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Experimental Performance on Strengthening of Soft Clay using Cemented Nano Organo Silane Compound

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Abstract: Roads are the essential component that ensures the continued development of an economy. The connectivity of rural roads is one of the most important aspects of development since it facilitates access to both economic and social services throughout rural areas. For the sake of the economy as a whole, it is imperative that the use of locally accessible resources, either in their natural state or after appropriate processing, be maximized to the greatest degree feasible. It would seem that the most effective method for maintaining their suitability for usage is to make use of stabilized pavement bases. When it comes to pavement layers, nanochemicals are goods that are based on nanotechnology and have the ability to supply solutions that prevent moisture migration and feature strong bonding powers. As an external factor, the addition of nanoparticles to locally accessible soil will result in soil manipulation at the atomic or molecular level. This manipulation will have an effect on the soil's strength, permeability, indices, and CBR qualities. The growing problem of roads of low quality may be addressed by the use of nanotechnology, which is a reformed manner. Through the use of nanochemicals, the purpose of this research is to enhance the engineering performance of in situ material that is readily accessible where it is located. Investigations in the laboratory have been carried out on cement-added clay soil that has been treated with varying concentrations of the nanochemical Terrasil. Several studies, including Atterberg's limit, compaction characteristics, UCS, California Bearing Ratio tests, and others, have been carried out in order to investigate the impact that its use has had. In addition, the durability properties of clay soil that has been improved with the use of Terrasil are evaluated in the context of wetting and drying experiments. In this research, it is suggested to examine the optimal mix of soil, cement, and Terrasil with the aim of determining how well it performs as a foundation material for pavement.

KEYWORDS : Nanochemical Terrasil. Several studies, including Atterberg's limit, compaction characteristics, UCS, California Bearing Ratio tests.

I. INTRODUCTIONS

Soft clay soil presents significant challenges in geotechnical engineering due to its low strength, high compressibility, and susceptibility to moisture-induced instability. In regions prone to heavy rainfall, such as tropical climates or monsoon-prone areas, the degradation of soft clay soil poses a considerable risk to infrastructure stability, particularly in transportation systems, building foundations, and embankments. Traditional methods of soil stabilization, such as the addition of lime or cement, have been employed to mitigate these challenges. However, these methods often have limitations in terms of effectiveness, cost, and environmental impact. In recent years, the development of innovative soil stabilization techniques utilizing nano-technology-based additives has garnered increasing attention as a potential solution to enhance the engineering properties of soft clay soil. One such promising approach involves the use of a cemented nano organo silane compound, herein referred to as Terrasil. This compound combines the binding properties of cement with the soil stabilization capabilities of organo silane, offering a novel solution to strengthen soft clay soil and mitigate the adverse effects of moisture ingress. The objective of this report is to investigate the effectiveness of Terrasil in strengthening soft clay soil and assess its suitability for practical applications in geotechnical engineering. Through laboratory experiments and analysis, the study aims to evaluate the mechanical properties, such as unconfined compressive strength, California

Bearing Ratio (CBR), and consolidation characteristics, of soft clay soil treated with varying concentrations of Terrasil. Furthermore, the research seeks to explore the microstructural changes induced by Terrasil within the soil matrix, providing insights into the mechanisms underlying its soil stabilization effects. The findings of this study are expected to contribute to the body of knowledge on innovative soil stabilization techniques and inform the development of sustainable solutions for addressing the challenges associated with soft clay soil in infrastructure projects.

Overall, the investigation into the strengthening of soft clay soil using a cemented nano organo silane compound represents a significant step towards enhancing the resilience and durability of geotechnical structures, particularly in regions prone to adverse weather conditions and soil instability.

Characterization of Soft Clay Soil for Index and Engineering Properties: Soft clay soil exhibits unique properties that significantly influence its behaviour under various loading conditions. To understand and quantify these properties, a comprehensive characterization is essential. This involves a series of laboratory tests aimed at determining both the index and engineering properties of the soil. Index properties include parameters such as grain size distribution, moisture content, and Atterberg's limits (plasticity index, liquid limit, and plastic limit). These properties provide insights into the soil's composition, water content, and plasticity, which are crucial for assessing its suitability for engineering purposes. Engineering properties encompass parameters related to the soil's strength, compaction, CBR and UCS properties. These properties are fundamental for designing foundations, embankments, and other civil engineering structures on soft clay soil. By characterizing the soft clay soil for its index and engineering properties, engineers and geotechnical professionals gain valuable insights into its behaviour and can make informed decisions regarding soil stabilization and foundation design.

Influence of Stabilization Additives on Strength Improvement: Soft clay soil often requires stabilization to enhance its engineering properties and mitigate potential hazards such as settlement and instability. Various additives, including cement and nano-based organo silane compounds, are employed to improve the soil's strength and durability. In this study, different dosages (0.02% to 0.05%) of Nano based organo silane compound are introduced in to soft clay soil samples at 1% cement binder, and their effects on strength improvement are investigated. The treated soil samples are subjected to standardized curing conditions for 28 days to allow the chemical reactions to complete and sustain the strength improvement. To evaluate the strength improvement, laboratory tests such as CBR and unconfined compression tests are conducted on treated soil samples at different curing times. The results are analysed to quantify the increase in strength achieved with each dosage of stabilization additive, providing valuable insights into the most effective dosage called optimal for enhancing the engineering properties of soft clay soil.

Investigation of Sustainability of Improved Strength Under Wet and Drying Cycles: While short-term strength improvement is essential, the long-term sustainability of treated soft clay soil under real climatic conditions is equally crucial. Environmental factors such as wetting and drying cycles can have a significant impact on the stability and durability of stabilized soil. In this phase of the study, treated soil samples are subjected to wet and drying cycles to simulate the effects of seasonal variations and environmental loading. These cycles involve alternating periods of saturation and drying, mimicking the natural conditions to which the soil may be exposed over its service life. During the wet and drying cycles, the strength and deformation characteristics of the treated soil samples are monitored. This allows for the assessment of how well the soil retains its improved strength and stability over time, providing insights into its long- term performance under cyclic loading conditions.

II. METHODOLOGY

Nanotechnology offers promising solutions for enhancing soft clay soil by providing innovative methods to modify its properties at the molecular level. Nano-chemical solutions, such as organo- silane compounds, can be tailored to interact with soil particles, thereby improving its mechanical characteristics and stability. Here's a detailed exploration of the steps involved in utilizing nanotechnology for soil enhancement and assessing its impact:

Exploration of Nanotechnology's Role: Nanotechnology introduces novel approaches to soil improvement by manipulating soil particles' properties on a nanoscale level. By employing nano-chemical solutions, it becomes possible to enhance soft clay soil's strength, stability, and durability.

Analysis of Soft Clay Soil Properties: Soft clay soil samples are collected from the field and conducted comprehensive laboratory testing to avail geotechnical properties. This includes determining the particle size distribution, Atterberg's limits, Compaction and UCS through laboratory testing.

Preparation and Stability Assessment of Nano-Chemical Solution: The nano-chemical solution, typically comprising organo-silane compounds, is prepared according to specifiedformulations. Its stability and compatibility with soft clay soil are assessed through laboratory experiments, ensuring effective dispersion and interaction with soil particles.

Testing on Treated and Untreated Soil Specimens: Compaction, and UCS tests are performed on both treated and untreated soil specimens. The treated specimens are subjected to different curing periods from 1 day to 28 days. These tests evaluate the soil's response to loading, deformation characteristics, under various wetting and drying conditions.

Analysis of test results: Test data, including soil gradation, Atterberg's limits, proctor compaction and UCS of untreated soil was analysed. Later Nano chemical treated soil samples are tested for UCS at different dosages of terrasil chemical with curing. A comparison between treated and untreated soil specimens allows for the quantification of improvements achieved with the nano-chemical solution.

Through this detailed approach, the impact of nanotechnology and nano-chemical solutions on enhancing soft clay soil can be thoroughly investigated and evaluated. The data obtained from laboratory experiments provide valuable insights into the effectiveness and feasibility of using nanotechnology for soil improvement applications, guiding future research and engineering practices in geotechnical engineering.

III. EXPERIMENTAL PROGRAMME

The experimental programme includes the collection of locally available soft clay, stabilizers of Terrasil and cement, and determination of the basic material properties. It discusses the test procedure to carry out the various soil tests on untreated and treated soils including the test programme explore the step wise series of various laboratory soil tests.

A. *Materials used*

Soft Clay: The soft clay used for the tests was collected from Champakulam, a place near the Kakinada region in AP. The soil sample was disturbed and taken from a depth of 2 meters below the ground in an open pit. Sample collected was air-dried and pulverized and the basic properties of the soil were determined.

Cement: Ordinary Portland cement of 43 grade was used for the testing. The brand of cement selected was RAMCO. Addition of cement causes modification of mechanical or physical characteristics of soil, such as flexural strength, resilient modulus, fatigue, shrinkage and durability. Soil plasticity and water content will be reduced.

Terrasil Nanochemical: Terrasil is a commercially available nanotechnology based chemical stabilizer. It is available in concentrated liquid form and is to be mixed with water in specified proportion before mixing with the soil. Terrasil was purchased from Zydex Industries Pvt. Ltd.

Table 1: Geotechnical characterisation of clay soil

S.NO.	EXPERIMENT	RESULT
1.	pH	3.26
2.	SPECIFIC GRAVITY	2.5
3.	GRAIN SIZE ANALYSIS	Sand: 4.2%, Clay and Silt: 95.8%
4	ATTERBERG'S LIMITS: LIQUID LIMIT	56.2%
5.	PLASTIC LIMIT	26.5%
6.	PLASTICITY INDEX	29.7%
7.	SHRINKAGE LIMIT	8.2%
8.	SOIL CLASSIFICATION	CH (Highly compressible clay)
9.	PROCTOR COMPACTION TEST:	

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	MAX DRY DENSITY	1.44 g/cm³
	OPTIMUM MOISTURE CONTENT	27%
7.	UCS	46 kPa
8	CBR	4%
9.	ORGANIC CONTENT	15%
10.	FREE SWELL INDEX	20%

IV. RESULTS AND DISCUSSION

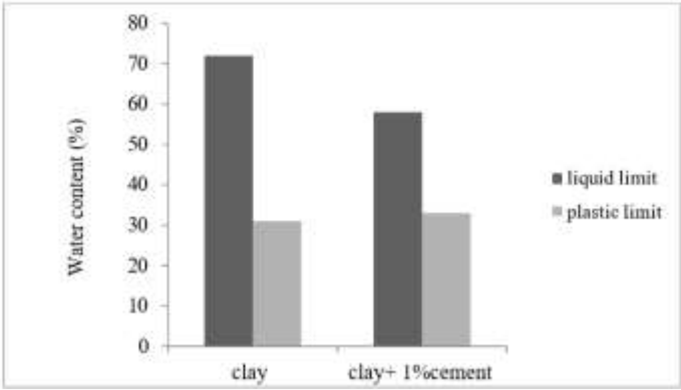
This chapter presents a discussion of results obtained after conducting the experiments on various soil mixtures. The focus of the present study is to evaluate the impact of Terrasil stabiliser agent on geotechnical properties of soft clay as a subgrade road base material. It is also planned to find the optimum percentage of additives i.e. Terrasil where the UCS strength is maximum. The strength values of treated soils are compared with the strength of untreated clay soil. The cement treated clay soil was prepared after mixing the 1% cement by dry weight of soil into the clay soil. Further, various laboratory tests like consistency limits, UCS strength, and CBR tests were conducted on soil-cement mixtures to examine the effect of cement on improvement of geotechnical properties of clay soil.

B. Consistency Limits

Liquid limit tests for the clay soil were conducted on prepared soil-cement mixture by using Casagrande apparatus according to IS: 2720- Part V. The liquid limit and plastic limit for the soil treated with 1% cement are found to 58% and 33% respectively. The comparison of consistency limits of clay and clay +1% cement mixture is shown in Fig. 4.1. It can be seen from figure that with the addition of cement into the clay soil, the liquid limit of cement treated clay is reduced to about 80% of the liquid limit of clay soil. The plasticity index of cement treated clay is reduces to 61% of PI of clay soil.

C. Unconfined Compressive Strength

UCS test was performed on cement-clay sample prepared at its maximum dry density by controlling the optimum water content of clay soil.



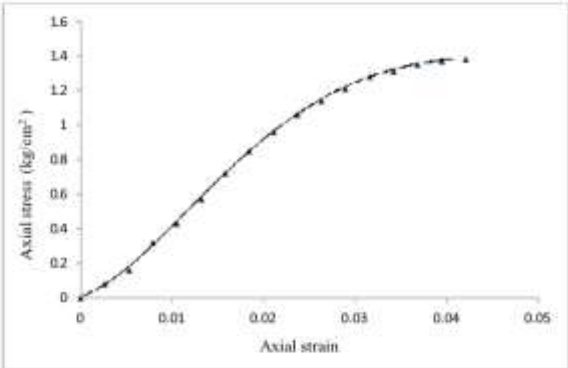
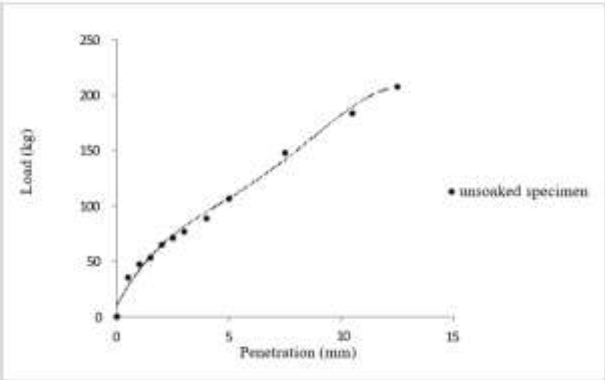


Fig 1: Comparison on consistency limits of clay and cement treated clay, Stress-Strain relationship for clay soil + 1% cement mixture

The sample was cured for 28 days prior to testing. Three similar UCS specimens were prepared and tested to report the average value of UCS strength. The typical stress-strain curve for soil- cement mixture shown in Fig. 4.2 is obtained after conducting the UCS test at the end of 28 days of curing. It shows the peak stress at 4% strain level is considered as UCS strength and it was found to 138 kN/m^2. Quantitatively, the strength of cement treated clay soil is improved about 200% higher than the strength of clay soil. This improvement may be possible due to cementation effect with curing on clay sample.

D. California Bearing Ratio

The CBR sample was prepared at maximum dry density after mixing the cement treated clay with optimum water content of 27%. The sample was compacted by using heavy compaction hammer. The tests were conducted on both the unsoaked and soaked cement treated clay samples. The sample was kept for 28 days curing in water prior to conducting the soaked CBR test. The obtained data arrived from the experimental test was predicted in the form of load-penetration curves as shown in Figs. 4.3 to 4.4 for both the unsoaked and soaked conditions respectively. In general, The CBR value is reported at 2.5 mm of penetration, however in the present test, the CBR value is high at 5 mm of penetration. Therefore, the test was repeated on another fresh similar prepared sample to confirm the higher CBR value. After repeating the test, the unsoaked CBR value of cement treated clay sample is found to 5% at 5 mm of penetration. Similarly, tests were repeated for soaked samples and the CBR of soaked sample was found to 4% at 5 mm of penetration. It indicates the CBR value of treated clay sample was improved significantly above the CBR of clay sample.



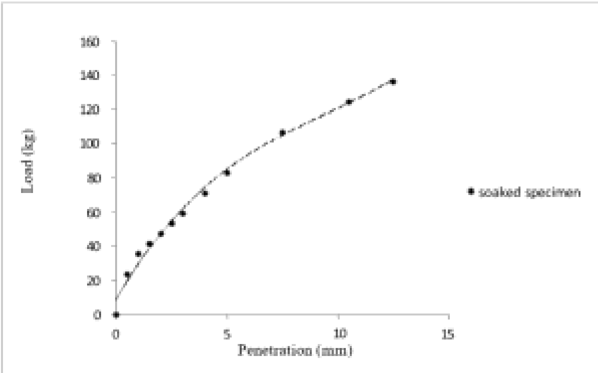


Fig 2: Load Vs penetration curve on unsoaked cement treated clay sample and Load Vs penetration curve on soaked cement treated clay sample

After conducting the all the required tests on cement treated clay samples explained above, the obtained test results

Table 2: Properties of cement treated clay soil

Sl. No.	Property	Value
1	Consistency limits Liquid limit (%) Plastic limit (%) Plasticity Index (%)	58 33 25
2	Unconfined compression strength, (kN/m^2)	138
3	CBR value for IS heavy compaction (a) Unsoaked specimen (b) Soaked specimen	 5 4
4	Free swell index (%)	14

E. Nanochemical treated clay soil

Herein, the nanochemical introduced into the clay soil is Terrasil with 1% cement binder. Totally four different nanochemical treated clay soil samples were prepared after adding the Terrasil amounts of 0.02%, 0.03%, 0.04% and 0.05% in to the clay soil. Initially, nano-chemical solution has been prepared after adding predetermined dosage of

Terrasil agent in the required optimum quantity of water. Further, the soil combinations prepared after spray the nano-chemical solution on loose soil and mixed uniformly. The nanochemical treated samples were tested for consistency limits, UCS and CBR strength properties. The samples were tested for compressive strength and CBR strength at different curing times in order to examine the effect of curing on strength properties.

F. Consistency Limits

The consistency limit tests were performed on chemical treated clay samples mixed with Terrasil dosages of 0.02%, 0.04% and 0.05% respectively. The treated samples were cured in open air for 24 hours prior to testing. After conducting the Liquid limit and Plastic limit tests on treated samples, the obtained results are tabulated in Table 4.2 given below. It can be seen from table that with the addition of Terrasil chemical into the clay soil up to 0.03% weight of soil, the plasticity index is reduces from 41 to 18%. Further increase of chemical dosage, PI is increases. It indicates that the soil changes to less plastic state with the addition of optimum level of 0.04% chemical into the clay soil. It also shows that even the liquid and plastic water contents are increases with the addition of chemical up to 0.04%, the plasticity index is decreases significantly.

Table 3: Consistency limits of Nano-chemical treated clay soil

Dosage of chemical	**LL (%)**	**PL (%)**	**PI (%)**
Untreated soil	72	31	41
(0.02%)	82	60	22
(0.04%)	88	70	18
(0.05%)	81	61	20

G. Unconfined Compression Strength

To obtain the compressive strength values of each chemical treated clay soil mixture, various UCS tests were performed on samples prepared at its maximum dry density by controlling the optimum water content. The samples were tested for different curing periods in order to examine the effect of curing on strength properties. For each chemical treated clay soil mixture, three similar UCS specimens were prepared and tested to report the average value of UCS strength.

Table 4: UCS Strength of Terrasil treated clay soils at different curing times

Terrasil Dosage, %	**UCS Strength, kN/m^2**		
	7 days of curing	**14 days of curing**	**28 days of curing**
0.02	136	160	204
0.03	141	167	216
0.04	**155**	**187**	**249**
0.05	148	177	223

H. California Bearing Ratio

Three combinations of samples were prepared after adding the Terrasil chemical in the dosages of 0.03%, 0.04% and 0.05% in to the clay soil with 1% cement. The CBR chemical treated samples were compacted at maximum dry density after mixing the chemical with optimum water content of 27%.

The sample was compacted by using heavy compaction hammer. The tests were conducted on soaked chemical treated clay samples. The samples were tested at the different curing times of 7 days, 14 days and 28 days in order to examine the effect of curing on CBR value. The soaked samples were soaked for 4 days after curing prior to CBR testing. The load-penetration curves for chemical treated clay soil mixtures shown in Figs. 4.9 to 4.11 are obtained after conducting the CBR tests at different curing times of 7, 14, and 28 days.

Table 5: CBR Strength of Terrasil treated clay soils at different curing times

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Terrasil Dosage, %	CBR Strength, %		
	7 days of curing	14 days of curing	28 days of curing
0.03	5.2	7.4	10.1
0.04	6.9	10	12.1
0.05	6	9.5	11.2

V. CONCLUSION

- The untreated soil is characterised as soft clay based on its UCS strength about 46 kPa. The soil is classified as highly compressible clay.
- The maximum dry density of clay soil corresponding to OMC of 27% is 1.44 g/cm^3
- The soaked CBR of clay soil was found to 2% and the coefficient of permeability is about 1.3×10^{-6} cm/sec.
- The addition of cement into the clay soil causes the liquid limit of treated clay reduced to about 80% of the liquid limit of clay soil. The plasticity index of cement treated clay is reduces to 61% of PI of clay soil.
- The increase of terrasil added into the clay soil up to 0.04% weight of soil causes the plasticity index reduces from 41 to 18%. There is drastic decrease in permeability due to increased dosage of terrasil into the soil.
- The unconfined compression and CBR strengths are increases with increase the curing time up to 28 days in all types of soil mixtures.
- The UCS strength of clay soil improved to 138 kPa with the addition of 1% cement content
- The UCS strength of soil mixed with optimum dosage of 0.04% terrasil chemical is improved to 249 kPa that about 441% higher than the strength of clay soil. This improvement may be possible due to the reaction of the chemical with the soil particles and as a result it water proofs the surface.
- The unconfined compression strengths of NC treated soils are increases with increase the curing time up to 28 days in all types of soil mixtures. It indicated that the chemical reaction may takes place up to 28 days to stabilize the soil and the improved strength becomes constant.
- The NC treated clay soils at 28 days of curing are capable to resist the wetting and drying loads up to 4 cycles with marginal reduction of UCS strength. Hence the improved strength of NC treated clay is sustainable up to long duration.

In conclusion, the soil + 1% cement mixture added with 0.04% terrasil is the best soil combination which is exhibiting the higher UCS strength. The stabilized soil of soil-cement-terrsil mixture is very useful as a subgrade material due to improved UCS that relevant with CBR strength.

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