Experimental Study on Chemically Stabilized Subgrade Soil for Flexible Pavement

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Abstract— Weak subgrade soils are most likely to cause damage to structures such as road pavements. Different types of remedial measures are developed to improve the strength parameters of the subgrade soil. It helps in improving dry density of subgrade soil besides reduction in the permeability and compressibility along with increase its shear strength and the bearing capacity of the subgrade soil. This study aims to improve the subgrade soil strength by chemical stabilization. The identified soil sample with a CBR of 1.76% is mixed with Nano Calcium Chloride and Sugarcane Bagasse Ash to undergo Standard Proctor Test and California Bearing Ratio tests. The percentage addition of Nano Calcium Chloride to the soil is varied as 0.2%, 0.4%, 0.6%, 0.8% and 1% respectively along with the 0.2%, 0.4% and 0.6% and 0.8% addition of Sugarcane Bagasse Ash respectively. The mixed composition is subjected to Standard Proctored and Soaked CBR tests. It is inferred from the results that the Soaked CBR value of soil was attained with the 0.8% of Nano Calcium Chloride and 0.6% of Sugarcane Bagasse Ash additions. The experimental results shows that the results to be applied in the weaker soil abundant areas to minimize the pavement thickness.

Index Terms- Flexible Pavement, Sugarcane Bagasse Ash, Standard Proctor, California Bearing Ratio, Expansive Soil.

I. INTRODUCTION

Soil stabilization is a process that aims to improve the engineering properties of soil, making it more suitable for construction, pavement, and other Civil Engineering applications. Soil stabilization is considered as one of the most important solutions in geotechnical practice, especially in weak round conditions. Today, different chemicals such as calcium chloride, sodium chloride, sodium silicate and calcium acrylate are most commonly used to improve the engineering properties of a variety of soils.

The primary purpose of subgrade stabilization is to enhance the load bearing capacity and durability of the subgrade soil, making it more suitable for supporting the traffic loads and preventing deformation, rutting, and other structural failures. When selecting a subgrade stabilization method, it is important to consider the environmental impact. Some stabilization agents may have environmental implications, so it is crucial to choose methods that minimize that negative effects.

Bagasse ash is a waste product generated from the combustion of bagasse a fibrous residue left behind after sugarcane is processed to extract the juice for sugar production. Bagasse ash is rich in silica and is considered an industrial waste material in the context of the sugarcane industry. It is important to note that the quality and properties of bagasse ash can vary depending on the source and the combustion process used in the sugar industry.

Nano calcium chloride refers to calcium chloride particles that have been processed at the nanoscale, typically with dimensions less than 100 nano meters(nm). This nano scale modification results in calcium chloride particles with increased surface area and unique properties compared to their bulk nano calcium chloride is used to improve soil stabilization in road construction and construction projects.

Nano-sized particles of calcium chloride can penetrate soil more effectively due to their smaller size and increased surface area. This can lead to better mixing with soil particles and more uniform distribution. Nano calcium chloride may accelerate the stabilization process compared to larger calcium chloride particles, as it can dissolve and disperse more quickly, leading to faster results.

In this study geotechnical properties such as particle size distribution, specific gravity, optimum moisture content, maximum dry density and California bearing ratio of subgrade soil are to be determined by the nano calcium chloride and bagasse ash added to the soil in different proportions and all the geotechnical properties are to be studied.

1.1 RESEARCH GAP

The subgrade soil has low bearing capacity, it increases the thickness of the flexible pavement. This leads to quantity of the material is high as well as cost of the construction of pavement. For minimize the flexible pavement thickness, the load bearing capacity of the subgrade soil is to be improved. These thickness is check for rutting and fatigue criteria of the pavement failure under the action of vertical wheel load either by manually or by IITPAVE software. The CBR value of the subgrade weak soil is increased by using chemicals such as nano calcium chloride and sugar cane bagasse ash as a ground improvement materials for geotechnical and construction engineering practice.

Nano calcium chloride used as a soil stabilizing material due to which it has a high surface area and sugar cane bagasse ash is used for stabilize the weak subgrade soil due to which it has a high silica content it improve the strength of the subgrade soil and it reduce the permeability of the soil.

II. MATERIALS AND METHODS

2.1 Soil

The soil sample used for this study work was collected from Velandipalayam, Coimbatore. The colour of the soil was a dark grey. In order to avoid biological matter from being contained, a disturbed sample is taken from a test pit at a depth of approximately 1.2 meters below the natural ground surface. The obtained soil was air dried, manually crushed, then sieved using an IS size 4.75 mm.

2.2 Nano calcium chloride

Nano calcium chloride refers to calcium chloride that has been processed into nanoscale particles, typically with dimensions in nanometer range. Nano particles are extremely small, with sizes ranging from 1 to 100 nanometers. Nano calcium chloride can be synthesized using various methods, such as precipitation, sol-gel processes, and other nano material production techniques. The resulting nanoparticles have a high surface area-to-volume ratio, which can lead to enhanced reactivity and improved performance in specific applications. The properties of the nano calcium chloride (4) are shown in Table 1.

Table 1. Properties of nano calcium chloride

Properties	Percentage
Calcium (%)	36.11
Chloride (%)	63.88
Compound Formula	$Cacl_2$
Molecular Weight (mg/l)	111
Specific Surface Area(m^2/g)	10-75
Melting point(°C)	772
IUPAC name	CalciumDichloride

2.3 Sugar Cane Bagasse Ash

Sugarcane bagasse ash (SCBA) is a by product obtained from the combustion of sugarcane bagasse, which is the fibrous residue left behind after sugarcane is crushed to extract its juice. SCBA is generated when bagasse is burned as fuel in sugar mills or other biomass combustion processes. Using SCBA as a soil stabilizing agent, it is typically mixed with the soil in varying proportions based on the specific soil type, desired engineering properties and requirements. The properties of the sugar cane bagasse ash (1) are presented in Table 2.

Table 2. Properties of sugar cane bagasse ash

Properties	Percentage
Silica (SiO_2)	64.38
Magnesium (MgO)	0.85
Calcium (Ca O)	10.26
Iron (Fe_2O_3)	4.56
Sodium (Na_2O)	1.05
Potassium (K_2O)	3.57
Alumina (Al_2O_3)	11.67

Sugar Cane Bagasse Ash exhibits pozzolanic properties, making it suitable as a supplementary cementitious material, it can enhance the performance of concrete by improving durability and reducing heat of hydration. Bagasse ash typically has a high specific surface area due to its fine particle size, which enhances its reactivity in various applications.

III. EXPERIMENTAL PROGRAMME

Various index and engineering properties of the subgrade soil such as specific gravity, particle size distribution, Optimum Moisture Content, Maximum Dry density and California Bearing Ratio were determined. All the tests were carried out as per IS codal provisions. In this experimentation work the soil is compared with Nano Calcium Chloride and Sugar Cane Bagasse Ash in different proportions. The effect of addition of the materials on the strength behaviour of the soil is studied by varying percentages Nano Calcium Chloride and Sugar Cane Bagasse Ash by weight of sample. The experimental study involves Standard Proctor Compaction test and California Bearing Ratio Test. Table 3 presents the properties of the subgrade soil

Table 3. Properties of subgrade soil

Properties	Result
Liquid limit	46
Plastic limit	31
Shrinkage limit	19
Specific gravity	2.71
Optimum moisture content	16%
Maximum dry density	1.71g/cc
CBR value	1.76%

3.1 Standard Proctor Compaction test

Standard proctor test shows the relationship between the moisture content and dry density of the soil. As per IS: 2720 (part 7) diameter of mould 100mm and the height of mould 127.3mm and capacity of mould is 1000 ml. The weight of rammer is 2.6 kg and 25 blows with free fall of rammer is 310mm. The soil was taken 2.5 kg passing through 4.75mm IS sieve. The percentage of water content was added to the soil sample from 10%, 12%, 14%, 16%and 18% respectively. And take the corresponding dry density values. The relationship between dry density and moisture content obtained by a compaction test. Compaction test results for the virgin soil (Velandipalayam clay at a depth of 1.2m) using the standard proctor test in figure 1.

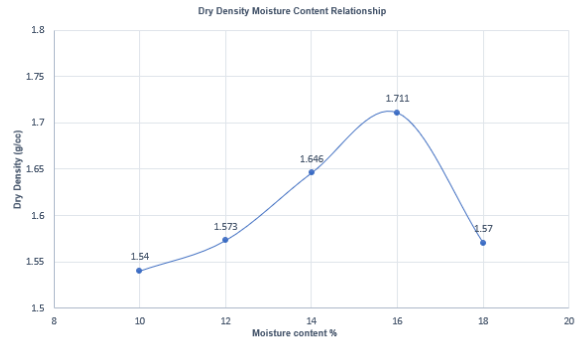

Fig. 1 Compaction curve for untreated soil

3.2 CALIFORNIA BEARING RATIO TEST

The CBR test was used for evaluating the strength of subgrade soil and for the design and construction of flexible pavements. This is the empirical method for design of flexible pavement based on accounting physical properties and strength parameters. It has a plunger diameter of 50mm penetrate into the soil at a rate of 1.25mm per minute. The sample should be soaked for 4 days where annual rainfall of the area is more than 50 cm. Test load for 2.5mm and 5mm penetration of plunger into the soil are recorded. Generally CBR value of 2.5mm penetration has a greater value than the 5mm penetration CBR value. Otherwise repeat the process with 6 number of samples.

Fig. 2 California Bearing Ratio Test

If the test result again gives the similar one are above mentioned, the higher value obtained at 5mm penetration is recorded as the CBR value of the sample. The CBR value extensively used for field corelation of flexible pavement. Figure 2 shows the schematic diagram of the California Bearing Ratio test.

$$\text{CBR \%} = \frac{\text{Test load corresponding to penetration value}}{\text{standard load for same penetration value}} \times 100 \quad (1)$$

For 2.5 mm penetration standard load = 1370 kg
For 5mm penetration standard load = 2055 kg

In this test 5000g sample was taken passing through 4.75mm IS sieve. The sample mixed with the water content of Optimum Moisture Content value from the standard proctor compaction test. The sample was compacted in three layers of each layer has 56 blows. Figure 3 presents the California Bearing Ratio graph of the virgin soil.

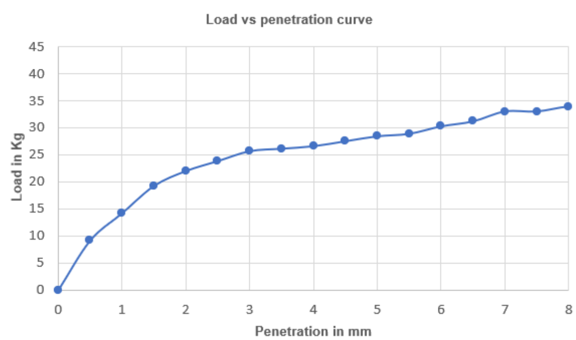

Fig. 3 CBR curve for untreated soil

The test result shows that load as ordinate and penetration value as abscissa of the subgrade sample. Where the 2.5mm penetration and 5mm penetration is need for the calculation. 2.5mm penetration load value are 24.2 kg and 5mm penetration load value are 28.44 kg. The calculating CBR value 2.5mm penetration give the greater value of CBR than the 5mm penetration CBR value. Then we 2.5mm penetration CBR value as the CBR value of the subgrade soil sample. The California Bearing Ratio for the untreated soil is 1.76%.

IV. RESULTS AND DISCUSSION

The Standard Proctor's Compaction tests are conducted on soil with 0.2%, 0.4%, 0.6% and 0.8% of Sugar Cane Bagasse Ash to determine the Optimum percentage of the sugar cane bagasse ash. Then the optimum percentage of sugar cane bagasse ash is 0.6%.

Standard Proctor's Compaction tests are conducted on soil with various percentage 0.2 %, 0.4%, 0.6%, 0.8% and 1% of Nano Calcium Chloride and optimum percentage 0.6% of Sugar Cane Bagasse Ash to determine the Optimum moisture content and Maximum dry density. This optimum moisture content values are used as the water content of the California Bearing Ratio Test. Figure 4 represents the relationship between the optimum moisture content and Maximum dry density of soil with 0.2 % of Nano Calcium Chloride and 0.6% of Sugar Cane Bagasse Ash.

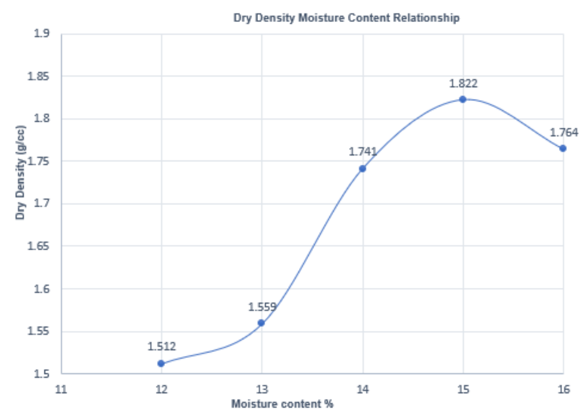

Fig. 4 Compaction curve for soil mixed with 0.2% of nano $CaCl_2$ and 0.6% of SCBA

The optimum moisture content and Maximum dry density of soil with 0.4% of nano Calcium Chloride and 0.6% of SCBA obtained from the Compaction curve is shown in figure 5.

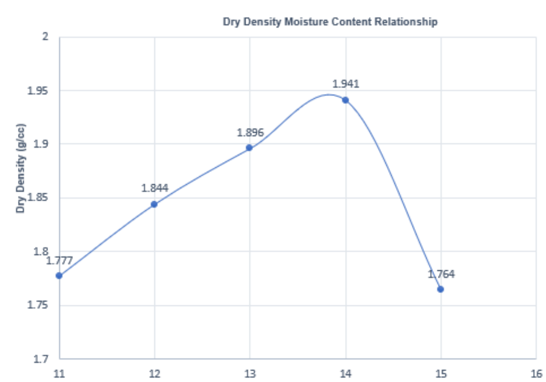

Fig. 5 Compaction curve for soil mixed with 0.4% of nano $CaCl_2$ and 0.6% of SCBA

The optimum moisture and Maximum dry density of soil with 0.8% of Nano Calcium Chloride and 0.6% of SCBA obtained from the compaction curve is shown in figure 6.

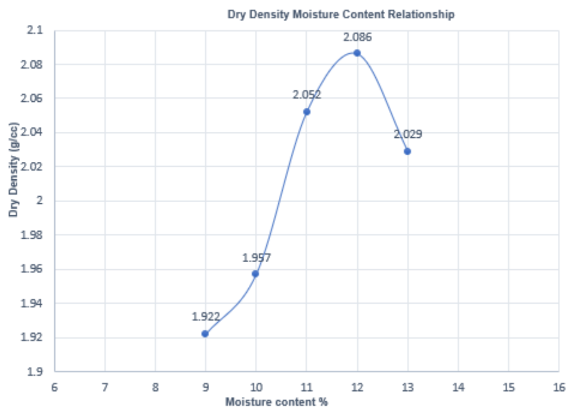

Fig. 6 Compaction curve for soil mixed with 0.8% of nano $CaCl_2$ and 0.6% of SCB

California Bearing ratio test are conducted on soil samples prepared under light compaction to determine the CBR value of subgrade soil with 0.2%, 0.4%, 0.6%, 0.8% and 1% of Nano Calcium Chloride and optimum percentage 0.6% of SCBA. The load Vs penetration curve of subgrade soil is shown figure 7, 8, 9.

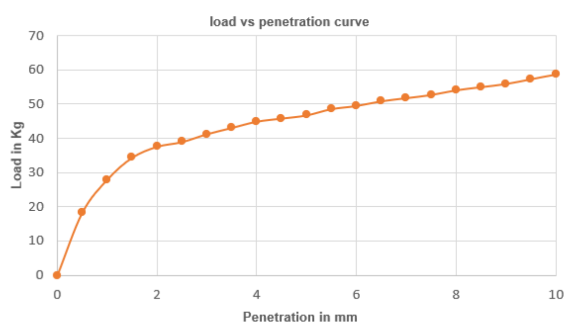

Fig. 7 CBR curve for soil mixed with 0.2% of nano $CaCl_2$ and 0.6% of SCBA

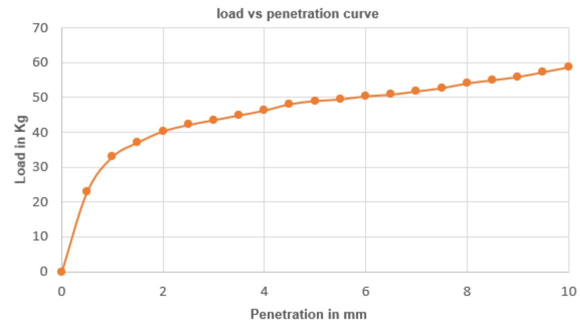

Fig. 8 CBR curve for soil mixed with 0.4% of nano $CaCl_2$ and 0.6% of SCBA

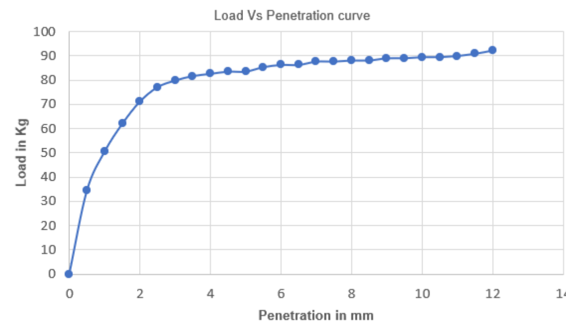

Fig. 9 CBR curve for soil mixed with 0.8% of nano $CaCl_2$ and 0.6% of SCBA

The above graph (figure. 9) shows that the load vs penetration value obtained from the CBR test. The subgrade sample is mixed with 0.8 % of nano calcium chloride and 0.6 % of sugar cane bagasse ash. The load bearing capacity of the subgrade soil sample is increases than the previous mix proportion. The load value of the 2.5 mm penetration are 78.24 kg and the load taken for 5mm penetration is 86.31kg. The calculated CBR values are higher in 2.5mm penetration than the 5mm penetration CBR values. The greatest CBR value are said that the CBR value of the subgrade soil sample. The CBR value of the trial mix are 5.71%. Percentage increase of CBR value is 22.27%.

V. PAVEMENT DESIGN

The Flexible pavement design based on the California Bearing Ratio value and traffic load in msa. Low CBR value has a larger thickness compare the high CBR value. Various percentage of msa value and CBR % the thickness of flexible pavement are derived from IRC37: 2018.

5.1 Design Calculation

The design parameters of the flexible pavements are listed below.

$$N_{Des} = \frac{365\times[(1+r)n-1]}{r} \times A \times D \times F \quad (2)$$

N_{Des} = cumulative number of standard axles to be catered
for during the design period of n year
A = initial traffic in the year of completion of construction (CVPD)
D = lateral distribution factor
F = vehicle damage factor
n = design period, n years
r = traffic growth rate per annum

Table 4. The Design thickness of flexible pavement subgrade soil for 30 msa

Description	Thickness of pavement
CBR of plain soil subgrade (%)	1.76
Total pavement thickness for CBR plain Subgrade soil (mm)	900
Improved CBR of stabilized subgrade at 0.2% & 0.6% of chemicals	2.85
Total pavement thickness for stabilized Soil (mm)	830
Reduction in pavement thickness (mm)	70
Improved CBR of subgrade soil at 0.4% & 0.6% of chemicals (%)	3.08
Total thickness of pavement for stabilized Soil (mm)	820
Improved CBR of subgrade soil at 0.8% & 0.6% of chemicals (%)	5.71
Total thickness of pavement for stabilized Soil (mm)	700
Reduction in pavement thickness (mm)	200

CONCLUSION

In this study, chemicals used to improve the strength characteristics of the subgrade soil. The following conclusions are drawn.

- The initial laboratory test showed that the selected subgrade soil sample is found to have low strength with the CBR values of 1.76%.
- The subgrade soil is mixed with various percentages of 0.4%, 0.6%, 0.8% and 1% of nano calcium chloride and optimum percentage 0.6% of sugar cane bagasse ash of weight of the soil sample.
- The Maximum dry density increased to 2.086% of the subgrade soil sample at 0.8% of nano calcium chloride and 0.6% of sugar cane bagasse ash.
- The California Bearing Ratio increased to 5.71% at 0.8% of nano calcium chloride and 0.6% of sugar cane bagasse ash.
- The pavement thickness of 1.76% of CBR value is 900mm.
- The pavement thickness of 5.71% of CBR value is 700mm. Increasing percentage of CBR value is 22.4%. Thus reduction of pavement thickness is 200mm. the percentage of reduction is 22.22 %. This is cost effective and optimum material used.

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