Stabilizing of Expansive soil by Lime and Metakaolin

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Abstract- *Expansive soils, such as black cotton soils, are a worldwide problem. Construction in this soil has been engaging the attention of practising engineering and researches for many years. Expansive soils are basically susceptible to detrimental volumetric changes, with changes in moisture regime. In monsoon, they take up water and swell, and in summer, they tend to shrink on evaporation of water, thus posing the problem of alternate swelling and shrinkage. This behaviour of expansive soils is attributed to the presence of mineral, montmorillonite, which has an expanding lattice.*

Transportation infrastructure is vital for the developed of any country. Road transport is prepared by most, due to its accessibility and connectivity. The road network is normally planned and developed for fulfilling the requirements if transportation, keeping the total transportation cost in mind. In the process of network development, many a time, the alignment of a road may have to be finalised through weak soils sub grades (Chandrasekhar et al., 1999). It has been established, that the stability and performance of road is poor strength and are expansive in their character, are bound to fail resulting in poor pavement performance and increase in maintenance costs (Jones and Holtz, 1973; steinberg, 1992). Structures built in or on them crack severely and as a results building foundations in these soils tends to become expansive when compared with foundation on ordinary soils.

Keeping in view the research findings outlined above, in the present work, experimentation was carried out to investigate the efficacy of different additives, Viz., Lime , Metakaolin and Lime + Metakaolin, in stabilizing the expansive soil sub grade, thereby, improving the strength and swell characteristic of stabilized soil.

Keywords- Expansive soil, Stabilization, Lime, Metakaolin.

I. INTRODUCTION

A Civil Engineer often has to face some problematic soils such as expansive soils. Expansive soils, commonly known as black cotton soils, covered approximately one-sixth of the total area of our country. Such soils exhibit extreme stages of consistency from very hard during dry conduction to very soft when saturated. The development of any country depends on the transportation facilities and on the projects constructed. For the projects to be successful, the soil used for the foundation beds must be strong with better soil properties. Many innovative foundation techniques have been devised as solutions to the problems posed by Expansive soils. The selection of any one of the techniques is to be done after detailed comparison of all techniques and finding a well suited technique for the particular system. The various additives used for stabilizing expansive soils are lime, cement, fly ash, calcium chloride and others.

All over the world, potential problems posed by expansive soils have been cracking and breaking-up of pavements, railway and highway embankments, roadways, building foundations, irrigation systems, water lines, canal and reservoir linings. The estimated damage was substantial to the pavements running over the expansive soils sub grades. Various remedial measures like soil replacement, pre-wetting, moisture control, chemical stabilization have been practiced with varying degrees of success. Unfortunately the limitations of these techniques questioned their adaptability in all conditions. So work is being done all over, for a more evolved and effective practical treatment methods, to control the problems caused to any structures laid on expansive soils strata.

Based on the review of literature, it is observed that a considerable amount of work pertaining to the determination of consolidation characteristics, deformation characteristics and a strength characteristic of expansive soils , has been carried out worldwide almost since last 60 years. From the various contributions, the investigations on consolidation & deformation characteristics and strength characteristics of expansive soils conducted by (Abdullah I et.al (2006), Anand et.al. (2000), Anandakrishnanetal(1966), Balasubramaniam (1989), Bhadriraju (2005), Chen et al(1985), Kaniraj (2004).

The technology of road construction is subjected to problems arising with changing vehicular pattern, construction materials and sub grade condition. Majority of the pavement failures could be attributed to the presence of poor sub grade conditions and expansive soils sub grade is one such problematic situation. Expansive soils, because of the specific physio-chemical makeup are subjected to volume changes with changes in their ambient environment. The losses due to extensive damage to highways running over expansive soils sub grade are estimated to be in billions of dollars all over the world. In many countries like India, these soils are so aerially extensive that alteration of highways routes to avoid the materials is virtually impossible.

II. LITERATURE RIEVIEW

Expansive soils are typical tropical formations, generally found in poorly drained locations where there are marked wet and dry seasons. The clay minerals are formed through extensive physical and chemical weathering of parent material. Donaldson (1973) classified the parent material into two groups, the first group comprises the basic igneous rocks and the second group comprises the sedimentary rocks, which contain montmorillonite as constituent. The basic igneous rocks, poor in silica and rich in feldspars, pyroxenes and amphiboles, weather to clay minerals.

Sedimentary rocks such as shale's and clay stone, which contain varying amount of volcanic ash and limestone and marls rich in magnesium, can also weather in to clay minerals. The absence of leaching in an alkaline environment favors' the formation of montmorillonite. The basic igneous rocks, volcanic ash and their derivatives serve as the parent materials for the formation of montmorillonite clay mineral.

Other important clay minerals are kaolinite and illite. Kaolinite formation is favored by prolonged leading under acidic environment and high temperature with present rocks containing ferric iron. The condition for the formation of montmorillonoite and in addition, the presence of potassium in the parent material essential.

This behavior of the expansive soil is attributed to the presence of clay minerals with expanding lattice structure. Among them, monotmorillonite clay mineral is very active and absorbs water many times more than its volume (200A^o). The soil is hard as long as it is dry but loses its stability almost completely on wetting. On drying, the soil cracks very badly as shown in Plate 2.2 and in the worst cases, the width of cracks is almost 150mm and travels down to 3m below ground level (Altemyer, 1955; CBRI-1978; Wayne et al., 1984; Picornell and lytton, 1989; Kasmalkar,1991).

Flexible pavements are those, which on the whole have low or negligible flexural strength and are rather flexible in their structural action under the loads. The flexible pavement layers reflect the deformation of the pavements or soil sub-grade is undulated the flexible pavement surface also gets undulated.

A typical flexible pavement consists of four components: i) Soil sub grade ii) sub grade course iii) Base course and iv) Surface course. The flexible pavement layers transmit the vertical or compressive stresses to the lower layers by grain to grain transfer through the points of contact in the granular structure. Therefore by taking full advantage of the stress distribution characteristic of the flexible pavement, the layer system concept was developed. The top layer has to be strongest as the highest compressive stresses are to be sustained by this layer, in addition to the wear and tear compressive stresses are to be sustained by this layer, in addition to the were and tear due to traffic. The lower layers have to take up only lesser magnitudes of stresses and there is no direct wearing action due to traffic loads, therefore inferior materials with lower cost can be used in the lower layer. This consist of a wearing surface at the top, below which is the base course followed by the sub base course and the lowest layer consists of the soil sub grade which has the lowest stability among the four typical flexible pavements components.

When the pavements are laid over poor sub grade materials, the performance of the flexible pavements system deteriorates and shows cracking, rutting, unevenness, etc.

Among various methods of improving the performance, some of the methods are providing reinforcement in the sub grade or sub base or base course, stabilizing the sub grade material or stabilizing the sub base material or stabilizing the base material or a combination these methods.

In the present investigation an attempt is made to evaluate the performance of untreated and treated expansive soil (lime, Metakaolin and lime+Metakaolin) sub grade with the conventional Murrum sub base course and with WBM-III base course in the model flexible pavement system.

Metakaolin is also a mineral admixture and is a fine, white, clay mineral that has been traditionally used in the manufacture of porcelain. Kaolin's are classifications of clay minerals, which like all clays, are phyllosilicates, i.e. a layer with silicate mineral. The Meta prefix in the term used to denote change. In case of Metakaolin, the change that is taking place is dehydroxylization, brought on by the application of heat over a deficed period of time. Dehydroxylation is a reaction of decomposition of kaolinite crystals to a partially disorded structure. The results of isothermal firing show that the dehydroxylation begins at 4200C.

III. METHODOLOGY

Expansive Soil

The Clay that has been used in this study was a typical BC soil collected from Bendamurlanka near

Amalapuram, East Godavari District. The soil used for the investigation was dried, pulverized and then sieved through 4.75mm size sieve. The properties of black cotton soil experimented, based on relevant I.S. code provisions are given in the Table 1 below.

Table 1 Physical properties of Black Cotton Soil

Laboratory Experimentation	Value
Specific gravity	2.72
Grain size distribution	
Sand(%)	03
Silt (%)	35
Clay(%)	62
Compaction Parameters	
Maximum Dry Density(g/cc)	1.52
O.M.C. (%)	28.8
Atterberg's limits	
Liquid limit (%)	66.4
Plastic limit (%)	23.5
Plasticity index(%)	42.9
IS classification	CH
Differential Free Swell (%)	105
CBR- Unsoaked	3.4
Soaked	1.6

Murrum soil

The murrum used as sub base material in this investigation, was collected from dwarapudi, East Godavari district. The properties obtained from the laboratory tests are furnished below in Table 3.2.

Table: properties of Murrum

S. No	Property	Value
1	Specific Gravity	2.7
2	Grain size Distribution	
	Gravel (%)	61
	Sand (%)	28
	Silt & Clay (%)	11
3	Compaction Properties	
	Maximum Dry Density (kN/m^3)	19
	OMC (%)	13
4	Atterberg Limits	
	Liquid Limit (%)	26
	Plastic Limit (%)	20
	Plasticity Index (%)	6
5	Soaked CBR (Compacted to MDD at OMC) (%)	17
6	Permeability(cm/sec)	1.2×10^{-4}

Road Metal

Road metal of size 20mm conforming to WBM-III was used as base course material.

Lime

Commercial grade lime mainly consisting of 61.05 % CaO and 7.9% silica was used I the study.

Metakaolin

Between 100-200˚C, clay minerals lose most of their adsorbed water. Heating up of clay with kaolinite at the temperature of 500-600˚C kaoline becomes calcined by loss of structural water which results in deformation of crystalline structure of kaolinite and formation of an unhydrated reactive form called Metakaolinite. Kaolinite becomes Metakaolin above this temperature range, with a two-dimensional order in crystal structure. In order to produce a pozzolan (supplementary cementing material) complete dehydroxilation without overheating produces an amorphous highly pozzolanic stat.

Metakaolin is manufactured by calcinations of pure kaolinite clay at a temperature between 650˚C and 850˚C followed by grinding to achieve fineness about 700 to 900m2/Kg. The optimum calcinations temperature that produce the most reactive Metakaolin is in the range of 600-800˚C. One study found that calcinations at 700˚C produced a high strength Metakaolin. However reactivity of the Metakaolin reduced at a calcinations temperature of 850˚C.

It is also a mineral admixture and it is obtained in kaolin as a fine, white, clay mineral that has been traditionally used in the manufacture of porcelain. Kaolin's are classifications of clay minerals, which like all clays, are phyllosilicates, i.e. a layer silicate mineral. The Meta prefix in the term is used to denote change. In case of Metakaolin, the change that is taking place is dehydroxylization, brought on by the application of heat over a deficed period of time. Dehydroxylation is a reaction of decompositionof kaolinite crystals to a partially disorded structure. The results of isothermal firing show that the dehydroxylation begins at 420^0C.

Physical and Chemical Properties of Metakaolin

In the present investigation Metakaolin marketed by Jeetmulla Jaichandlall Pvt Limt Chennai is used. The characteristic furnished by the manufacturer is presented in table. Its specific gravity as found is 2.65 and bulk density is 0.5kg/m^3.

Table: Physical Properties of Metakaolin

Average particle size, µm	1.5
Specific Gravity	2.65
Bulk density (kg/m^2)	710 kg/m^3
Physical form	Off- white powder

Table: Chemical Properties of Metakaolin

SL.No	Characteristics	Result Metakaolin (%wt.)
1	Loss of Ignition	1.2
2	Silica (as Sio_2)	52.10
3	Alumina (as Al_2O_3)	44.6
4	Iron (as Fe_2O_3)	4.32
5	Calcium (as Cao)	0.10
6	Magnesium (as MgO)	0.10
7	Potash (K_2O)	0.20
8	Sodium (Na_2O)	0.05

IV. RESULTS AND DISCUSSION

Cyclic Load Test

These tests were carried out on flexible pavements systems in a circular steel tank of diameter 60cm as shown in Fig. 3.1 and Plate 3.2. The loading was done through a circular metal Plate of 10cm diameter laid on the model pavement system. The steel tank was placed on the pedestal of the compression testing machine. A 50 kN capacity proving ring was connected to the loading frame and the extension rod welded to the circular plate was brought in contact with proving ring. Two dial gauges of least count 0.01mm were placed on the metal flats welded to the vertical rod to measure the vertical displacements of the loading plate. The load was applied in increments corresponding to tyre pressures of 500, 560, 630, 700 and 1000 kPa and so on and for each pressure increment was applied, cyclically, until there was insignificant increase in the settlement of the plate between successive cycles. The testing was further continued till the occurrences of failure to record the corresponding ultimate loads.

For tests in saturated condition, the soil was allowed to absorb water by providing a thin sand layer (10 mm thick) at the bottom and also through vertical sand drains. Two inlet valves were welded on opposite sides of the tank through which water was supplied. The dial gauge readings were recorded until maximum heave was obtained and during this process, proving ring was disconnected. Cyclic load tests were also carried out at saturated state exactly in the same manner as for those at OMC. These tests were carried out at OMC and in saturated states of all the model flexible pavements

California bearing ratio (CBR) test results of expansive soil treated with lime, Metakaolin and lime + Metakaolin.

CBR tests were carried out in the laboratory on the expansive soil treated with different combinations of additives and the results are presented in Table and Fig..

Table: Variation of Soaked CBR Values for expansive soil Stabilized with Different Percentages of Lime

% of lime added to expansive soil	Soaked CBR %
0	2.2
2	3.46
4	4.68
6	6.20
8	7.36
10	8.60

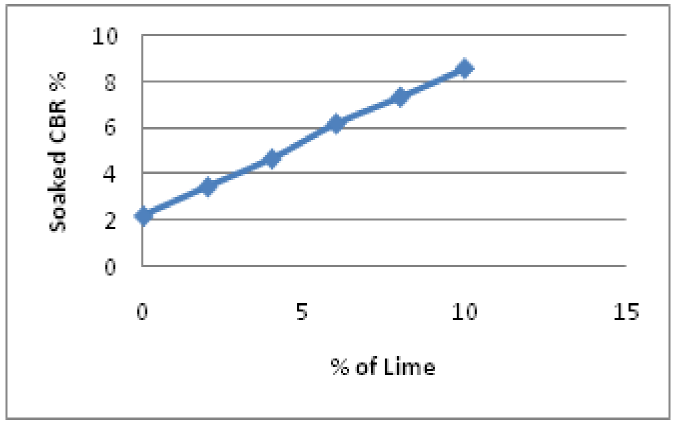

Fig. Effect of lime on the Soaked California bearing ratio (CBR) of the soil.

Based on the results as shown in the above Table and Fig, it is observed that the mix having 10% lime is giving a soaked CBR value of more than 8%, which is desirable for sub grade material as per IRC specifications.

Table : Variation of Soaked CBR Values for Expansive Soil Stabilized with Different percentages of Metakaolin.

% of Metakaolin added to expansive soil	soaked CBR %
0	2.2
1	3.42
2	4.80
3	6.24
4	7.40
5	8.36

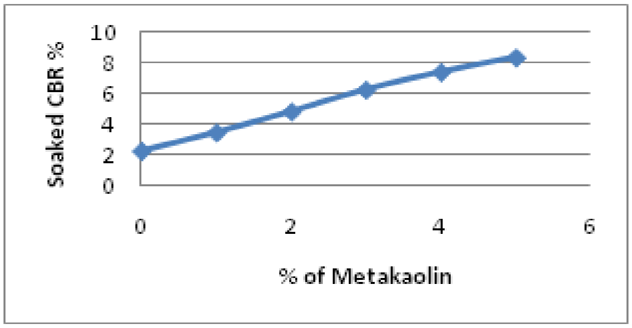

Fig. Variation of Soaked CBR Values for expansive soil Stabilized with Different Percentages of Metakaolin.

Based on the results shown in the above table and fig, it is observed that the mix having 5% Metakaolin is given a soaked CBR value of more than 8%, which is desirable for sub grade material as per IRC specification.

Table: Variation of Soaked CBR Values for expansive soil Stabilized with Different Percentages of Lime + Metakaolin

% of lime + Metakaolin added to expansive soil	**Soaked CBR %**
0	2.2
2+1	3.02
4+1	4.28
6+1	5.24
2+2	6.26
4+2	7.42
6+2	8.72

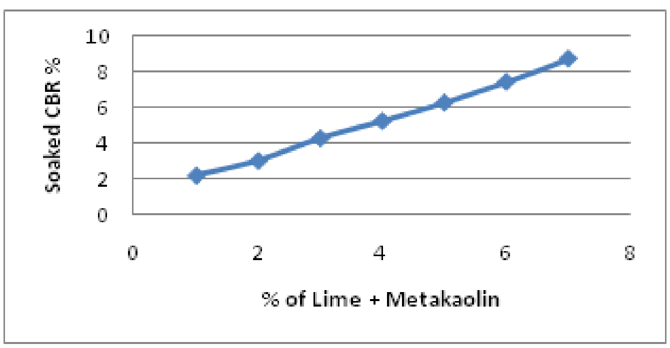

Fig Effect OF LIME + metakaolin on the Soaked California bearing ratio (CBR) of the soil.

Percentages of Lime, Metakaolin and Lime + Metakaolin Mixtures corresponding to 8% soaked CBR

S. No	Sub grade	Percentage Addition corresponding to 8% soaked CBR
1	Lime stabilized expansive soil	10%
2	Metakaolin stabilized expansive soil	5%
3	lime + Metakaolin stabilized expansive soil	6% + 2%

Load Test Results for Different Alternatives of expansive soil Sub grades at OMC.

Depict the pressure deformation curves for different model flexible pavements constructed with lime, Metakaolin and lime + Metakaolin stabilized expansive soil sub grade used in this investigation. It can be observed from these figures, that the load carrying capacity has substantially increased for lime + Metakaolin stabilized expansive soil model pavement followed by other pavements.

At all the deformation levels, lime + Metakaolin stabilized expansive soil sub grade has shown better performance, followed by lime, Metakaolin and untreated expansive soil sub grade. At all the load intensities, the untreated expansive soil sub grade has shown higher deformations than any other sub grades.

The addition of Lime and Metakaolin resulted in pozzolanic reactions between chemical additives and soil, and they occur at a later time, finally resulting in the replacement of clay mineralogy. Hence the load carrying capacity of treated sub grades was increased. It may be concluded that the total and elastic deformations had been decreased for all the treated alternatives.

Table variation of Pressure – Deformation for soil treated with different combinations testes at OMC

Pressure (kPa)	Soil + lime + Metakaolin		Soil + Metakaolin		Soil + lime		Un treated soil	
	TD (mm)	ED (mm)	TD (mm)	ED (mm)	TD (mm)	ED (mm)	TD (mm)	ED (mm)
0	0	0	0	0	0	0	0	0
500	0.86	0.54	1.86	0.89	2.86	1.69	5.54	2.64
560	1.46	0.82	2.42	1.54	3.68	2.26	8.02	3.26
630	1.96	1.2	3.29	2.2	5.82	3.50	10.06	5.42
700	2.86	1.64	5.00	2.86	8.32	4.26	13.64	7.68
1000	4.38	2.04	7.46	3.54	13.2	5.64	19.54	10.56
1500	6.40	2.54	12.64	4.26	18.56	9.24		
1900	8.2	2.89	14.48	5.86	24.82	10.84		
2100	9.86	3.24	16.42	6.42				
2200	11.36	3.78						

It can be observed from the above that the load carrying capacity of the pavement structure was maximum for lime + Metakaolin stabilized expansive soil sub grade. At all the deformation levels, lime + Metakaolin stabilized expansive soil model pavement exhibits highest load carrying capacity followed by other model pavements.

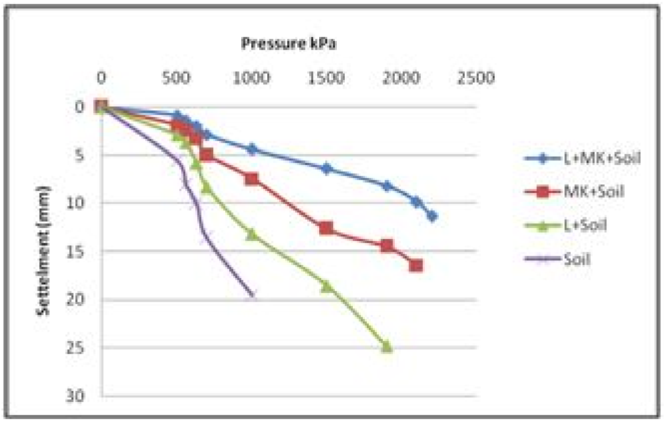

Fig variation of Pressure – Total Deformation Curves for different expansive soil sub grades at OMC

Table 4.6 variation of Pressure – Deformation for soil treated with different combinations at full saturation

Pressure (Kpa)	Soil + lime + Metakaolin		Soil + Metakaolin		Soil + lime		Un treated soil	
	TD (mm)	ED (mm)	TD (mm)	ED (mm)	TD (mm)	ED (mm)	TD (mm)	ED (mm)
0	0	0	0	0	0	0	0	0
500	1.22	0.66	1.86	1.24	2.36	1.80	5.54	2.86
560	1.64	1.04	2.04	1.84	3.70	2.54	6.64	3.84
630	2.08	1.24	2.96	2.0	4.69	3.20	9.48	5.88
700	2.46	1.68	3.64	2.46	6.84	3.92	13.54	8.26
1000	4.02	2.64	6.2	3.36	9.20	4.68		
1100	5.86	3.64	7.86	4.0	10.63	5.62		
1200	7.46	3.98	9.86	4.62	12.94	6.42		
1300	8.97	4.46	10.90	5.04				
1400	9.48	5.02	11.45	5.62				
1500	10.23	5.64						
1600	11.46	6.02						

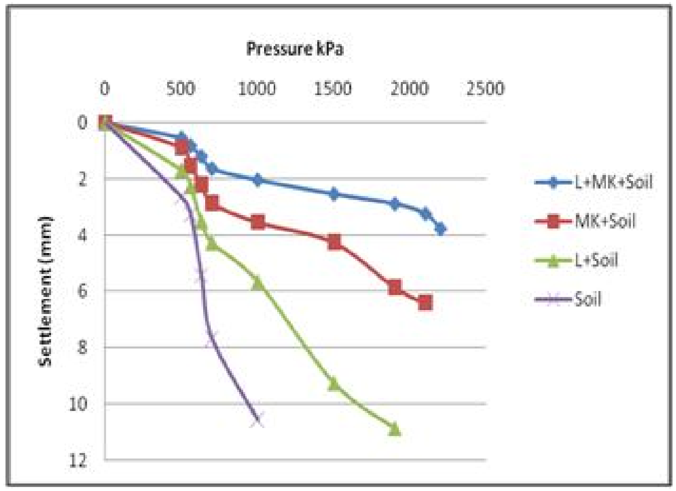

Fig variation of Pressure – Elastic Deformation Curves for different expansive soil sub grades at OMC

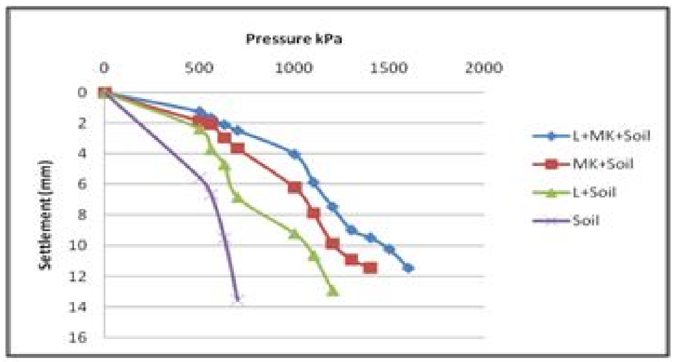

Fig variation of Pressure – Total Deformation Curves for Different expansive soil sub grades at FSC

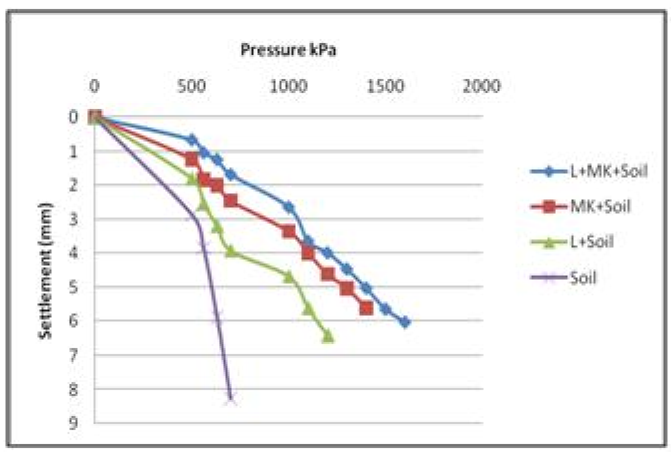

Fig. variation of Pressure – Elastic Deformation Curves for different expansive soil sub grades at Full Saturation

Load Test Results for Different Alternatives of expansive soil Sub grades at full saturation.

Table 4.6 and Fig.4.7 to 4.8 depict the pressure deformation curves for different model flexible pavements constructed with lime, Metakaolin and lime + Metakaolin stabilized expansive soil sub grade used in this investigation. It can be observed from these figures, that the load carrying capacity has substantially increased for lime + Metakaolin stabilized expansive soil model pavement followed by other pavements.

At all the deformation levels, lime + Metakaolin stabilized expansive soil sub grade has shown better performance, followed by Metakaolin, lime and untreated expansive soil sub grades. At all the load intensities, the untreated expansive soil sub grades have shown higher deformations than any other sub grades.

The addition of Lime and Metakaolin resulted in pozzolanic reactions between chemical additives and soil, and they occur at a later time, finally resulting in the replacement of clay mineralogy. Hence the load carrying capacity of treated sub grades was increased. It may be concluded that the total and elastic deformations had been decreased for all the treated alternatives.

It can be observed from the above that the load carrying capacity of the pavement structure was maximum for lime + Metakaolin stabilized expansive soil sub grade. At all the deformation levels, lime + Metakaolin stabilized expansive soil model pavement exhibits highest load carrying capacity followed by other model pavements.

V. CONCLUSION

The following conclusions are made based on the laboratory experiments carried out in this investigation.

When the virgin soil is treated with 10% lime, the percentage improvement in soaked CBR is 74.44% and treated with 5% metakaolin the percentage improvement was further increased to 73.68 % and also the combination of both lime + metakaolin i.e., (6% L + 2%M) the percentage improvement is 74.77%.

The results reveal that the optimum moisture content for all the three alternative additives are 10%, 5% and 6%L + 2%M for Lime, Metakaolin and Lime + Metakaolin respectively for both compaction and penetration characteristics.

There is an improvement in the Engineering Properties of the expansive soil treated with lime, Metakaolin, and Metakaolin + lime.

The Untreated and treated sub grade options were tested with murrum as sub base and WBM-III as base course.

Finally, it can concluded from the laboratory cyclic plate load test results, that there is an improvement in the ultimate load carrying capacity, when the expansive soil sub grade was treated with lime, Metakaolin and lime + Metakaolin.

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