Stabilization of Subgrade Soil using Nano-Chemicals and Fly Ash

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Abstract. Due to heavy rainfall in some of the areas in India, road remains under water for certain period of time. Excess moisture is an enemy of roads, especially for subgrade. So, it becomes necessary to address in this issue to modify the property of soil and its engineering performances. Stabilization is a technique which invariably changes the physical and chemical properties of soil and ameliorate its capacity to make suitable for supporting any pavement structures. By addition of both nano-materials and fly ash with natural soil, are often affected the soil structure and therefore improve its physical properties like strength, permeability and durability. In this study, soil is collected near Agartala city in Tripura, India which is silty sand in nature. Terrasil and zycobond are used as nano-material supplied by Zydex Industries, Vadodora and their standard protocol is followed to fix the dosages. Fly ash is a waste product collected from thermal power plant and used as a stabilizer. Various laboratory tests have been performed on natural and stabilized soil and results are discussed. From the results, soil is silty sand and medium plastic in nature. As fly ash is added in soil, MDD value increased corresponding OMC value decreases. CBR property is also studied with varying percentage of fly ash. Optimum content of fly ash is chosen based on MDD Value and 28 days soaked CBR Value. UCS test of different curing period and durability tests are also performed taking optimum percentage of fly ash along with nano-chemicals. Using these materials in soil, CBR value increase 3 times, but this stabilized soil is not durable as the weight loss is more than 14% while testing.

Keywords: Nano-material, Fly ash, CBR, UCS, Permeability.

1 Introduction

Development of a society depends on an advanced, cost-effective and easily accessible transportation system, which can be easily designed, maintained and controlled. For the country like India, blessed with robust monsoons, moisture become enemy of pavements. Ingress of water in rainy season weakens the roads' soil base. Instead of cutting out and replacing the unstable soil, soil adjustment is the only alternative as it saves lot of time and money too. Soil adjustment can be clarified as the change of soil properties by synthetic or physical mean keeping in mind that end goal is to improve the nature of soil. This stabilization process can be done by two ways. By mechanical stabilization process, mechanical solutions involve which physically

changing the property of soil by affecting its gradation, solidity, and other characteristics. Chemical soil stabilization depends mainly on chemical reactions between stabilizer (cementitious material) and soil minerals (pozzolanic materials) to achieve the desired effect. By using Terrasil of 0.041% by weight of soil as a chemical stabilizer, CBR value get modified[1-4]. This CBR value is very important to study the strength of soil. Further some investigation was done by mixing Portland Pozzolana Cement (PPC) with 0.041% of terrasil and soil, in which significant changes notified[5]. Black cotton soil which is expansive in nature are also very difficult to construct any structure over it. By chemical stabilization process, its strength can be improved[2, 6-9]. A study was also done by varying percentage of terrasil dosage in soil to find out the suitable percentage of this stabilizer[2, 4, 9-13]. Lime can also be added with terrasil and which can be used as a stabilizer to improve soil property[11, 14-17].

Different types of test (like CBR, UCS etc.)[18-23] have been performed to identify the improvement of properties of subgrade soil using terrasil and zycobond.

1.1 Objective

The objectives of the present study are to determine the physical and designing properties of undisturbed soil as well as after adding nano-chemicals with different proportion of filler material. Nano-chemical like terrasil and zycobond are used and fly ash is used as filler material. Different tests are done to study permeability effect, CBR, and effect on strength in different curing period when additives are added. To determine the Nano-chemical additive effect on moisture susceptibility in soil mix prepare with and without Nano-chemical additive with filler.

1.2 Material used in the study

Soil: For this study, soil was taken near Agartala city, Tripura, India. Soil is excavated from a depth of 2.0m from the ground level. From sieve and hydrometer analysis, the soil mainly contains sand and silt.

Terrasil: Terrasil is a nanotechnology based organosilane, water-solvent, UV and heat stable solution. Terrasil produced by Zydex Industries, Gujarat having ingredients Hydroxyalkyl-alkoxy-alkysilyl compounds (65-70 %), Benzyl alcohol (25-27%), Ethylene glycol (3-5%). It attempts to bond with soil's oxygen & silica atoms which chemically converts water absorbing silanon groups to water resistance alkyle siloxane surfaces at normal temperature. According to Zydex industries procedure, dosage of terrasil is 0.07% by dry weight of soil is sufficient for stabilization process[24].

Zycobond: Zycobond is an acrylic co-polymer which hold the soil particles and prevent soil disintegration and control dust. According to Zydex Industries, very small amount of zycobond (0.02%) blended with terrasil arrangement is sufficient to show the flexible bonding with soil[24].

Fly ash: Fly ash is a by-product induced from combustion of high ash bituminous coal in pulverized fuel fired system in thermal power plant. Because of the environmental problem created by fly ash, considerable research has been undertaken on the subjects worldwide. According to ASTM-618, two major classes of fly ash are recognized i.e class F and class C. Class F fly ash with calcium oxide (CaO) content less

than 6% designated as low calcium ashes and this type of fly ash has no self-hardening properties. Class C fly ash containing more than 15% CaO and called high calcium ashes also pozzolanic in nature. For this study, fly ash is collected from Sagardighi Thermal Power Plant, West Bengal, India. From Chemical Test it is found that the fly ash is class F type and Specific Gravity is 2.

Table 1: Basic properties of soil

Sl No.	Properties	Value
1	Specific Gravity	2.5
2	Fineness	2-0.002 mm
3	Nature of soil	Silty sand
4	Consistancy Limit	
	Liquid Limit (%)	34.1
	Plastic Limit (%)	21.6
	Shrinkage limit (%)	13.8
5	Plasticity Index	12.5
	Engineering Properties	
6	IS Heavy Compaction	
	OMC (%)	13.5
	MDD (gm/cc)	1.9
7	CBR Value for IS Heavy Compaction	
	Unsoaked (%)	10.75
	Soaked (%)	6.6
8	UCS Test (kg/cm^2)	
	7 Days	1.4
	28 Days	1.27
9	Permeability (10^{-5} cm/sec)	1.56

2 Results and discussion

2.1 Fly ash Treated soil:

Different percentage of fly ash is added by weight of dry soil. Further various laboratory tests like Proctor test, CBR test are conducted. Actual cause behind it was to understand the effect of fly ash on the improvement of properties of the soil. The results are tabulated below:

Table 2: Proctor Test results of Fly ash treated Soil

Sl No.	Fly ash Content (%)	Optimum Moisture Content (%)	Maximum Dry Density (gm/cc)
1.	Untreated soil	1.9	13.5
2.	3% Fly ash	2.2	10
3.	5% Fly ash	1.97	12
4.	7% Fly ash	1.96	13

5.	10% Fly ash	1.94	10.5

Table 3: CBR Test results of fly ash treated Soil

Sl no.	Soil type	Unsoked CBR value (%)	Soaked CBR value (%) (4 days curing)	Soaked CBR value (%) (28 days curing)
1.	Untreated soil	10.75	6.6	6.3
2.	Soil+3% Fly ash	19.2	17.37	21.6
3.	Soil+5% Fly ash	16.62	20.23	20.8
4.	Soil+7% Fly ash	17.8	15.6	18.57
5.	Soil+10% Fly ash	18.94	14.77	17.48

From above two tests (Table 2&3) were conducted with different percentage of fly ash content (3%, 5%, 7%, 10%) to determine the optimum fly ash content in soil which will give maximum strength. The results from proctor test shows that when fly ash is added with soil, dry density increases and corresponding water content decrease. In CBR test, samples were compacted at maximum dry density after mixing fly ash with optimum moisture content. The samples were compacted using heavy compaction. The tests are conducted at the different curing times of 4 days and 28 days in order to examine the effect of curing on CBR value. From the test results, it is shown that when 3% fly ash by weight of dry soil is added, CBR test result get maximum among all the combination both in soaked and unsoaked test. So from the results, optimum fly ash content is 3%. Further tests are conducted with 3% fly ash mixing with soil.

2.2 Nano-chemicals Treated Soil

Here soil samples are treated with 0.07% terrasil and 0.02% zycobond along with 3% fly ash. Nano-chemical solution has been prepared after adding predetermined dosage of Terrasil and zycobond agent as per zydex industries guideline in the required optimum quantity of water. Further, the soil mix with fly ash are prepared by spraying the nano-chemical solution on loose soil and mixed uniformly. The nano-chemicals treated samples were tested for consistency limits, permeability, UCS and CBR strength properties.

Consistency Test:

For consistency limit test, sample were prepared 6 hours before the testing, so that the chemicals can properly bonded with soil. From this test, as the chemicals are treated with fly ash mixed soil, liquid limit (LL) and plastic limit (PL) decreases. So plasticity Index (PI) decreases from 12.5% to 7.2%. It indicates that the soil changes to less plastic state with the addition of chemicals into the fly ash mixed soil.

Table 4: Consistency limits for nano-chemically treated soil mix

Sl no.	Soil Type	LL (%)	PL (%)	PI (%)
1	Untreated Soil	34.1	21.6	12.5
2	Soil+3% Fly ash	25.5	17.8	7.7
3	Soil+ 0.07% terrasil+ 0.02% zycobond	27.8	19.4	8.4
4	Soil+3% F.A+0.07% terrasil+ 0.02% zycobond	25.2	18	7.2

Proctor Test

Modified proctor test has been conducted to know the Optimum Moisture Content (OMC) and Maximum Dry Density (MDD). Based on this OMC value, CBR and UCS test was conducted. As terrasil, zycobond and fly ash are added with soil, density of soil mix increases. Dry density of treated soil is 10% higher than the normal soil. This indirectly increase the strength.

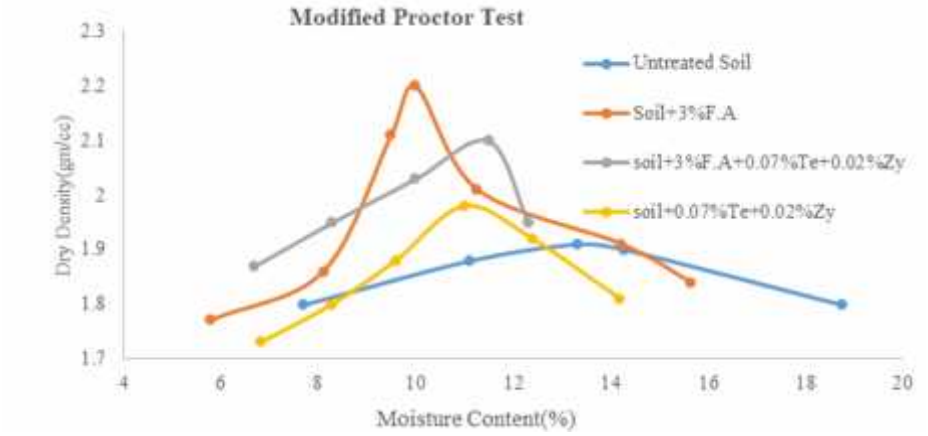

Fig. 1. Moisture Content V/S Dry Density Curve.

CBR test for treated soil

From the above test result, CBR value of soil-fly ash-terrasil-zycobond mix is 17.82% in unsoaked condition, after soaked for 4 days the value is increased to 19.27% and also after 28 days of curing, CBR value increased to 21.19%. there is a significant difference between the untreated and treated one. CBR value increases around 110% when nano-chemicals are added. This is also signifies that as the curing period increase, the strength of soil increases.

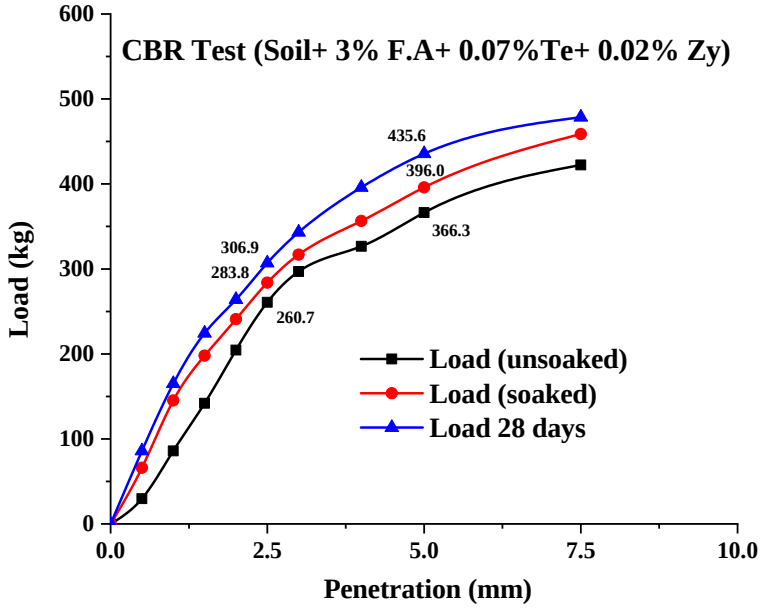

Fig. 2. Load v/s Penetration Curve of Soil-Fly ash-Terrasil-Zycobond.

Unconfined Compressive Strength Test

UCS value of Untreated soil is 816.59 kN/m^2. When soil is treated with fly ash UCS value increases. As the curing period increased, strength is improved. As terrasil and zycobond are mixed with fly ash treated soil, strength is increased significantly after 28 days of curing. UCS value of fly ash-terrasil-zycobond treated soil is 2153.59 kN/m^2 after 28 days of curing.

Table 5: UCS Test results of various soil-additive mix.

SL No.	Soil Type	Time Period (days)	UCS Value (kN/m^2)
1.	Untreated soil	7	816.59
		28	-
2.	Soil+ 3% fly ash	7	1168.65
		28	1338.68
3.	Soil+ 3%F.A+ 0.07% Te + 0.02% Zy	7	1757.42
		28	2153.59

Permeability Test:

From Permeability Test, permeability of untreated soil 1.56×10^-5 cm/sec. As fly ash added permeability reduces partially. When terrasil and zycobond added with soil and Fly ash mixture permeability reduces significantly. This may be due to chemical reaction of terrasil. Terrasil and zycobond react with soil and creates molecular level hydrophobic zone which leads to permanent siliconization of the surfaces by converting the water loving silanol groups to water repellent siloxane bonds[24].

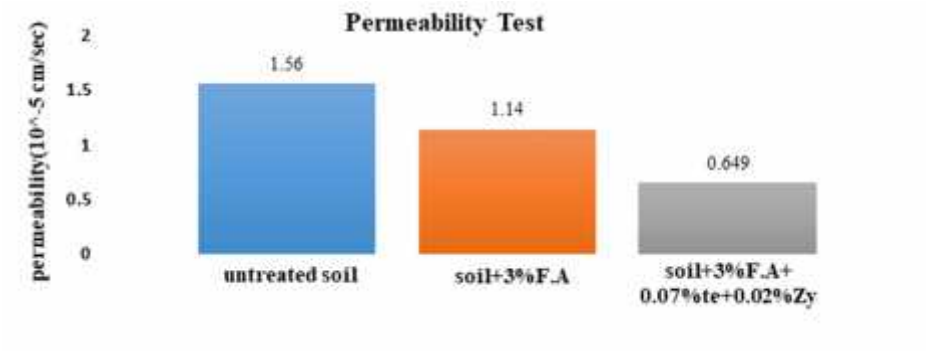

Fig. 3. Permeability Test results of Soil-Additives.

XRD Test

X-Ray Diffraction test is done for identification of crystalline material presence in it. When X-Rays interact with crystalline substance, for every group one get different pattern. In a mixture of substance, each produces its pattern independently or others. So from this test, one can find out the material presence in it, and also the molecular distance between the particles. From fig. 4 and fig. 5 it is shown that at different angle of diffraction, the distance between particles decreases as nano-chemicals are mixed with soil.

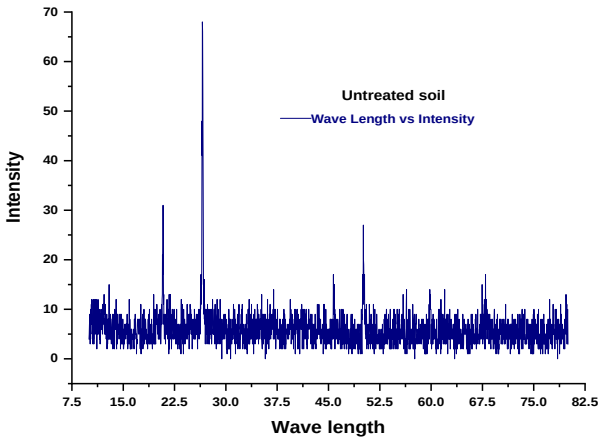

Fig. 4. XRD test result of Untreated Soil.

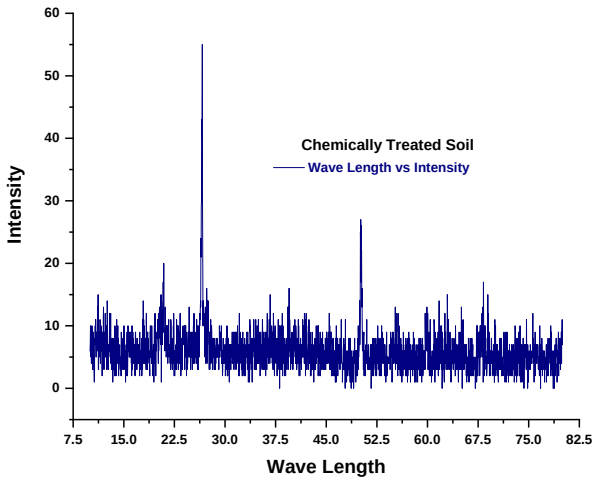

Fig. 5. XRD Test of Chemically Treated Soil.

2.3 Limitations

As nano-chemicals are chemically reactive, if chemicals are present in soil then above reaction may not take place. In that condition stabilization process will restrain. The chemical attribute of the soil must be tested before improving the physical characteristics of the soil treated by terrasil and fly ash.

3 Conclusions

In present study, firstly soil is treated with different percentage of fly ash. Taking the optimum percentage of fly ash (3%), nano-chemicals like terrasil (0.07%) and zycobond (0.02%) are added with soil and different tests were performed. Tests showed the change in the engineering property of soil when the chemicals are added. Based on the above experimental test results, it can be concluded that:

i. As different percentage of fly ash is added with natural soil, soil particle getting dense. So dry density increases and corresponding water content decrease.
ii. In CBR test, maximum bearing ratio is achieved when 3% fly ash is added. As the curing period increases, bearing capacity also increases.
iii. Liquid limit and plastic limit decreases as the nano-chemicals and fly ash are added with soil. So plasticity index decrease. This is very significant in case of soil improvement.
iv. CBR value also increases significantly when terrasil and zycobond are added. Fly ash formed cementitious properties and terrasil formed Si-O-Si (Siloxane bond), water proofing surface. Due to this action water cannot penetrate through

the soil mass. So strength increased, and soil particles bonded closely by filling pore spaces.

v. From UCS test, it is cleared that strength of soil increases. Fly ash which is a pozzolanic material gain strength slowly. As the time passed, strength of soil mix increases.

vi. Terrasil form a water proofing layer on the top of soil surface. So the water cannot penetrate through the soil mass. Test result shows that permeability of soil decreases as nano-chemicals added.

vii. XRD test is a micro level investigation which shows that in treated soil the spacing between the particles is reduced compare to virgin soil. Also from analysis the presence of alumina, silica are significantly noticed.

Based on this present study it can be concluded that here fly ash is used as a filler material which helped to increase the strength of soil. Nano-material terrasil and zycobond are reacted with soil and make a film on the surface which will act as an impermeable layer. So the permeability problem can reduce and enhance the property of soil by using this type of stabilizer in soil.

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