Subgrade CBR improvement with fly ash as mineral and NaOH as a chemical admixture

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Abstract. Increase in the rate of traffic volume and heavy vehicle loads gave a revolution in highway construction technology, this increase is due to continuous growth in economic activities. Therefore, it is necessary to construct highly durable and serviceable road structures on any type of soil. In continuation, a good subgrade can influence the thickness of road structure, increases the strength pavement, and reduce the cost of road structure construction. California bearing ratio (CBR) is a generally used in-direct method to estimate the strength of sub-grade and it directly gives the pavement thickness in pavement analysis and design work. So, if increasing in the CBR value results thicknesses of the pavement will decrease and it, in turn, reduces the construction cost of the pavement structure. In the present investigation, the collected soil samples are Black Cotton soils from Dharmapuri, Vizianagaram, AP. Same soil stabilized with various replace percentages of Fly ash (i.e.10, 20, 30, and 40%) and NaOH (i.e. 3, 5, and 7%). The Atterberg limits, Free swell Index, and CBR tests were completed on original and stabilized soils. Finally, authors observed that the considered BC soil stabilized with mineral admixture (Fly ash) and chemical admixture (NaOH) results in more than 400% increase in CBR with 40% decrease in pavement thickness, and 25% decrease in pavement construction cost.

Keywords: Black cotton soil, CBR, Fly-ash and NaOH;

1. Introduction
The highway is a main-road for travel by the public between key destinations, such as cities, large towns. Geotechnical engineering has been critically related to highway construction in case of Bearing-capacity and shear strength of the soil. To construct an economical highway, the engineer must design the best thickness from the lower layer of subgrade to surface course. So, the present study is conducted out to improve the CBR value of the soil by using Fly-ash to decrease the pavement thickness.

1.1. Black Cotton Soil
Soil is generally depicted as silt or another variety of mineral-particles generated by the physical or compound breaking down of rocks in addition to the air, water, natural issue, and different fixings that might be incorporated. Soil is normally a non-homogeneous-, permeable, earthen-material’ whose engineering performance is affected by modifications on dampness substance and density. If the rate of montmorillonite is more in soil, then it is said to be Black-cotton soil or Regur soil [8]. This is developed by the weathering of igneous-rocks’ and cooling of lava after a volcanic explosion. These do not give any warning and are expansive which is dangerous for construction activity. Normally,
lands with black cotton soils are abundant and very great for agriculture, but their bearing capacity is very low (15000 kg/m²) to lay pavements on them. In general, black-cotton soils discovered in India are a typical example of soft expansive soils. Differential free swell index is one simple method of identifying the expansive soils. Black-cotton soils absorb water, swell heavily loses strength and are easily compressible. This soil shrinks and develops cracks during summer. These soils produce a CBR of 2 to 5% and such soils undergo volumetric modifications leading to pavement distortion, cracking, and general unevenness due to regular wetting and drying [12]. Following are some important reasons for the failure of roads laid on Black-cotton soils, 1) Nature of Black-cotton soils, 2) Poor drainage services, 3) Use of gravel in base and subbase, 4) Supplying of overloaded vehicles and iron wheeled tractors, trolleys etc.,

1.2. Problems of Flexible pavements on Black cotton soils
Flexible pavements having a lesser amount of flexural strength and act as a flexible sheet. These will circulate wheel load stresses to smaller layers by grain-to-grain distribution through the points of contact in the granular section. Embankment design of flexible roads requires to fulfil two important needs on BC soils, they are stability and settlement [13]. The short-term permanence for embankment over soft clay is always extra vital than long term simply because the sub-soil with time under loading and the strength improves.

Some of the failures of flexible pavements built on BC soil are as follows.
- Rutting: Surface recession in the wheel path.
- Corrugation: Occur under dry weather conditions.
- Potholes: These are the end effect of alligator cracking. As alligator cracking turn out to be serious, the interrelated cracks create small lumps on the pavement, the residual hole after the lump is known as potholes.
- Cracking: Cracks may be small and fine (hairline cracks), small interlinked near-circular cracks (fatigue cracks), parallel to pavement centerline longitudinal cracks.

2. Utilization of admixtures in BC soil stabilization

2.1. Using Fly ash as a mineral admixture
Fly-ash’ is a solid-waste by-product invention generated by the burndown of coal, it is conducted out of the boiler by flue-gases and removed by electrostatic precipitators or cyclone filters and filter bags. Fly ash used in the current study is gathered from a thermal power station located in Visakhapatnam. Fly-ash brings down the capability of a plastic-soil’ to attempt volumetric extension by a physical-cementing’ system, which can't be assessed by the plasticity-index (PI). Fly-ash ‘self-controls shrink/swell by cementing the soil reviewing all the while much like Portland-cement bonding aggregates simultaneously to make concrete. By holding the soil grains all the while, soil molecule developments are constrained. Fly-ash’ is acts as pozzolans [1] [2] [3]. It has been viably utilized with granular and fine-grained materials to enhance soil qualities, proposing sufficient help for pavements and upgrading working situations where unwanted soils are confronted.

2.2. Using NaOH as Chemical admixture
Using chemicals is similarly a conventional soil stabilization technique since it creates a superior characteristic original soil with greater strength and durability than mechanical & physical methods [9] [10] [11]. All chemical methods are reliant on reaction among chemical-additives and soil particles which then generate a solid network that combine the soil grains. Chemically proves mineral polymers are contained of crosslinked units of AlO4 and SiO4-tetrahedral, there charge comparing reactions (Na+, k+, Li+, Ca2+, Ba2+, H3O+) are delivered by alkali metals. In the present investigation the chemical additive used as Sodium-hydroxide’ (NaOH). Sodium-hydroxide appears white, feels odorless, non-volatile solution. It may not burn but tremendously responsive. It reacts aggressively with water and several usually encountered materials, producing adequate heat to ignite close to igneous materials. Following key advantages are that it can simply respond with water which results in a strong compaction aid giving a larger density for the same compaction effort [7] [12]. Sodium-
hydroxide reacts very effectively with soil abundant in aluminium. The experimental materials are shown in figure 1 (a) and figure 1 (b).

2.3. Objectives of the present work
The present experimental investigation carried for the following objectives,
- To study the engineering-properties of locally obtainable black cotton soil.
- To improve the CBR value by adding together different % of fly-ash’ and NaOH.
- To find the optimal percentage of fly-ash’ and NaOH for soil sample that enhances CBR value.
- To determine the suitable structure thickness for the pavement before and after adding fly ash and NaOH.

3. Experimental Investigation and Discussion
For the present study, an experimental investigation was conducted out by two different stages. In the first stage, determine the optimum dosage of fly ash for better CBR among the five design soil mix samples as shown in Table 1. In the second stage, determine the optimum dosage of NaOH with selected soil mix in stage-01 as shown in Table 3.

Table 1. Mix proportions of BC Soil partially replaced with Fly ash in Stage-01

| Type of Mix | M  | M1 | M2 | M3 | M4 |
|-------------|----|----|----|----|----|
| BC-Soil %   | 100| 90 | 80 | 70 | 60 |
| Fly ash %   | -  | 10 | 20 | 30 | 40 |

All the five different soil mixes as shown in table 1, with partial replacement of fly ash in stage-01 are tested in the laboratory for Atterberg-limits, Free-swell Index, and CBR value to fix the optimum dosage of fly ash as a replacement in BC soil for stabilization.
Table 2. (a) Atterberg Limits and Free-swell-index (FSI) values for Trial mixes

| Type of Mix | Atterberg Limits |  |  | FSI (%) |
|-------------|-----------------|---|---|--------|
|             | Liquid Limit    | Plastic limit | Plastic Index |
| M           | 89              | 42            | 47            | 74     |
| M1          | 68              | 30            | 38            | 68     |
| M2          | 62              | 25            | 37            | 48     |
| M3          | 55              | 24            | 31            | 19     |
| M4          | 54              | 24            | 30            | 07     |

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Table 2. (b) Optimum-Moisture-Content, Maximum-Dry-Density and CBR values for Trial mixes

| Type of Mix | OMC (%) | MDD (g/cc) | CBR (%) |
|-------------|---------|------------|---------|
| M           | 25.80   | 1.54       | 2.90    |
| M1          | 22.20   | 1.53       | 5.58    |
| M2          | 21.80   | 1.52       | 5.62    |
| M3          | 20.45   | 1.52       | 5.98    |
| M4          | 19.05   | 1.51       | 7.18    |

| Code of Practice | IS: 2720 (Part-7) | IS: 2720 (Part-7) | IS: 2720 (Part-16) |

From Table 2(a) & 2(b), Among all five trial mixes of BC soil partially replaced with fly ash (10 to 40% respectively), M4 mix shows reasonable values. Selected M4 mix is used as an optimum mix for stabilization for further study. In continuation of experimental investigation as a part of stage-02, M4 is considered in determining the optimum dosage of NaOH.

Table 3. Mix proportions of BC Soil partially replaced with Fly ash & NaOH in Stage-02

| Type of Mix | NaOH (%) | M4-01 | M4-02 | M4-03 |
|-------------|----------|-------|-------|-------|
| NaOH (%)    | 03       | 05    | 07    |

All the three different soil mixes as shown in table 3, with partial replacement of fly ash and NaOH in stage-02 are tested in the laboratory for CBR value to fix the optimum dosage of NaOH as a replacement in BC soil for stabilization.

Table 4. CBR values for Trial mixes in Stage-02

| Type of Mix | OMC (%) | MDD (gm/cc) | NaOH (%) (Replacement) | CBR (%) |
|-------------|---------|-------------|------------------------|---------|
| M4-01       | 19.05   | 1.51        | 03                     | 9.97    |
| M4-02       | 19.05   | 1.51        | 05                     | 14.16   |
| M4-03       | 19.05   | 1.51        | 07                     | 15.56   |

| Code of Practice | IS: 2720 (Part-16) |
Figure 2. Comparison of CBR for all trail soil mixes

According to the results obtained and presented in figure 2, 7% replacement of NaOH in Mix M4-03 gives better CBR value among all results from the present investigation.

4. Design Criteria for Pavement Structure

According to IRC-37, the thickness of layers for the pavement with CBR 2.9 % (Mix ‘M’) is 890mm. The individual thickness of all layers for the proposed pavement mentioned in the below table.

Table 5. Thickness of Pavement layers for CBR 2.9 %

| CBR 2.9 % | Total pavement thickness (mm) | LAYER COMPOSITION FOR PAVEMENT |
|-----------|------------------------------|--------------------------------|
| Salient points | Bituminous surfacing | Base (mm) | Sub-Base (mm) |
| Cumulative Traffic 150 msa | BC (mm) | DBM (mm) | BC (mm) | DBM (mm) |
| 890 | 50 | 210 | 250 | 380 |
| Width of layers for 100 m length | 3500 | 4100 | 4700 | 5300 |

According to IRC-37, the thickness of layers for the pavement with CBR 15.56 % (Mix ‘M4-03’) is 520mm. The individual thickness of all layers for the proposed pavement mentioned in table 6.

Table 6. The thickness of Pavement layers for CBR 15.56 %

| CBR 15.56 % | Total pavement thickness (mm) | LAYER COMPOSITION FOR PAVEMENT |
|--------------|------------------------------|--------------------------------|
| Salient points | Bituminous surfacing | Base (mm) | Sub-Base (mm) |
| Cumulative Traffic 150 msa | BC (mm) | DBM (mm) | BC (mm) | DBM (mm) |
| 530 | 30 | 100 | 200 | 200 |
| Width of layers for 100 m length | 3500 | 4100 | 4700 | 5300 |

From the standard rates, the construction cost of the above road layers for CBR 2.9 and 15.56% calculated and compared the final construction cost approximately and presented in the below figure 3.
Figure 3. Comparison of the construction cost of road layers

From Table 5 & 6, It is concluded that pavement structure decreases from 890mm to 530mm, means all most more than 25% of cost reduction for the CBR 15.56 % compared to the CBR 2.9 %.

5. Conclusions
From the above study an effort has been made to use fly-ash’ and NaOH as mineral and chemical admixtures for improving the properties of the black cotton soil and to reduce the road structure construction cost. The following are the conclusions drawn from the above study,
1. It is noticed that there is a decrease in OMC, PI and FSI with an increase in fly ash.
2. There is an upsurge in CBR value observed with an increase in the percentage of fly ash also with NaOH.
3. Black cotton soil stabilized with 40 % fly ash had resulted in a substantial decline in liquid limit and plasticity index.
4. The effect of the addition of chemical admixture NaOH (3 to 7 %) was studied and it was found that CBR had tremendously increased with mixture M4-03 i.e. natural soil with 40 % fly ash and 7 % NaOH.
5. CBR value of the present soil sample replaced with 40% fly-ash’ and 7% NaOH improved considerably up to 400%.
6. The upsurge in CBR had resulted in a decrease in the pavement thickness by 40 % and thereby resulted in more than 25 % decrease in the cost of the road project.

References
[1] Ali M, Sreenivasulu V 2004 An experimental study on the influence of rice husk ash and lime on properties of betonies Proceedings of Indian Geotechnical Conference Warangal (India) p 468-71
[2] Brooks R M 2009 Soil stabilization with fly ash as hard rice husk ash International Journal of Research and Reviews in Applied Sciences 1 (3) p 209-17
[3] Robert M Brooks 2009 Soil stabilization with fly ash and rice husk ash International Journal of Research and Reviews in Applied Science 1 (3) p 209-17
[4] IS 2720 1987 (Part 16) Laboratory determination of CBR Bureau of Indian standards New Delhi
[5] IS 2720 1977 (Part 40) Determination of free swell index of soil Bureau of Indian standards New Delhi
[6] IRC 37 2001 Guidelines for the Design of flexible pavements The Indian Rods Congress New Delhi
[7] Islam M Rafizul, Md. Assaduzzaman, Muhammed Alamgir 2012 The effect of chemical admixtures on the geotechnical parameters of organic soil International Journal of Applied Sciences and Engineering Research 1 (4) p 623-34
[8] Laxmikant Yadu, Rajesh Kumar Tripathi, Dharamveer Singh 2011 Comparison of Fly Ash and Rice Husk Ash Stabilized Black Cotton Soil International Journal of Earth Sciences and Engineering 4 (6 Spl.) p 42-5
[9]  Sudheer P, Munireddy M G, Adiseshu S 2017 Study on Strength of Hybrid Mortar Synthesis with Epoxy Resin, Fly Ash and Quarry Dust under Extreme Conditions *IOP Conference Series: Materials Science and Engineering* **225** (1) 012169

[10] Sudheer P, Munireddy M G, Adiseshu S 2016 An experimental study on strength of hybrid mortar synthesis with epoxy resin, fly ash and quarry dust under mild condition *Journal of Advances in Materials Research, An International Journal Techno-press* **5** (3) p 171-9

[11] Sudheer P, Munireddy M G, Adiseshu S 2016 Study on Strength of Innovative Mortar Synthesis with Epoxy Resin, Fly Ash and Quarry Dust *American Journal of Engineering Research* **5** (5) p 221-6

[12] Pankaj R Modak, Prakash B Nangare, Sanjay D Nagrale, Ravindra D Nalawade, Vivek S Chavhan 2012 Stabilization of Black Cotton Soil Using Admixtures *International Journal of Engineering and Innovative Technology* **1** (5) p 1-3

[13] Surendra P Jadhav, R M Damgir 2011 Use of Jute Geo Textile for Strengthening of Sub Grade of Road Work *Innovative Systems Design and Engineering* **2** (4) p 40-8