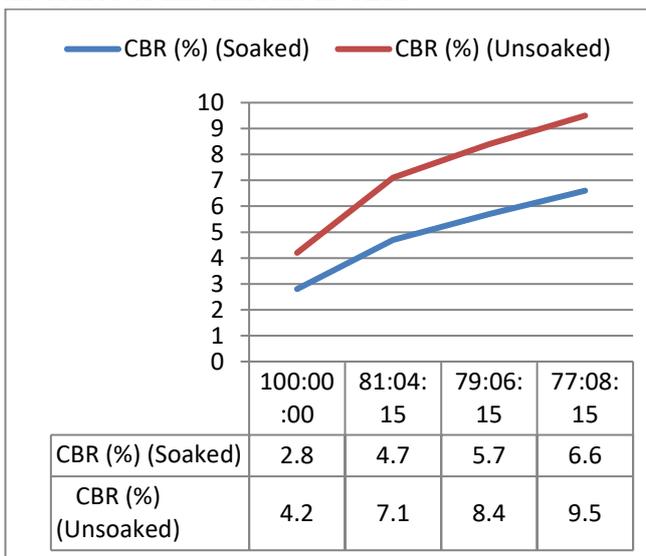


Fig:-5 Variations b/w CBR Values of Nano Silica mix with Fly Ash

4.8.3 UCS TEST:

- The UCS values of untreated soil also improve considerably with expansion of Nano Silica 08% and Fly Ash 15%. The value increases from 190kN/m² to 490kN/m² with addition of Nano Silica and Fly Ash.
- The reason behind of this when Nano Silica and Fly Ash comes in contact with Water, pozzolanic reactions takes place during the curing period.

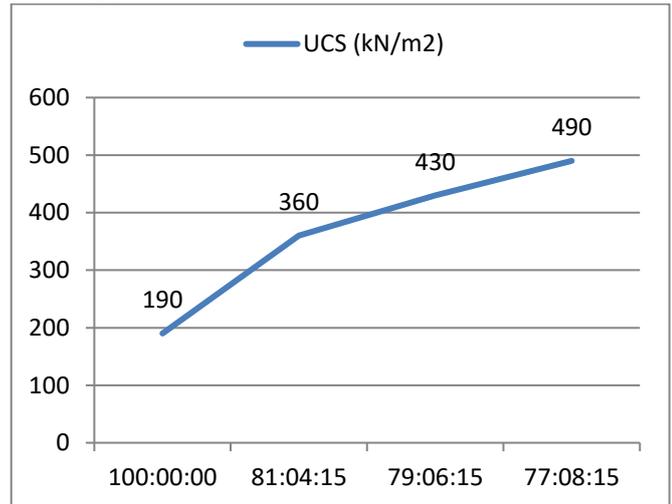


Fig:-6 Variations b/w UCS Values of Nano Silica mix with Fly Ash

6. CONCLUSIONS

Following conclusions can be inferred on the basis of the experiments performed:

1. The different percentages of Nano Silica and Fly Ash used in this study were 05%, 07% & 09% and 10%, 15% & 20%. Finally, the value of Nano Silica varies from 05 to 09% at the interval of 02% with the fixed quantity of Fly Ash 15% to clayey soil.
2. The addition of the fixed quantity of Fly Ash 15% with changing the content of Nano Silica increase the value of optimum moisture content and decreases the value of maximum dry density.
3. The UCS value increases with an increase of Nano Silica content along with a fixed quantity of Fly Ash. It increased 2.57 times from the untreated soil. Based on the unconfined compression strength test results, the value of UCS increases from 190kN/m² to 490kN/m² with addition of Nano Silica and Fly Ash.
4. According to the UCS study results obtained after seven days of curing, 8% nano-silica and 15% Fly Ash make the best mixing stabilizing agents for

clay soil.

5. The Maximum value of California Bearing Ratio test was found at Nano Silica 08% and Fly Ash 15%. The value of CBR increases from 2.8% to 6.6% with addition of Nano Silica and Fly Ash.

6. For use as a soil stabilization procedure, the ideal mix of 77% soil, 8% NS and 15% Fly Ash is therefore recommended.

Addition of Nano Silica and Fly Ash stabilizer makes the soil mixes durable, low cost and effective for soil improvement. If these two materials are easily available near to the site.

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