

Stabilization of Expansive Soil with Micro Silica, Lime and Fly Ash for Pavement

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Abstract— *Geotechnical Engineering properties of soft clayey soil deposits such as black cotton soil may need to be improved by stabilization to make such soils suitable for construction of road pavements. Stabilization of such soils has been traditionally relied on treatment with lime, cement and waste materials such as fly ash. Micro silica is waste material obtained from electric arc furnaces. This paper presents the results of stabilization of local black cotton soil with lime, fly ash and micro silica. Series of laboratory tests have been conducted with varying percentage of these stabilizers, added individually and in combinations, to determine their optimum percentages. From the results, it is observed that CBR value, for both soaked and unsoaked conditions, increases substantially by addition of 5% micro silica along with 3% fly ash and 3% lime. The pavement designed with these improved values of CBR indicated a marked reduction in its thickness leading to economy in the construction of road pavements on or using soft clayey soils.*

Keywords— Micro silica, BC soil, Stabilization

1. Introduction

Black cotton soil extends over the states of Maharashtra, Madhya Pradesh, Karnataka, Andhra Pradesh, Tamilnadu and Uttar Pradesh. These soils are expansive in nature due to presence of Montmorillonite and Illite clay minerals. The soil surface is hard in nature in summer season but becomes slushy & loses its strength substantially during rainy season. A difficult problem in civil engineering work exists when the subgrade is found to be clay. Frequently, these clayey soils cause the cracking and breaking up of pavements, railways, highway embankments, roadways, foundations and channel or reservoir linings. When civil engineers are faced such problems, a need for improving the engineering properties of the soil is justified using some sort of stabilization methods. Stabilization of pavement subgrade soils has traditionally relied on treatment with lime, cement, and special additives such as pozzolanic materials. Pozzolanic materials, such as Fly Ash, Micro silica (silica fume), etc., which are regarded as wastes may be used for soil improvement.

Lime stabilization enhances engineering properties of soil, including improvement in strength, reduction swelling, and resistance to the damaging effect of moisture. However, Industrial wastes attracted the attention of researchers recently

because of the cheapness of material cost in comparison with other materials.

The concept of soil reinforcement is not new. Various materials were used in reinforcement of both pavement materials and sub-grade soils. The Geotextiles and Geogrids are the most commonly used forms of soil reinforcement now-a-days. A geogrid is any synthetic planer structure formed by a regular network of tensile elements with apertures of sufficient size to allow interlocking with surrounding soil, rock, earth or any other geotechnical material.

From literature review, it was observed that the lime, fly ash, micro silica and geogrid were separately mixed with black cotton soil, improved the geotechnical properties (Nadgouda et al. 2010, katti et al. 2011; Tuncer et al. 2006; M. Hussein et al 2007; Haeda et al. 2013; Kalkan et al 2004; A. Al-Azzawi et al. 2012; Negi et al 2013; Gupta et al. 2014).Also the combination effect of lime- fly ash and lime- micro silica had been studied (athanasopoulou et al. 2014; Jafer et al. 2013; Singh et al. 2012).

This paper presents the results of experimental investigations carried out to study the effect of micro silica, fly ash, lime and geogrid on geotechnical properties of black cotton soil. Expansive soil used for experimental investigations was a locally available soil known as black cotton soil.

The tests were conducted on oven dried expansive soil with different mix proportions. Focus of research was on the influence of different stabilizers mixed with black cotton soil in improving the following properties of soil,

- Unconfined compressive strength
- California bearing ratio(CBR)
- Swelling pressure

The effect of improved CBR value of stabilized soil on the design of pavement is also presented

2. Material and Methodology

2.1 Materials Used

2.1.1 Black Cotton Soil

The soil used in testing was locally available soil from Amravati District of State of Maharashtra. The properties of black cotton soil used in this study are given in Table 1.

Table 1 Properties of Black Cotton soil

| Sr. No. | Properties of Clay | Value |
|---------|--|----------------|
| 1 | Atterberg's Limits | |
| | Liquid Limit (%) | 59.60 |
| | Plastic Limit (%) | 26.98 |
| | Plasticity Index (%) | 32.62 |
| 2 | IS-Classification (Clay of High Compressibility) | CH |
| 3 | Compaction Properties | |
| | Optimum Moisture Content (%) | 25 |
| | Maximum Dry Density (kN/m ³) | 14.5 |
| 4 | Free Swell Index (%) | 81 (Very high) |

2.1.2 Lime

The lime used for stabilizing the soil was locally available hydraulic lime. The Lime was sieve through IS 75 μ sieve so as to remove all the larger size particles.

2.1.3 Micro Silica

The micro silica used in this study for stabilizing black cotton soil was procured from IndiaMART, Indor. Table 2 shows the properties of fly ash.

Table 2 Properties of Micro silica

| Sr. No | Properties of Micro silica | Value |
|--------|-----------------------------------|-------------|
| 1 | Specific gravity | 2.20 - 2.23 |
| 2 | Bulk density (kg/m ³) | 375 - 420 |
| 3 | Moisture content (%) | < 1.0 |

2.1.2 Fly ash

The fly ash used in experimental investigation for stabilized black cotton soil was procured from the Sophia Power Plant, near Nandgaon Peth, Amravati. Table 3 shows the properties of fly ash.

Table 3 Properties of Fly ash

| Sr. No | Properties of Fly ash | Value |
|--------|--|-------|
| 1 | Specific gravity | 2.05 |
| 2 | Maximum Dry Density (kN/m ³) | 10.6 |
| 3 | Optimum Moisture Content (%) | 26.2 |
| 4 | Cohesion (kN/m ²) | 1 |
| 5 | PHI | 33 |

2.2 Experimental Investigations

The experimental investigations were divided in the following groups.

- **Group A:** Stabilization of soil with lime, fly ash and micro silica

The experiments were conducted for each stabilizer separately as presented in Table 4. Standard Proctor Tests were conducted on soil mixed with stabilizers and OMC and MDD were determined. The soil samples were then prepared for UCS test using

water content corresponding to OMC. UCS tests were then conducted and UCSs were determined. Similar tests were conducted for varying percentages of stabilizers. The optimum percentage of stabilizers was then determined based upon the results of UCS tests. The quantity corresponding to the optimum percentage of stabilizers were mixed to the oven dried sample of soil and CBR (soaked & unsoaked) test were conducted. Swelling pressure test were also conducted.

- **Group B:** Stabilization of soil with combination of lime, fly ash and micro silica

In this group of experiments, the soil was mixed with combination of optimum percentages of micro silica, fly ash and lime. The stabilizers were thoroughly mixed with soil and Standard Proctor Test was then conducted to determine OMC and MDD. The soil samples were then prepared for UCS test using water content corresponding to OMC. UCS tests were then conducted and UCSs were determined. The CBR (soaked & unsoaked) tests were also conducted on soil stabilized with the same combination of stabilizers. Swelling pressure tests were also conducted.

- **Group C:** Stabilization of soil with lime, fly ash, micro silica and reinforced with geogrid

In this group, the soil was mixed with optimum percentages of micro silica, fly ash and lime as determined from the results of group A. The samples were then prepared by placing the geogrid at various locations viz, h/2, h/3 and 2h/3 with different combinations of geogrid position. The CBR tests were conducted on stabilized soil. Swelling pressure tests were also conducted.

Table 4 Complete Programme for Experimental Investigation

| Group | Stabilizer | Tests | Percentage of Stabilizer |
|---------|--------------------------------------|--|--|
| Group A | Micro silica, Fly ash, Lime | Proctor test, Unconfined Compression Strength (UCS) test, Swelling pressure test, CBR test | Micro silica (0, 2.5, 5, 7.5, 10, 15, 20) Fly ash (0, 3, 6, 9, 12, 15) Lime (0, 3, 6, 9) |
| Group B | Micro silica, Fly ash, Lime | Proctor test, Unconfined Compression Strength (UCS) test, Swelling pressure test, CBR test | Optimum % of Micro silica + Optimum % of Fly ash + Optimum % of Lime |
| Group C | Lime, Fly ash, Micro silica, Geogrid | Swelling Pressure test, CBR test | Optimum % of Micro silica + Optimum % of Lime + Optimum % of Fly ash + Geogrid (h/2, h/3, 2 h/3) |

3. Results and Discussions

3.1 Group A: Soil stabilized with lime, fly ash and micro silica

Laboratory tests were conducted on soil mixed with lime, fly ash and micro silica separately. Table 5 shows the UCS value of soil stabilized with stabilizers.

From the UCS test results, 5 % micro silica, 3 % lime and 3 % fly ash were considered as optimum percentages. Therefore, the UCS tests and CBR tests were conducted on soil mixed with 5% micro silica for various curing periods. Table 6 shows the UCS and CBR tests results. From Fig 1, it was observed that the UCS increased with increase in curing period. The soaked CBR value increased from 1.44 % to 4 % and unsoaked CBR value increased from 10.33 % to 15.39 %.

Table 5 Variation of UCS with different percentages stabilizers

| Soil Mix | Stabilizer (%) | UCS (kN/m ²) |
|------------------------|----------------|--------------------------|
| BC Soil | 0 | 114.01 |
| BC soil + lime | 3 | 216.03 |
| | 6 | 206.68 |
| | 9 | 249.61 |
| BC soil + fly ash | 3 | 241.66 |
| | 6 | 192.43 |
| | 9 | 233.28 |
| | 12 | 160.72 |
| | 15 | 168.66 |
| BC soil + micro silica | 2.5 | 234.19 |
| | 5 | 261.38 |
| | 7.5 | 277.53 |
| | 10 | 276.5 |
| | 15 | 257.23 |
| | 20 | 131.42 |

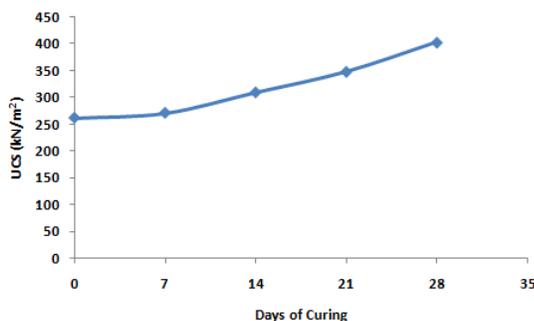


Figure 1 Variation of UCS of soil mixed with 5 % micro silica for different curing period

3.2 Group B: Soil stabilized with combination of lime, fly ash and micro silica

The soil was mixed with combination of optimum percentages of lime (3 %), optimum percentage of fly ash (3 %) and optimum percentage of micro silica (5 %) and standard proctor tests were conducted. Using the OMC obtained, UCS test was conducted and UCS was obtained as 237.91 kN/m².

Table 6 UCS, soaked CBR and Unsoaked CBR for different curing periods

| Soil Mix | Days of curing | UCS (kN/m ²) | CBR value (%) | |
|------------------------|----------------|--------------------------|---------------|----------|
| | | | Soaked | Unsoaked |
| Black cotton soil | - | 114 | 1.43 | 10.33 |
| Soil + 5% Micro silica | 0 | 261.38 | 2.02 | 10.86 |
| | 7 | 270.63 | 3.21 | 11.28 |
| | 14 | 309.3 | 3.63 | 12.92 |
| | 21 | 347.98 | 3.84 | 14.11 |
| | 28 | 403.04 | 4 | 15.39 |

Also, it was found that the unconfined compressive strength increased from 237.91 kN/m² to 433.30 kN/m² with increase in curing period from 0 days to 28 days. The soaked and unsoaked CBR test results are tabulated in Table 8. From the test results, it was observed that the soaked CBR value increased from 1.43 % to 8.96 % and Unsoaked CBR value increased from 10.33% to 17.96 %, when curing period was increased to 28 days, It was also found that the swelling pressure reduced from 169.43 kN/m² to 71.08 kN/m².

Table 8 CBR and UCS of stabilized soil for different curing period

| Soil Mix | Days of curing | CBR Value (%) | |
|---|----------------|---------------|----------|
| | | Soaked | Unsoaked |
| Black cotton soil | - | 1.43 | 10.33 |
| Soil+ 5% micro silica + 3% flyash + 3% lime | 0 | 6.3 | 11.54 |
| | 7 | 7.79 | 11.93 |
| | 14 | 7.87 | 14.96 |
| | 21 | 8.1 | 17.1 |
| | 28 | 8.96 | 17.96 |

3.3 Group C: Soil Stabilized with lime, fly ash, micro silica and reinforced with geogrid

In this group of test, the soil was mixed with optimum percentages of micro silica, fly ash and lime and reinforced with Geogrid. Three samples were prepared having position of geogrid at (h/3), (h/3 + h/2) and (h/3 + h/2 + 2h/3) respectively. Table 9 shows the soaked and unsoaked CBR test results. From the test results it was found that, the soaked CBR value increased from 1.44 % to 9.44 % and unsoaked CBR value increased from 10.33 % to 18.81 %. From the swelling pressure test results, it was found that the swelling pressure reduced from 169.43 kN/m² to 27.85 kN/m². Fig 2 shows the variation of swelling pressure with geogrid position.

Table 9 Soaked and Unsoaked CBR value for Stabilized Soil

with Geogrid reinforcement

| Soil Mix | Geogrid Position | CBR value (%) | |
|--|------------------|---------------|----------|
| | | soaked | Unsoaked |
| BC soil | - | 1.44 | 10.33 |
| BC soil + 5% micro silica + 3 % fly ash + 3 % lime | h/3 | 9.02 | 18.16 |
| | h/3 + h/2 | 9.42 | 18.39 |
| | h/3 + h/2 + 2h/3 | 9.44 | 18.81 |

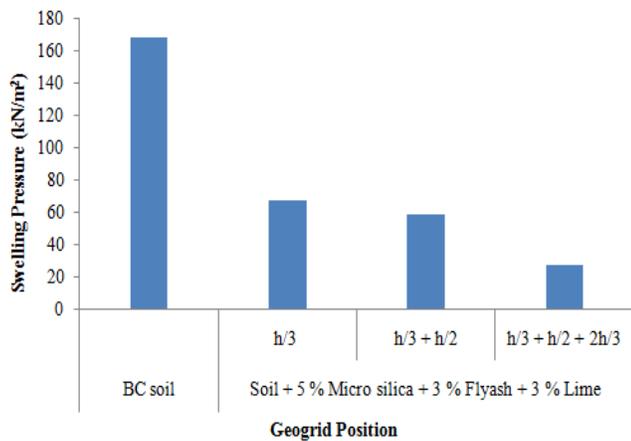


Figure 2 Variation of Swelling Pressure for different position of Geogrid

3.4 Reduction in Flexible Pavement Thickness

Flexible pavement with black cotton soil was designed with 1.44 % soaked CBR value. Table 10 shows the pavement layer thickness. Table 11 shows the reduction in pavement thickness of stabilized soil and table 12 shows the reduction in pavement thickness of stabilized reinforced soil. The stabilized soil was designed with 4 % soaked CBR value. It was found that there was 15.52 %, 14.10 % and 17.02 % reduction in the layer thickness for 50 msa, 100 msa and 150 msa traffic intensities compared to unstabilized soil as presented in Table 11. The stabilized soil was designed with 8.96 % soaked CBR value. It was found that there was 15.27 %, 14.67 % and 17.57 % reduction in the layer thickness for 50 msa, 100 msa and 150 msa traffic intensities compared to unstabilized soil.

The pavement thickness reduction of stabilized reinforced soil is as given in Table 12. In case of geogrid at (h/3) and (h/3 + h/2), it was found that there was 18.58 %, 18.77 % and 21 % reduction in the layer thickness for 50 msa, 100 msa and 150 msa traffic intensities respectively, compared to unstabilized soil. In case of geogrid at (h/3 + h/2 + 2h/3), it was found that there was 18.67 %, 18.85 % and 21.56 % reduction in layer thickness for 50 msa, 100 msa and 150 msa traffic intensities compared to unstabilized soil.

Table 10 Pavement Thickness of Black cotton soil

| Black cotton soil | CBR value | Total thickness (mm) |
|-------------------|-----------|----------------------|
| 50 msa | 1.44 % | 1205 |
| 100 msa | 1.44 % | 1220 |
| 150 msa | 1.44 % | 1275 |

Table 11 Pavement Thickness of Stabilized Soil

| Soil mixed | CBR value | Total thickness (mm) | % Reduction |
|---|-----------|----------------------|-------------|
| BC soil + 5 % micro silica | | | |
| 50 msa | 4% | 1018 | 15.52 |
| 100 msa | | 1048 | 14.1 |
| 150 msa | | 1058 | 17.02 |
| BC soil + 3 % lime + 3 % fly ash + 5 % micro silica | | | |
| 50 msa | 8.96% | 1021 | 15.27 |
| 100 msa | | 1041 | 14.67 |
| 150 msa | | 1051 | 17.57 |

Table 12 Pavement Thickness Reduction of Stabilized reinforced

| Soil mixed | CBR value | Total thickness (mm) | % Reduction |
|--------------------------------------|-----------|----------------------|-------------|
| Soil | | | |
| Geogrid (h/3) and Geogrid (h/3, h/2) | | | |
| 50 msa | 9% | 981 | 18.58 |
| 100 msa | | 991 | 18.77 |
| 150 msa | | 1001 | 21.49 |
| Geogrid (h/3, h/2, 2h/3) | | | |
| 50 msa | 10% | 980 | 18.67 |
| 100 msa | | 990 | 18.85 |
| 150 msa | | 1000 | 21.56 |

4. Conclusion

- 1) Stabilization of black cotton soil with lime, fly ash, lime and their combinations shows significant improvement in the unconfined compressive strength of soil to the extent of 3.8 times that of unstabilized soil.
- 2) Optimum percentages of micro silica, lime and fly ash for stabilizing black cotton soil are found to be 5%, 3% and 3% respectively.
- 3) Black cotton soil stabilized with lime, fly ash, micro silica and their combinations shows noticeable improvement in soaked CBR of soil up to extent of 6.5 times of unstabilized soil.
- 4) Black cotton soil stabilized with lime, fly ash, micro silica and their combinations shows noticeable improvement in unsoaked CBR of soil up to extent of 1.8 times of unstabilized soil.
- 5) Stabilization of soil with lime, fly ash, micro silica and their combination shows 57 % reduction in swelling pressure of soil. Stabilized reinforced soil shows the 83 % reduction in swelling pressure.
- 6) Stabilization of black cotton soil with lime, fly ash, micro silica and their combinations shows 15 %, 14 % & 17

% reduction in pavement thickness for design traffic 50 msa, 100 msa & 150 msa respectively.

7) The thickness of flexible pavement may be reduced by 18.6 %, 18.8 % and 21.5 % in for stabilized reinforced BC soil for design traffic of 50 msa, 100 msa and 150 msa.

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