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Design of a Chemical Grout to Stabilize Poor Subgrade Soil

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***Abstract*: Mostly the damaged road conditions indicates the poor subgrade soil conditions, because after every monsoon there are minor to major potholes in the road as well as many other damages like rutting and cracking. While repairing these damage and make it serviceable often the traffic is to be diverted therefore in this study a quick method of grouting the subgrade for improving its bearing capacity is proposed which would be relatively faster as well as can be done without disturbing traffic for longer duration and also without excavation of the existing road. For this, the laboratory investigations would be carried out for the design of the grout mix and proper method, grouting pressure etc will be calculated. In this study an attempt is made to design a chemical grout with which material sodium silicate and sodium hydroxide. Firstly, all the index properties and engineering properties of the virgin soil is tested. Secondly, the grout is designed by changing the molarity and concentration of the sodium silicate and sodium hydroxide. Various tests are performed like viscosity, gel time and strength. Lastly, the finalized grout is used to grout the soil which was expected to behave as poor subgrade soil in the field. For this, the black-cotton soil was poorly compacted at 50% of its MDD and the grout was proposed to be injected from a test setup designed in house lab. With pressure of 70 MPa. After the grouting the soil sample was retrieve for UCS and the failed samples of UCS were pulverized to check the plasticity characteristics. The results revealed that the proposed grout is working fine and UCS strength of poorly compacted soil is increased by 18.06%.**

***Keywords*: Black cotton soil, Compressive strength, Design grout, Grouting, Pavement distress, Subgrade soil, Sodium silicate, Sodium hydroxide.**

1. Introduction

A highway pavement is a structure consisting of superimposed layers of processed materials above the natural soil sub-grade, whose function is to distribute the applied vehicle loads to the sub-grade. The pavement structure should be able to provide a surface of acceptable riding quality, skid resistance, favorable light reflecting characteristics, and low noise pollution. The ultimate aim is to ensure that the transmitted stress due to wheel load is sufficiently reduced, so that they will not exceed bearing capacity of the sub-grade. A rigid pavement is constructed from cement concrete or reinforced concrete slabs. Flexible pavement can be defined as the one consisting of mixing of asphaltic or bituminous material and aggregates placed on a bed of compacted granular material of appropriate quality in layers over the sub-grade. Pavement should be proper, because improper pavement affects riding quality. Flexible pavement consists of component layers like Sub-grade, Sub-base course, Base course and Surface course. Instability in any of the layers will result in the complete failure of pavement system. Some of the structural distresses which can cause failure in flexible pavements are alligator cracking, rutting, potholes, swelling of pavement, etc.

There are many methods for ground improvement; in this study grouting is selected. Grouting is a process of injection of setting fluids in to the voids of the alluvium, or into the fissures of rock either to reduce permeability or to increase strength or both. The success of the grouting is mainly dependent on selection and type of grout materials and suitable grouting techniques. There are many materials used for grouting, cement is most common. Chemical compounds such as lignin, silicates, acrylic, and urea or epoxy resins and polyurethanes complying with environmental laws may used in geotechnical injection projects. First successful application of injection technology for soil improvement was by Berigny in 1802.

Cement grout is widely applied because of its inexpensiveness, ready sources and high strength. Since it is particulate material, disadvantages such as poor ductility confine it practical applications and poor injection ability (penetration into tiny fracture and silty sand layers can be difficult). Chemical grout work swell because of its good injection ability, its adjustable gel time, and its flexibility after solidification. Although chemical grout has special functions, it does not have wide applications due to expensiveness and lower solid strength.

Sodium silicates have been developed into variety of different grout systems and are used as a chemical grout. The sodium silicate system consists of sodium silicate and reactor/accelerator. Two compound systems has been used in grouting in the soil, below a water table or with high moisture content, and produces a high – strength permanent grout if not allowed to dry out. The compressive strength will increases with increase in dosage of geopolymer.

In past study to stabilize the poor soil, repair damage of pavement due to poor subgrade like rutting, alligator cracking, potholes etc are done. But repairing the damage due to poor subgrade it very costly & time consuming to re-excavated entire pavement which is constructed, the grouting technique will help without re-excavated & removing layers of road & will be very economical & fast once designed & executed property.

The objective of present research work is, to design a grout mix which is suitable for improving the pavement sub-grade, To verify the grout mix design by laboratory experiments like to Check engineering properties of grouted sub-grade & calculate the optimum pressure of grouting.

2. Materials

A. *Black cotton soil*

Black cotton soils also called Regur soils are generally clayey, deep and impermeable. These soils expand and become sticky during rainy season and contract during the dry season causing deep cracks into the soil. Chemically black soils consist of lime, iron, magnesium, alumina and potash but they lack in nitrogen, phosphorus and organic matter. All test was done as per IS code. Soil was selected from farm near Marwadi University Rajkot. Soil was oven dried for 24 hours at 110º C before using.

Table 1
Index properties of BCS soil

Test	BCS value	IS Code
Specific gravity	2.28	IS 2720- 3
Hydrometer test	Clay =38% Silt= 62%	IS 2720- 4
Liquid Limit	74.03%	IS 2720- 5
Plastic Limit	30.86%	IS 2720- 5
Plasticity index	43.17%	IS 2720- 5
Permeability test	0	IS 2720- 17
ISSCS	CH	-
OMC	23%	IS 2720- 9
MDD	1.46gm/cc	IS 2720- 9
UCS	0.27Kg/cm²	IS 2720- 7

B. *Sodium silicate*

Sodium silicate is a generic name for chemical compounds with the formula Na_2SiO_3. These compounds are generally colorless transparent solids or white powders, and soluble in water in various amounts. Molar mass is 122.06g/mol. Density is 2.4g/cm³.Melting point is 1088˚C. It is soluble in water. Molarity =moles of solute/ liters of solution. 1 molar = 122gm Na_2SiO_3 /1 litre water. Sodium oxide was brought from Sadguru Chemical Gondal.

C. *Sodium hydroxide*

Sodium hydroxide inorganic compound with the formula NaOH. It is a white solid ionic compound consisting of sodium cations Na^+ and hydroxide anions OH^-. Sodium hydroxide is a highly caustic base and alkali that decomposes proteins at ordinary ambient temperatures and may cause severe chemical burns. It is highly soluble in water, and readily absorbs moisture and carbon dioxide from the air. Molar mass is 39.9971 g mol^{-1}. Appearance is white color & opaque crystals. Density is 2.13 g/cm^3. Melting point is 323˚C. Boiling point is 1388˚C. For preparing 1 molar NaOH = 40gm of sodium hydroxide is dissolve in 1litre water. Sodium hydroxide was brought from Sadguru Chemical Gondal.

3. Sample Preparation and Procedure

After laboratory investigation of virgin soil's geotechnical characteristics grout test were performed Viscosity test, Gel time & UCS test. Firstly, Viscosity test was performed as per IS 14343. With help of marsh funnel cone viscosity is performed. Test was performed of different molar concentrations of alkaline activator of 2, 4, 7, & 9. The ratio sodium silicate and sodium hydroxide (grout) was kept 2:1. It has been noticed that as concentration increases liquid gets thick and decreases it gets thin. Then gel time test was performed as research paper. Sample of soil passes from 4.36mm sieve was used in this test. Grout was mixed in soil with different proportions of all different molar concentration. After gel time, UCS test was performed to check the strength of soil. UCS test was performed as per IS CODE 2720 – Part- 8. Proportion was decided according to proctor compaction test, liquid as per OMC and Mass as per to MDD.

Table 2
Details of sample prepared for testing

Molarity	Title of test	Curing period(days)	No. of sample
2	UCS	15 & 28	3
4	UCS	15 & 28	3
7	UCS	15 & 28	3
9	UCS	15 & 28	3

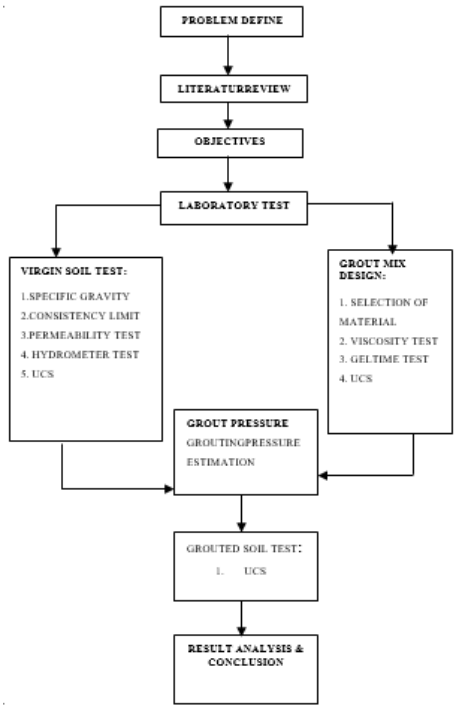

Fig. 1. Flow chart of methodology

Grouting set up was at house lab. Take soil sample fill with specimen. Take another specimen fill with grout. Connect both specimen filled with pipe. One specimen filled with grout should connect with air compressor. The pressure is applied to penetrate the grout into soil. After few days that soil will tested by UCS test to check strength.

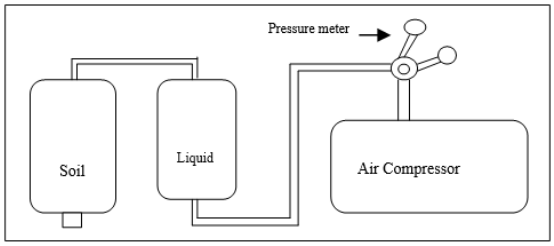

Fig. 2. Set of grouting test

4. Result and Discussion

To improve poor subgrade soil grouting method is used. Grout is design for grouting method. Chemical grout of sodium silicate and sodium hydroxide is used. Test performed were viscosity test, gel time test and UCS test. Test on different molarity were performed of 2, 4, 7, & 9.

A. Viscosity Test and Gel time

Viscosity test results show that as molarity increases it takes more time to flow, so its takes more time to penetrate. As time decreases molarity increases. Here 9 molar solution took 12mint 38sec which is more time than other. While 2 molar solution took least time. As soil is BCS, it cannot penetrate the solution if it is thick, it requires thin liquid solution, so less molar solution is preferable in Black cotton soil. As 2molar solution took 49sec which is thin and which penetrated easily.

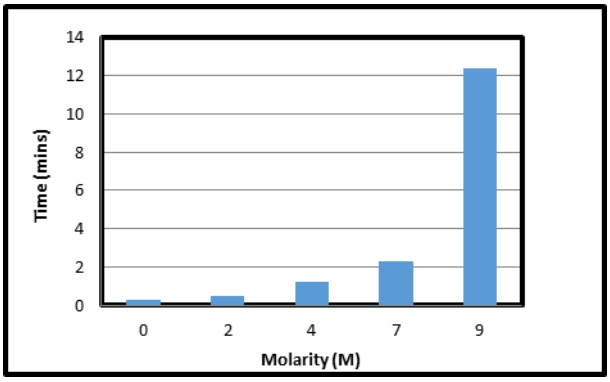

Fig. 3. Graphical representation of Viscosity test

Gel time was examined by two proportion of alkaline solution (grout) and soil. 1:1 took 10 minutes to gel while 1.5: 1 took 1 hour to gel. It has been observed that as grout is thin it took less time to gel compare to thick. Gel time was performed for all the molarity grout was best with 2molar solution. Proportion of 1:1 of grout was best selected for the grouting, as it took less time to gel.

B. Unconfined Compression test

UCS results shows in fig. that 7 molar after 28days gain highest strength of 12.52 Kg/cm^2 compare to others, but grout of 7 molar solution will not be able to penetrate into soil easily, so 2molar solution was used as it gain sufficient strength of 3.06Kg/cm^2 as well as penetrate into soil fast.

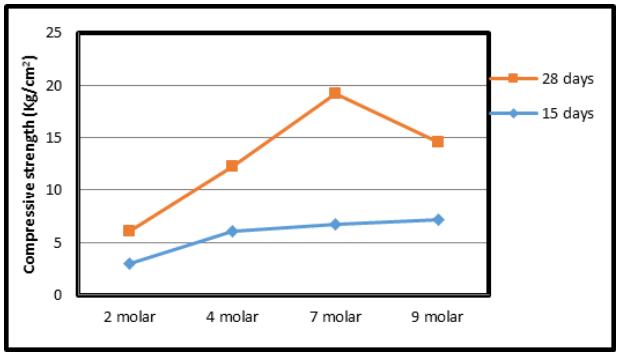

Fig. 4. Graphical representation of effect of molarity on strength of soil

Improvement of subgrade soil is achieved after designing grout then grouting into the subgrade soil with chemical grout sodium silicate and sodium hydroxide. It increases strength as well as bond of soil. In this study, it has been seen that it is very costly and time consuming affair to re-excavate entire pavement layer for several kilometers and do the soil-stabilization once the pavement is constructed, the grouting will help without re-excavation and removing the layers of the road and will be very economical and fast once designed and executed properly.

5. Conclusion

In the present study an attempt was made to design a grout mix which is suitable for improving pavement sub-grade. The grout mix was design by laboratory experiments which includes viscosity of the grout, gel time of grout and engineering properties of grouted sub-grade.

After careful observation of results following conclusion are drawn:

1. Sodium silicate and sodium hydroxide mixture with viscosity of 2 molarity solution will be easily penetrated into soil compare to other molarity (4, 7, and 9).
2. The unconfined compressive strength was increased by 18% after adding solution (2:1) in it.

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