Weak Soil Stabilization using Different Admixtures- A Comparitive Study

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Abstract:. Right from the ancient times when man started building huts for shelter he has been dealing with soils . soils are weathered products of rocks which are formed mainly because of the process called weathering. Weathering process introduces physical and chemical changes leading to the formation of coarse and fine grained soils. The former resemble the parent material namely the rock while the latter doesn't. Majority of the clayey soils (fine grained) in the world often pose a problem of swelling and shrinkage to a geotechnical engineer while admitting and loosing water. Hence they are often referred as weak soils or soft soils in the context of their swelling and shrinkage aspects. The main reason behind this quality of clayey soils is because of different clay minerals like smectite, atapulgite, chlorite, hallosite, illite and a chief mineral namely montmorillionite. In the case of foundations the swelling and shrinkage problems induce differential settlements, and in pavements problems like potholes, cracking and undulations are created leading to discomfort for the passengers which in turn lessen the life of vehicle. The quality of clayey soils has been improved substantially with quite a lot of admixtures available either natural or artificial by lot of researchers. This paper discusses the results of the laboratory study conducted on local clayey soil in chennai and its improvement by stabilizing it with different admixtures say Quarry dust, Flyash and Lime. The improvement of clayey soils at last indicate the increment of load resisting capacity which is substantiated with results brought out by various laboratory tests as discussed below. The final conclusion drawn from this investigation is such that quarry dust, flyash and lime can be used as a effective stabilizing agents in stabilizing clayey soils for its usage as a foundation material.

KEY WORDS: Montmorillionite, California Bearing Ratio, Quarry Dust, Flyash, Lime, Compaction, Natural Soil

1 INTRODUCTION

Approximately classification of entire soils of the world split into either clay or sandy type of soils. The latter hardly pose any problem due to seepage of water into it, which is mainly because of its formation from the parent material namely rock. Rather the clayey type of soils are formed by chemical weathering which involves chemical reactions constituting hydration, carbonation and leaching. Due to these aspects the clayey soils swell when it comes in contact with water during winter season and shrink when water is lost due to evaporation during summer. A lot of investigation has been carried out by researchers in modifying the swelling and shrinkage properties of clayey soils. The modification can be brought about by variety of options say by either removing water from those soils in form of de-watering methods, by compacting them, by introducing reinforcements and by additives. The last option is sorted in this study on a multiple basis which is found to be economical in certain aspects when the quantum of soil to be stabilized is larger, especially in the case of laying flexible pavements and before laying very large shallow foundations. Early studies have carried out in stabilizing the clayey soil with a lot of additives say flyash [sridharan et al.,], palm oil ash, marble dust, brick kiln dust [Deepa], Cement [Christensen], Bitumen, Egg shell [olarewaju et al.,] stone dust [Mir sohail et al.,], Fuel oil [Hussein et al.,], Quarry dust [Jayapal], etc., and considerable modification was observed. The current study aims to stabilize the soil using different admixtures say quarry dust, flyash and lime as an additives. Some discussions oriented to flexible pavements are also included in the present study which was conducted by the same author before, using quarry dust.

Figure.1. Clay Soil Sample

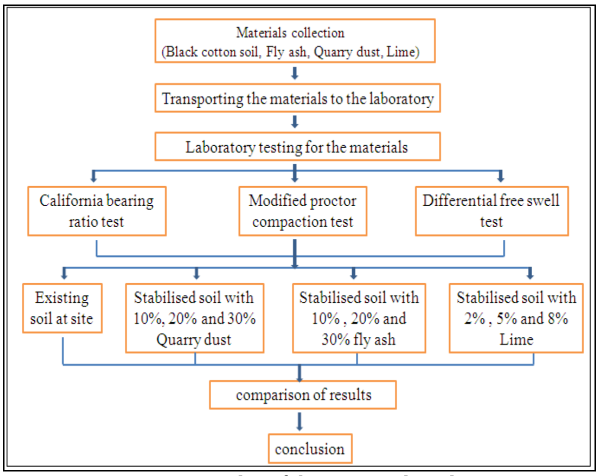

Figure 2 Plan of the tests conducted

List of Symbols used :

Liquid Limit	LL
Plastic Limit	PL
Plasticity Index	PI
Non Plastic	NP
Maximum Dry Density	MDD
Modified Proctor Test	MPT
California Bearing Ratio	CBR
Differential Free Swell	DFS
Million Standard Axle	MSA
Scanning Electron Microscope	SEM

2. EXPERIMENTAL INVESTIGATION

Tests were conducted in laboratory premises by mixing natural clay soil obtained from Velachery region of Chennai with three different admixtures say Quarry dust, Flyash and Lime. Quarry dust was obtained from the an aggregate quarry at Vinayagapuram. Flyash was collected from Neyveli Lignite Corporation and Hydrated Lime was bought from a chalk factory in Coimbatore. Random proportions were tried to find out the optimum percentage of above mentioned admixtures in improving the clayey soil. The properties of the materials and tests conducted are furnished below.

2.1 MATERIALS AND PROPERTIES

The properties of the clayey soil, quarry dust, Flyash and Lime are presented in Table 1,2,3 and 4.

Table 1 Properties of Clay

Specific gravity, Gs	2.59
Differential Free Swell (%)	93.3
LL (%)	87
PL (%)	21.1
PI	65.9
Coefficient of uniformity (C_u)	0.85
AASHTO Classification	A-7.5
BIS Classification	CH

Table 2 Properties of Quarry Dust

Specific gravity, Gs	2.72
Absorption (%)	1.5
Bulk Density g/cm^3	1.8
Moisture Content (%)	Nil
PI	NP
Coefficient of uniformity (C_u)	0.84
AASHTO Classification	A-4
BIS Classification	SM

Table 3 Properties of Flyash

Specific gravity, Gs	2.05
Absorption (%)	1.9
Bulk Density g/cm^3	1.51
PI	NP
MDD (g/cm^3)	12.4
OMC (%)	24.5
AASHTO Classification	A-4

Table 4 Chemical Properties of Lime

Calcium Oxide, CaO (%)	73.22
Phosphorus Oxide, P2O5 (%)	0.08
Calcium Sulphate, CaSO4 (%)	0.12
Ferric Oxide, Fe2O3 (%)	0.17
Aluminium Oxide, (%)	0.11
Magnesium Oxide, MgO (%)	0.74
Loss on Ignition, LOI (%)	24.35

2.2 TESTS CONDUCTED

A series of tests were conducted to enhance and ensure the improvement of clayey soil with the above mentioned admixtures in various proportions as listed below.

Table 5 Details of Tests Conducted

Name of the Test
Atterberg limits (LL & PL)
Modified Proctor Compaction (MPC)
California Bearing Ratio (CBR)
Differential Free Swell (DFS)

2.3 SIEVE ANALYSIS & ATTERBERG LIMITS

The preliminary laboratory tests like specific gravity, grain size distribution confirming to Indian Standards were conducted to optimize the proportioning of different admixtures with the natural soil. The proportions adopted are similar for all the tests conducted in series. The details of the sieve analysis test along with Atterberg limits are furnished below.

SIEVE ANALYSIS AND ATTERBERG LIMITS								
S.No	Soil Composition	Sieve Analysis % Passing				Atterberg Limits (%)		
		4.75 mm	2 mm	0.425 mm	0.075 mm	LL	PL	PI
1	Natural Soil	100.0	93.3	75.4	63.4	87.0	21.1	65.9
2	Natural Soil + 10 % Quarry Dust	99.8	92.9	72.8	58.6	71.0	21.9	49.1
3	Natural Soil + 20 % Quarry Dust	99.7	92.5	70.2	53.7	69.0	24.2	44.9
4	Natural Soil + 30 % Quarry Dust	99.5	92.1	67.6	48.9	40.5	24.6	15.9
5	Natural Soil + 10 % Fly ash	99.7	93.5	71.4	64.4	53.4	20.3	33.1
6	Natural Soil + 20 % Fly ash	99.5	92.8	71.2	63.5	47.0	17.3	29.7
7	Natural Soil + 30 % Fly ash	99.4	92.4	67.4	45.6	37.5	18.0	19.5
8	Natural Soil + 2 % Lime	100.0	93.3	75.4	63.4	55.4	21.3	34.1
9	Natural Soil + 5 % Lime	99.9	93.1	75.4	63.1	45.1	21.8	23.3
10	Natural Soil + 8 % Lime	99.7	93.1	75.1	62.8	41.4	22.2	19.5
Note : + indicates "with" Eg: (2) natural soil with 10 % Quarry Dust								

Figure.3. Details of Sieve Analysis and Atterberg Limits

Atterberg limits say Liquid Limit and Plastic Limit are indicative limits which speak about the soil indirectly. Studies indicate that higher the Liquid Limit higher the clay content and lesser is the strength. In order to find the increment in the strength of the soil Liquid Limit and Plastic Limit tests were conducted based on Indian Standards IS 2720 (Part V) - 1970 for various proportions as indicated above .

It was clearly seen that the LL and PI values showed a marked decrement till 30 % replacement of Quarry dust and 8 % of lime. The rate of decrement was observed to be a bit higher in the case of natural weak soil mixed with flyash. Plasticity index was also showing a similar decrement in values for all the proportions and with all the three admixtures. The variation is listed out in Figure.3. The tests conclude that the Atterberg limits reduce by half of the value as that of the natural soil while adding the admixtures. A separate representation of variation of Liquid and Plastic limit along with plasticity index is indicated in the Figure.4.

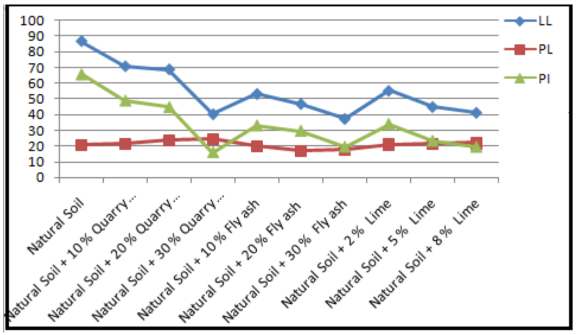

Figure.4. Variation of Atterberg Limits

2.4 MODIFIED PROCTOR COMPACTION TEST

Modified proctor compaction test is normally opted for higher loading applications like airport base courses and for superior quality roads like National highways. The modified proctor compaction test was conducted to show the level of improvement in density for various mix proportions. The energy applied to the soil is around 4.5 times that of a standard proctor compaction test, higher the energy higher will be the density achieved and hence this test was opted for the study. The plot between dry density and moisture content for various proportions are indicated below separately for all the three types of admixtures.

Table 6 Modified Proctor Compaction test results

MODIFIED PROCTOR COMPACTION TEST			
S.No	Soil Composition	(MDD) g/cc	(OMC) %
1	Natural Soil	1.51	24.00
2	Natural Soil + 10 % Quarry Dust	1.52	21.40
3	Natural Soil + 20 % Quarry Dust	1.53	21.10
4	Natural Soil + 30 % Quarry Dust	1.58	19.19
5	Natural Soil + 10 % Fly ash	1.43	24.71
6	Natural Soil + 20 % Fly ash	1.58	21.40
7	Natural Soil + 30 % Fly ash	1.64	20.80
8	Natural Soil + 2 % Lime	1.61	21.00
9	Natural Soil + 5 % Lime	1.64	20.00
10	Natural Soil + 8 % Lime	1.66	20.26
Note : + indicates "with" Eg: (2) natural soil with 10 % Quarry Dust			

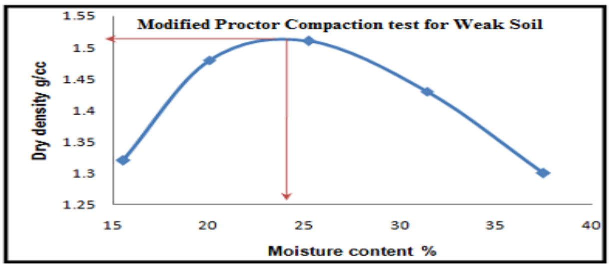

Figure.5. Modified Proctor Compaction Test for Weak soil

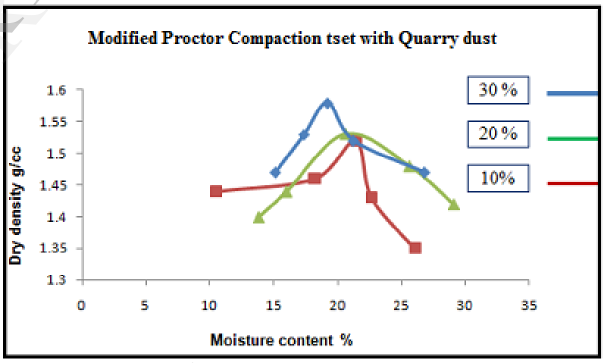

Figure.6. Modified Proctor Compaction with Quarry dust

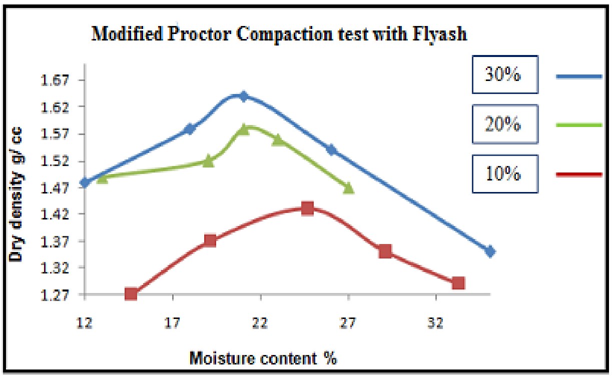

Figure.7. Modified Proctor Compaction with Flyash

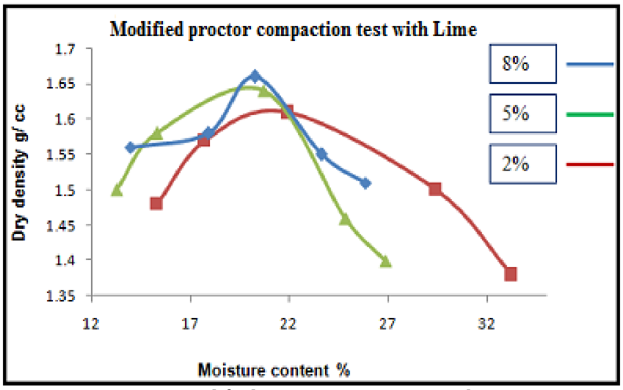

Figure.8. Modified Proctor Compaction with Lime

The maximum dry density values of the weak soil when stabilized with quarry dust show an appreciable increase in replacement of the soil with 10 and 20 % whereas in the case of 30% replacement a higher rate of improvement is observed as it shoots from 1.51 g/cc to 1.58 g/cc which indicates that the quarry dust has imparted its part of a coarse fraction in the clayey soil in improving the density of the weak soil. Similar observations are found in the case of optimum moisture content as a sharp decrement is found for the 30 % replacement of quarry dust when compared to the other two proportions. The reasons attributed in this case also falls similar to that of increment in maximum dry density as indicated from Figure.5 to Figure.8.

In the case of flyash an interesting behavior was observed as initially for the 10 % replacement the MDD and OMC values went down around 6% below actual values of the in-situ weak soil. The reasons behind this aspect could be because of the mineralogical aspects of both the weak soil and flyash, advanced tests like SEM images can reveal the chemical changes happening between flyash and weak soil which is not discussed in this paper. An increment of 5% and 10 % was observed for the other two proportions with MDD on an approximate basis. Regarding the optimum moisture content similar trend of the decrement and increment of values for the first and the remaining two proportions were observed.

It was observed that Lime as an admixture has shown promising results in the values with increment in proportions from 2% to 8% as shown in Figure.8. The increment in maximum dry density is observed in the ratio of 7, 8 and 9 % with respect to the weak clayey soil without adding any admixture. It is also observed that the replacement of clayey soil with 30 % flyash and 5% lime bring the same result of improvement in maximum dry density. Hence the builder or a road contractor can decide the tender quotation based on the cost aspects and availability of flyash and lime in the velachery region. The optimum moisture content values have decreased considerably accounting to 12.5 % from that of the in-situ weak soil which indicates a positive sign for using lime as an admixture for this weak soil.

A clear representation of variation of maximum dry density with all the three admixtures are indicated in Figure.9 and 10.

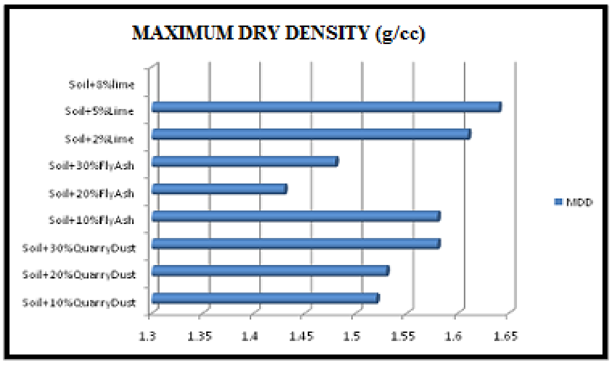

Figure.9. MDD variation with Quarry Dust, Lime and Flyash

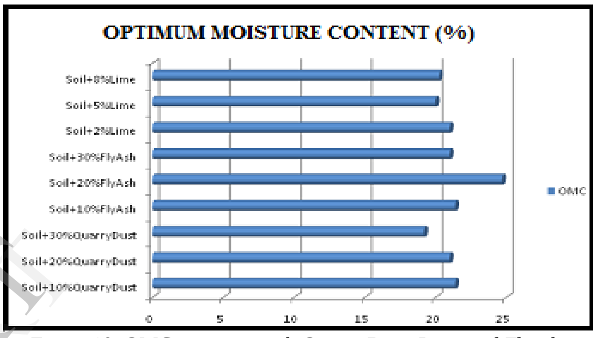

Figure.10. OMC variation with Quarry Dust, Lime and Flyash

2.5 CALIFORNIA BEARING RATIO & DFS TEST

California Bearing Ratio (CBR) test is a penetration test wherein a standard piston, having an area of 50 mm diameter, is used to penetrate the soil at a standard rate of 1.25 mm/minute. The pressure up to a penetration of 12.5 mm and it's ratio to the bearing value of a standard crushed rock is termed as the CBR. A photograph showing CBR test apparatus in loading position for the test conducted in laboratory is shown in Figure.11.

In most cases, CBR decreases as the penetration increases. The ratio at 2.5 mm penetration is used as the CBR. In some case, the ratio at 5 mm may be greater than that at 2.5 mm. If this occurs, the ratio at 5 mm penetration should be used. The CBR is a measure of resistance of a material to penetration of standard plunger under controlled density and moisture conditions.

$$\textbf{CBR} = \frac{\textbf{Load carried by specimen}}{\textbf{Load carried by standard specimen}} \times 100$$

Figure 11 CBR Apparatus in test position

Differential free swell test (DFS) is conducted to identify the quantum of swell in the soft soils by pouring 10 grams of soil passing through 425µ sieve in a 100 cc glass cylinder one filled with water and other with kerosene. Kerosene being a non-polar liquid does not cause any volume change in the soil. After 24 hours the volumes of the soil in the two cylinders are measured and Differential free swell is obtained.

$$\textbf{DFS} = \frac{\textbf{Soil Volume in water - Soil volume in kerosene}}{\textbf{Soil volume in kerosene}} \times 100$$

Both the tests were conducted in accordance with the Indian Standards and with the same proportions as that of the previous tests. The results are tabulated in Table 7 and figures are represented from Figure.12 to Figure.17.

Table 7 CBR & DFS Test for various Proportions

CALIFORNIA BEARING RATIO (CBR) AND DIFFERENTIAL FREE SWELL TEST			
S.No	Soil Composition	CBR(%)	DFS (%)
1	Natural Soil	5.29	93.3
2	Natural Soil + 10 % Quarry Dust	7.50	65.2
3	Natural Soil + 20 % Quarry Dust	9.43	47.3
4	Natural Soil + 30 % Quarry Dust	18.55	35.6
5	Natural Soil + 10 % Fly ash	6.94	76.9
6	Natural Soil + 20 % Fly ash	9.15	69.2
7	Natural Soil + 30 % Fly ash	10.26	61.5
8	Natural Soil + 2 % Lime	7.50	83.3
9	Natural Soil + 5 % Lime	26.84	73.3
10	Natural Soil + 8 % Lime	40.10	69.2
Note : + indicates "with" Eg: (2) natural soil with 10 % Quarry Dust			

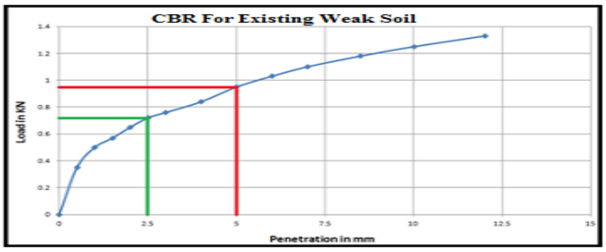

Figure.12. CBR test for existing weak clayey soil

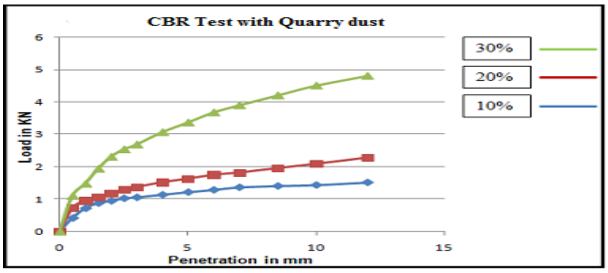

Figure.13. CBR test with Quarry dust

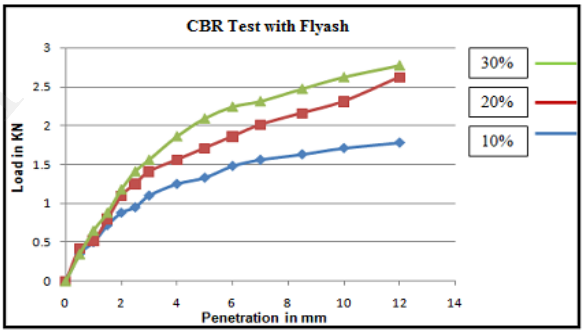

Figure.14. CBR test with Flyash

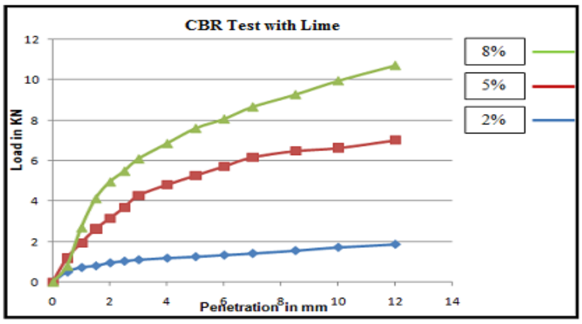

Figure.15. CBR test with Lime

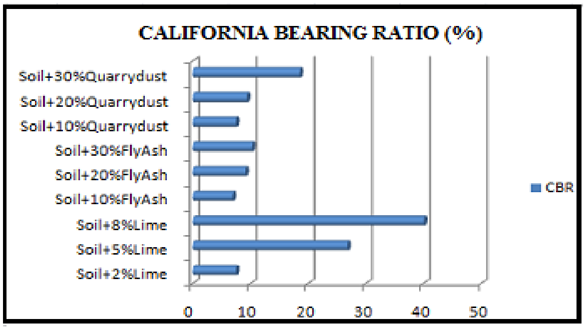

Figure.16. CBR variation with Quarry Dust, Lime and Flyash

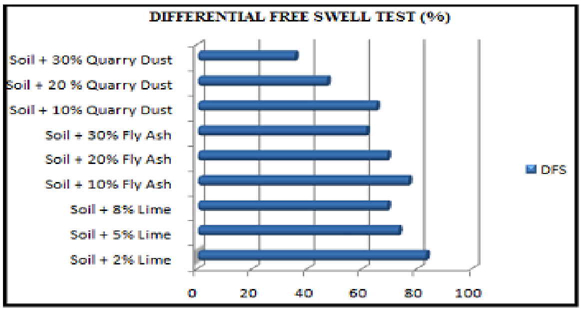

Figure.17. DFS variation with Quarry Dust, Lime and Flyash

The results obtained shows a gradual increment in the CBR value from 5 % to a maximum of 40 % as shown in the figure from Figure.12 to Figure15 with the increase in the proportion of quarry dust, Flyash and Lime. For 10 % and 20 % replacement of the soil with quarry dust and flyash same ratio of increment in the CBR values with respect to the weak clayey soil is observed. but 30 % replacement of the soil with the above said admixtures have made considerable difference between them in the improvement of CBR values. The reason behind the improvement of CBR is attributed to the coarse fraction and gradation of the admixtures.

Lime when added with this clayey soil has improved the CBR value to a maximum of 40 % with increase in percentage of lime from 2% to 8%. Hence among the three admixtures lime can be sorted to improve this weak clayey soil especially when laying flexible pavements. Whereas in the case of foundation for small residential buildings quarry dust and flyash can be sorted to for arresting the swelling and shrinkage. Additionally further shear strength tests and load tests should add on for supporting the above said admixtures say quarry dust and lime for promising results.

According to IRC 37-2001,the subgrade should have a minimum CBR value of 5.9% to provide a pavement of total thickness 615 mm for 10 MSA traffic. Hence a minimum of 10 % replacement by quarry dust or 2 % Lime is required for laying a flexible pavement of thickness 615 mm. Further the same above mentioned standard says that mere 10 % replacement of flyash has improved the CBR value from 5% to 7% approximately and have brought down the pavement thickness to 580 mm, which will reduce the cost of laying the pavement to a substantial rate as pavements are laid in long kilometers of stretches.

The stabilized soil with a replacement of 30% quarry dust can be used in the pavement layers as a sub – base as IRC 37-2001 clearly mentions that for a sub- base layer a minimum CBR value of 20 % is required for handling 2 MSA traffic. Moreover 8 % of soil replaced with lime has doubled the requirement as per standard to 40 % for sub-base construction, and hence based on the requirement, availability of the material, nature of the project and its importance the contractor can decide the type of admixture.

The response of the soil stabilized with quarry dust has arrested the differential free swell values to a considerable extent rather than flyash and lime. It is also observed that the DFS values fall in a narrow range in the case of other admixtures apart from quarry dust for this type of clayey soil taken for study.

As per IS 2911 part 3 (1980) if the soil has to be used in the top 500 mm subgrade of a flexible pavement the DFS value should lie between 35 to 50 and hence addition of 20 % quarry dust will arrest the swelling substantially in using the clay soil as a subgrade material.

3 CONCLUSIONS

The study on stabilizing the locally available clayey soil in by quarry dust, flyash and lime with the support of series of laboratory investigations in specific arrived at the following conclusions.

1. With the preliminary studies conducted substantial improvement in quality of weak clay soil collected in velachery region is observed with addition of Quarry Dust, Flyash and Lime as admixtures.

2. The addition of quarry dust, flyash and lime have not only arrested the swelling nature but also increased the CBR value which in turn can reduce the thickness of pavement and swelling potential of weak clayey soils.

3. When laying flexible pavements, the total pavement thickness can be reduced from 615 mm to 580 mm by replacement of clayey soil with 10 % Quarry Dust, Flyash or 2 % Lime.

4. Minimum of 20 % replacement in clayey soil with quarry dust is required to arrest the swelling nature of the soil as per IS 2911 standards, Whereas other admixtures like flyash and lime have not effectively arrested swelling to the above specified standards for the weak soil tested.

5. As a whole the quantum of replacement of quarry dust and lime is found to be in the range of 30% or 8% in laying road pavements for the in-situ weak clayey soil.

6. For laying cost effective local pavements, lightly loaded structures like residential buildings which are not more than 2 floors the replacement of clayey soil with admixtures can be decided by the contractor

based on the cost of admixtures and the level of improvement required.

7. As quarry dust and flyash are easy to handle and less reactive when compared to lime, choice can be biased to the former admixtures for a low rate of strength improvement and for the higher rate of strength aspects the latter can be opted
8. Further detailed investigations are necessary in finding out the rate of strength improvement in clay soil by adding all the three admixtures and conducting laboratory shear strength tests, observing the chemical reaction taking place between soil and the admixtures.

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