Performance Evaluation of Clay Soil by the Addition of Nano Silica and Basalt Fiber

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Abstract - Transportation satisfies a fundamental human need. Since the beginning of time, people have traveled for pleasure or nourishment. Because the success of a country is closely linked to the quality of its transportation infrastructure, everyone has high expectations for these amenities. The need for a transportation system that is economically viable, environmentally benign, socially legitimate, sustainable, and practically acceptable presents significant issues for civil engineers today. The current construction environment makes standard procedures inappropriate, which is fueling interest in technology such as ground improvement. Among all forms of transportation, an affordable road network is essential to the economic development of developing nations like India. If the subgrade layer of the pavement is weak in the case of a highway, then more pavement thickness is needed, which raises the cost of pavement construction. Basalt fibers are utilized to fortify the subgrade soil because they are practically acceptable, affordable, and readily available regionally, and environmentally friendly. Proctor Compaction tests and California Bearing Ratio (CBR) testing were performed on locally accessible soil that was reinforced with basalt fiber and nano-silica in this study. By dry weight of soil, the percentages of basalt fiber and nano-silica were calculated to be 4%, 6%, and 8%. To determine the ideal amount, basalt fiber was taken at 02%, 03%, and 04% in the current study. From these experiments, it has been analyzed that with the increase of Basalt fiber content in addition to Nano-Silica, the UCS increases and maximum value of UCS is obtained at 8% of Nano-Silica with 03% of Basalt fiber. The intermixing of Basalt fiber with the soil acts as a reinforcing material in binding the soil particles and the 'bridge effect' of fiber reinforcement in soil impedes the further development of tension cracks.

***Key Words*:** Compaction test, CBR, UCS, Nano Silica, Basalt Fiber

1. INTRODUCTION

Expansive soils are the soils which have high shrinkage and swelling characteristics and lower strength when it came in contact with water. These soils are very sensitive to variations in water content and show excessive volume changes and has high compressibility. This highly plastic soil may create cracks and damage the construction work done above these types of soils.

In India, expansive soil covers nearly about 20% of the land and includes approximately the entire Deccan Plateau. They are mostly black and reddish brown in colour and are generally found with layer thickness between 0.5 m to 10 m below the surface. Because the expansive soil is prone to volume changes when it came in contact with the water by rain or water table capillary action, it will get expand and may cause lifting of the structures built over it. So, these soils are not suitable for construction works until they are properly stabilized which can increase the low bearing capacity of expansive soils.

In India, nearly 46% of total land is covered by Alluvial soil which is the most important soil type of or country. Other soils such as Black cotton soil, desert soil, laterite soil and marine soil are also the important soil groups of India. The Alluvial soil and the black cotton soil mainly consists of clay which is very fine soil and it's the main constituent of expansive soils and due to the cohesive nature of clay, these soils absorb large amounts of water and show swelling characteristics which create problems such as bulging of soil, low bearing strength of soil, and can cause cracks in the foundation.

2. Literature Review

Kumar et al. (2023)

The major goal of the study in this work is to improve the geotechnical qualities of soil by the effective usage of stabilization utilizing basalt fiber and ground granulated blast furnace slag (GGBS) in varied quantities. The study used 2%, 3%, and 4% of basalt fiber and 5%, 10%, and 15% of powdered granulated blast furnace slag in three different amounts. Compaction and an unconfined compressive test (UCS) were performed on the reinforced soil. The findings of the trial indicated that the soil's compressive strength and shear strength had been effectively improved.

Megha S. Mahaladkar et al. (2022)

The main objective of this study is to investigate the effect of index properties of clayey soils when blended with silica fume and basalt fiber. A series of laboratory experiments have been conducted on samples with 0%, 5%, 10%, 15% and 20% of Silica fume and 0.05%, 0.1%, 0.15% and 0.2% of Basalt fiber by weight of dry soil. The test results showed a significant change in consistency limits of samples containing Silica fume and basalt fiber. The investigation showed that the Silica fume is a valuable material to modify the index properties of black cotton soil to make them suitable for different construction activities. The addition of basalt fiber gives a very good compressive strength to the BC soil as compared to silica fume.

Anju George (2022)

In this paper, the effects of basalt chopped fiber with coir pith on geotechnical properties of clayey soil in varying proportions are discussed. The utilisation of waste material and natural fibers helps to boost soil quality is beneficial, because they are inexpensive, accessible locally and ecological. Basalt fiber is a non - metal inorganic fiber which acts as a reinforcement for soil. It has excellent thermal, chemical, mechanical properties and environmental friendly material. The stabilizing effect of both the fibers on soil properties was observed. Addition of fibers improved the soil properties such as shear strength, and showed significant effects on cohesion, shrinkage characters. Also, it reduces desiccation and cracking.

P. Kulanthaivel et al (2021) The current study presents the laboratory investigation on the use of nano-silica (0.2, 0.4, 0.8 and 1.0%) and polypropylene fiber (0.25, 0.50, 0.75 and 1.0%) in problematic clayey soil to enhance the shear strength and compaction characteristics. From the Transmission electron microscopy (TEM) analysis, it is observed that the diameter of nano-particles used in this study was in the range of 10–20 nm. The nano-particles have a spherical shape and amorphous in nature. Extensive laboratory tests such as the standard Proctor compaction test and unconfined compressive strength test have been conducted on untreated and polypropylene fiber along with nano-silica treated clayey soil. The outcomes showed that the addition of polypropylene fiber in poor soil, increase the maximum dry density and reduce the optimum moisture content of the soil. The optimum dosage of polypropylene fiber and nano-silica added to the poor soil was 0.75% and 0.8%, respectively.

Samin et al. (2021)

In this study, PE and PP have been used in the form of fibres. The effect of the stabilisation was evaluated through carrying out standard laboratory tests. These tests have been conducted on natural and stabilised soils with four fibre contents (1%, 2%, 3%, and 4%) of the soil weight. The tests included the standard compaction test, unconfined compressive strength (UCS) test, California Bearing Ratio (CBR) test, and resilient modulus (Mr) tests. In all these tests, the fibre content was added in two lengths, which were 1.0 cm and 2.0 cm. Laboratory test results revealed that the plastic pieces decrease maximum dry density (MDD) and optimum moisture content (OMC) of the stabilised soils, which are required for the construction of embankments of lightweight materials. In addition, there was a significant improvement in the UCS of soils by 76.4 and 96.6% for both lengths of PE fibres and 57.4% and 73.0% for both lengths of PP fibres, respectively. Results of the CBR tests demonstrated that the inclusion of plastic fibres in clayey soils improves the strength and deformation behaviour of the soil especially with 4% fibre content for both lengths 1.0 cm and 2.0 cm, respectively, to a figure of 185 to 150% for PE and PP, respectively. Furthermore, the results of the Mr tests demonstrated that the mechanical properties improved to an extent. For an increase in fibre content, the resilient modulus increased by about 120% at 4% fibre content for PE. However, for PP, improvement in resilient modulus declined at 3% fibre content. Therefore, for soil stabilisation with fibre material, optimum fibre content shall be sought.

Adla Prathyusha et al. (2020)

The purpose of this study is to evaluate the suitability of red soil from a nearby source with the addition of basalt fiber for highway building. Basalt fibers are added to the conventional red soil in varying proportions (by weight of the raw soil, 0%, 0.2%, 0.4%, 0.6%, 0.8%, 1%, 1.2%, and 1.4%). Proctor compaction tests and California bearing ratio (CBR) testing were performed on stabilized soil in addition to the preliminary tests. The experiment's results show that strengthening the soil by adding basalt fiber was greatly enhanced. By adding basalt fiber to subgrade soil at a rate of 0.8% (by soil weight), it is possible to dramatically boost the strength of the soil, which also has a positive impact on the design of highway pavement structures.

Singh et al. (2019) The main motive of this research is to investigate the optimal combination of Nano-Silica and Polypropylene fiber with clay soil. The engineering properties such as liquid limit, plastic limit, maximum dry density and unconfined compressive Strength (UCS) are analyzed with virgin soil, the soil with Nano-Silica and combination of soil with Nano-Silica and polypropylene fiber. The Durability test is performed to understand the durability of stabilized soil by analyzing wetting–drying cycles Also, Scanning Electron Microscopy (SEM) test is carried out and images are obtained to understand micro-structural modification towards mixture of Nano-SiO_2 and PPF. Four different combinations of Nano-Silica at different percentages 1%, 3%, 5% and 7% are used in integration with polypropylene fiber is used in different percentages such as, 0.1%, 0.4%, 0.7%, 1%, and 1.3%. From these experiments, it has been analyzed that with the increase of PPF content in addition to Nano-Silica, the UCS increases and maximum value of UCS is obtained at 7% of Nano-Silica with 0.7% of PPF. The intermixing of PP fiber with the soil acts as a reinforcing material in binding the soil particles and the 'bridge effect' of fiber reinforcement in soil impedes the further development of tension cracks.

Sharma et al. (2019)

In the present study, therefore we have investigated the influence of waste polypropylene fibers on the resilient modulus of clay soil. Under this investigation, several cyclic CBR tests were performed on soil specimens by reinforcing the clay soil with polypropylene fibers which were added in different percentages i.e. 0.3%, 0.4%, 0.5%, 0.6% by weight of soil. The outcomes show that the experimented technique is very effective to improve the resilient modulus of clay soil. It is found that for the best results, optimum percentage of waste polypropylene fibers to be added is 0.4 % by weight of soil. Finally, it has been concluded that reinforcing the clay soil with polypropylene fibers provides positive influence on resilient modulus of the soil.

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.

Faseela M et al. (2018)

In order to strengthen the sub grade soil, jute fibre is used because they are economically sound, locally available, biodegradable, environment sensitive and practically acceptable. On the basis of CBR value of the subgrade and traffic on the proposed road, flexible pavements design being done.In this study a series of Proctor Compaction tests and California Bearing Ratio (CBR) tests were carried out on locally available soil reinforced with jute fibre and basalt. The percentage of Jute fibre and basalt by dry weight of soil was taken as 0.4%, 0.8%, 1.2% and 1.4%. In the present investigation the lengths of fibre was taken as 6mm and 12mm for each fibre length to find out the optimal quantity.

Anjana V. et al. (2018)

Fibre reinforced soil has advantages such as low cost, light weight, capability of maintaining strength isotropy etc. Fibre reinforced soil can be used can be effectively used as subgrade material for pavements where the available soil at subgrade is lacking the desired strength. Basalt fibre which is similar to glass fibre, is a newcomer in the field of geotechnical engineering. It is more resistant to alkaline, acid and salt attack when compared with glass fibre. This study aims at evaluating the effect of Basalt fibre on the strength characteristics of soil.

C.P. Ndepete et al. (2016) Soil reinforcement with natural and man-made fibers is one of the techniques to improve a number of mechanical and physical properties of soils. Although basalt originated fibers are currently being used for concrete, it is not an easy task to find a source in literature concerning the use of basalt fibers for soil improvement. In this study, basalt fibers have been used for this new aim. This study is an investigation into evaluation of the increase in soil strength, which is reinforced, in different percentages, by basalt chopped fibers. A silty soil sample has been chosen for this study and has been mixed, with 6, 12, and 24 mm long basalt fiber at varying contents. The unconsolidated undrained triaxial tests show that the addition of 24 mm long fibers into soil gives the maximum improvement in strength and the optimum fiber content (by dry weight of soil) is 1.5%.

3. Materials

3.1 SOIL

Source of soil

The soil required for the project is taken from an empty field in Jammu. The soil is alluvial in nature and contains high amounts of clay. The total quantity of soil collected is about 120 Kg.

All the soil that is used is sieved using 4.75mm sieve before start of the tests. The soil is oven dried for 24 hours before use to eliminate presence of any moisture in the soil. Firstly, Virgin soil without any admixture is tested for its properties and strength value and after that it is tested along with the addition of various proportions of Nano silica and Basalt Fiber.

Table no. 1 Properties of soil used in the study

S.No.	Properties	Result
1.	Liquid limit (%)	36
2.	Plastic limit (%)	21
3.	Plasticity Index (%)	15
4.	Specific Gravity	2.63
5.	Maximum Dry Density (KN/m³)	17.50
6.	Optimum Moisture Content (%)	14.6
7.	Soil Classification	CI (Intermediate Compressive Clay)
8.	CBR (%) (soaked)	2.3
9.	CBR (%) (Unsoaked)	3.7
10.	UCS (kN/m^{2})	240

3.2 NANO SILICA

Source of NANO SILICA

Nano Silica used in this research work was collected from Ludhiana.

Table 2: Physical properties of Nano Silica

Physical properties	Value
Diameter (nm)	20 – 30
Surface volume ratio (m2 /g)	193
Density (g/cm3)	1.7
Purity (%)	>99

Table 3: Chemcial properties of Nano Silica

Sr. No.	Compound	Value (%)
1	Silicon Oxide(SiO2)	99.88
2	Al_2O_3	0.05
3	Iron Oxide (Fe2O3)	0.01
4	Carbon content	0.06
5	Chloride content	0.09

3.3 BASALT FIBER

Source of Basalt Fiber

In the test, 6mm Basalt Fiber of various lengths will be used. The basalt fiber is equally distributed throughout the clay soil sample prior to dispersion. The filamentous Basalt Fiber is bought online from Delhi.

Table 3:- Properties of Basalt Fiber

Density	2.65g/cm^3
Elastic modulus	85.9Gpa
Elongation at break	3.12%
Tensile at strength	2611Mpa
Length	6mm

4. EXPERIMENTAL RESULTS

4.1 STANDARD PROCTOR TEST

Table no. 4: MDD and OMC for soil– Nano Silica–Basalt Fiber mix

SOIL:NS:BF	MDD (kN/m³)	OMC (%)
100:00:00	17.50	14.6
90.0:08:02	16.10	15.6
89.5:08:2.5	16.90	15.1
89:08:3.0	17.80	14.4

Fig:-1 Variations b/w MDD and OMC of Nano Silica, Basalt Fiber & soil with different proportions

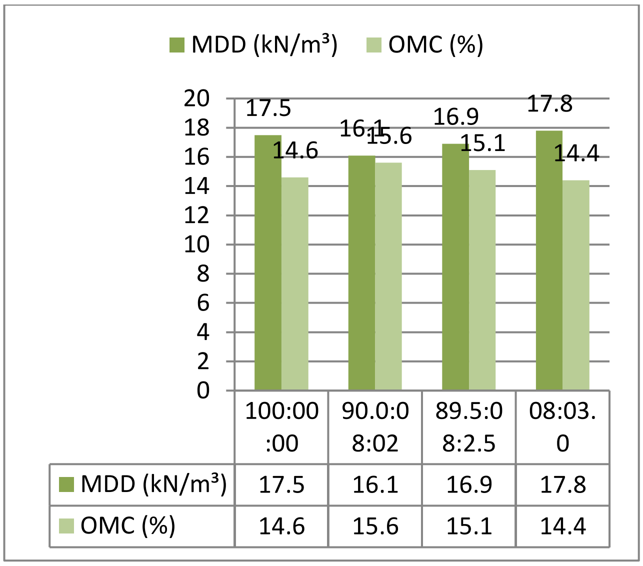


Table 5: Results of UCS of Nano Silica and Basalt Fiber Mix with Soil

SOIL:NS:BF	Curing Period (Days)	UCS (kN/m^2)
100:00:00	7	240
90.0:08:02	7	340
89.5:08:2.5	7	410
89:08:3.0	7	470

Fig:-2 Variations b/w UCS Values of Clayey soil, Nano Silica and Basalt Fiber with different proportions

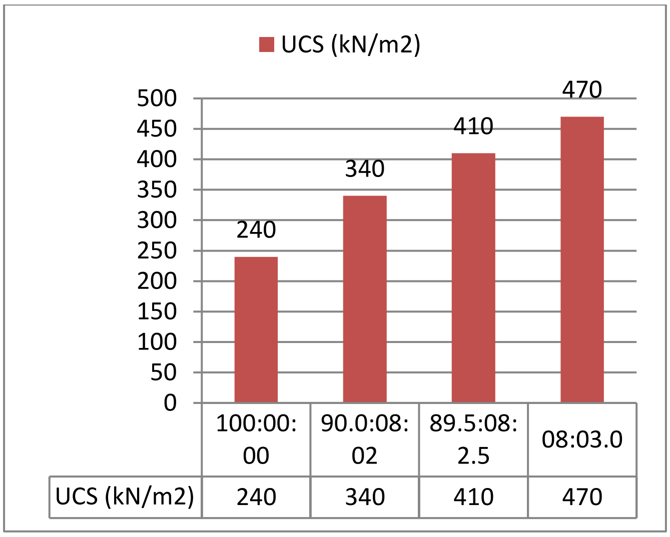
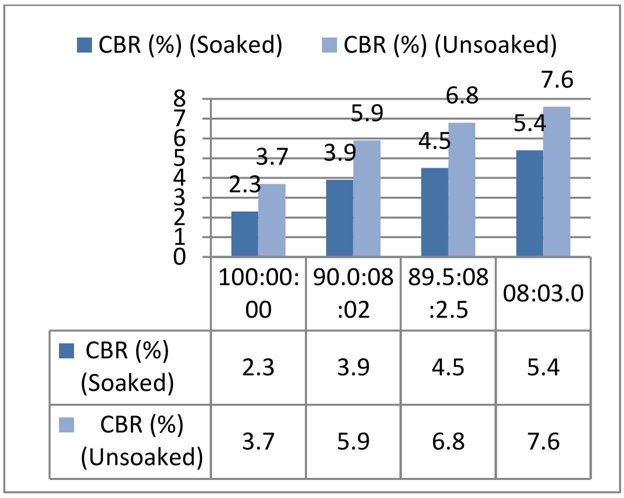


Table 6: Results of CBR of Nano Silica and Basalt Fiber Mix with Soil

SOIL:NS:BF	CBR (% (Soaked)	CBR (% (Unsoaked)
100:00:00	2.3	3.7
90.0:08:02	3.9	5.9
89.5:08:2.5	4.5	6.8
89:08:3.0	5.4	7.6

Fig:-3 Variations b/w CBR Values of Clayey soil, Nano Silica and Basalt Fiber with different proportions



5. DISCUSSIONS

5.1 STANDARD PROCTOR TEST:

- There is an increase of MDD from 17.50 to 17.80kN/m^3 and decrease of OMC from 14.60 to 14.4% when the percentages of Basalt Fiber vary from 2% to 3% and Nano Silica is fixed at 8%.

- There is an increase in MDD of modified soil with increase in percentage of Nano Silica, due to the lower specific gravity of Nano Silica as compared to the unmodified soil and OMC of modified soil is decrease as the percentages of Nano Silica increases, due to the increase in cohesive property of soil.

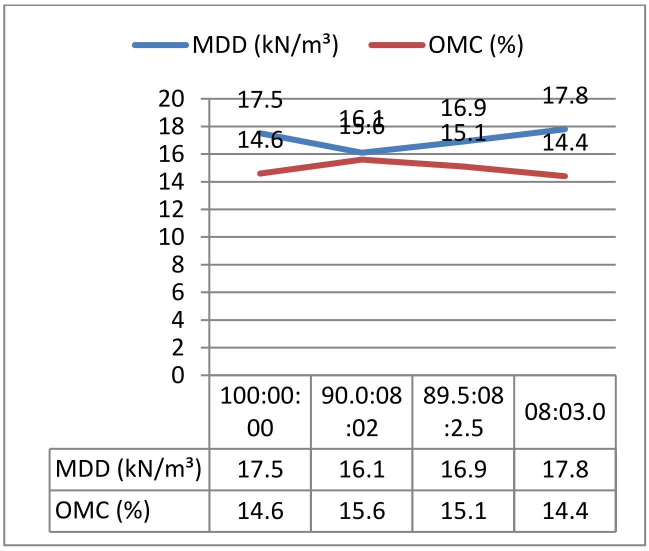


Fig:-4 Variations b/w MDD and OMC values of Nano Silica and Basalt Fiber Mix with Soil

5.2 CBR TEST:

- The CBR value of untreated soil is 2.3 and it increases to 1.78 times with addition of 8% Nano Silica when observed in soaked conditions.
- The CBR value of untreated soil is 2.3 and it increase to 2.34 times when Nano Silica 8% and Basalt Fiber 3.0% is added to untreated soil. This enhancement in CBR may be because of the gradual formation of hydration compounds in the soil due to the reaction between the stabilizers and the essentials particle present in the soil.

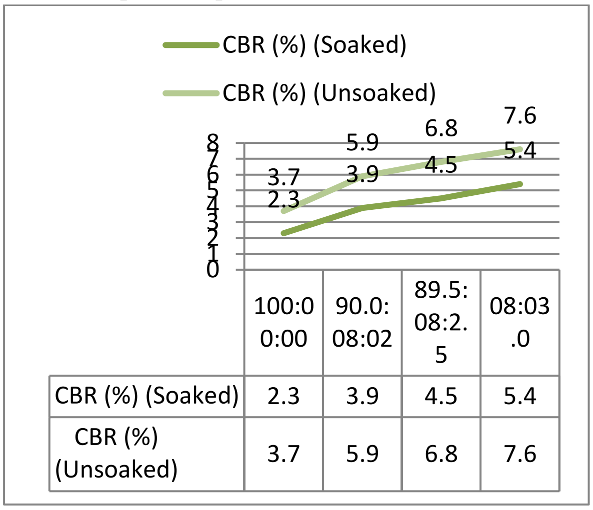


Fig:-5 Variations b/w CBR Values of Nano Silica and Basalt Fiber Mix with Soil

5.3 UCS TEST:

- The UCS values of untreated soil also improve considerably with expansion of Nano Silica 8% and Basalt Fiber 3.0%. The value increases from 240kN/m² to 470kN/m² with addition of Nano Silica and Basalt Fiber.
- The reason behind of this when Nano Silica and Basalt Fiber comes in contact with water, Because Nano-silica wraps the outer surface of the Fiber and hence form better bond between the soil particles and the Fiber surface which results in improving soil characteristics.

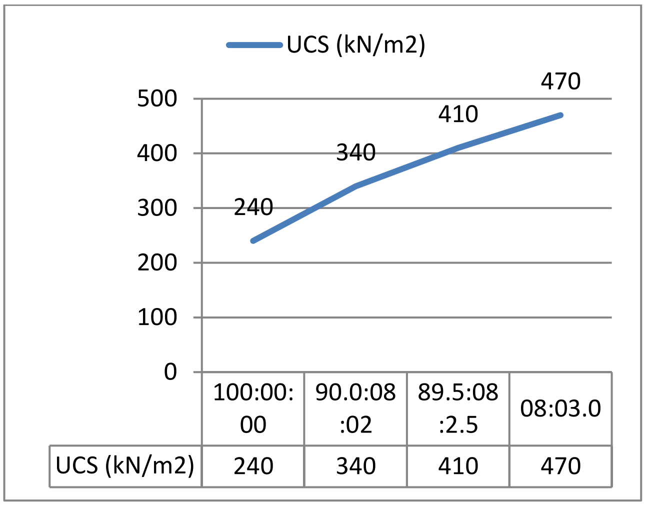


Fig:-6 Variations b/w UCS Values of Nano Silica and Basalt Fiber Mix with Soil

6. CONCLUSIONS

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

In present time, there has been an investigation into the use of recycled fiber. It is a hot issue due to environmental benefits and cost efficiency. Past studies had shown that the addition of waste chemicals can improve the strength properties of soft clay. This study investigates the effects of recycled Nano Silica and Basalt Fiber on the mechanical properties of clay based on the results a number of series of tests like – LL, PL, PI, Compaction, CBR, and UCS. The following conclusions can be drawn;

I. Based on the test results achieved from UCS after the curing periods of 7 days, the optimum mixing stabilizing agent for clay soil is 8% of Nano-silica and at 3.0% of Basalt Fiber.

II. Because nano-silica wraps the outer surface of the fiber and hence form better bond between the soil particles and the fiber surface which results in improving soil characteristics.

III. Surface cracks in the form of narrow and Nano-cracks on the compressed soil surface are visibly observed. The minimization of cracks in the soil shows that the Nano silica and Basalt Fiber material acts as bridge between the particles of soil and hence results in increasing soil strength. As a result, the Basalt Fiber material strengthens the spreading soil site and maintains it during load transfer condition.

IV. The C.B.R value increases with increase of Nano Silica along with increasing quantity of Basalt Fiber. It increased 2.34 times from the untreated soil.

V. Thus the optimum ratio of mixture of 89% soil/ 8% NS/ 3.0% Basalt Fiber is suggested for usage as soil stabilization process.

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