Construction of Roads in Black Cotton Soil Areas

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Introduction

Four major types of soils met in India cover around 70 to 80 per cent of the total land area. These are alluvial soils, desert sands, red earth and black cotton (BC) soils. BC soils are basically inorganic clays. Black cotton soil covers an area of about 5,20,000 square km in India. It derives its name from its black colour and also from the fact that cotton grows on it very well. The B.C soil has high swelling and shrinkage properties. The soil is hard so long as it is dry but loses its stability almost completely when wet. After drying, the soil shrinks and cracks very badly. Construction of roads in such soil areas has always presented serious problems because of the extremely low bearing capacity of the subgrade when it is wet and also on account of high swelling characteristics during the process of wetting.

BC soils can exert swelling pressure which may range from 50 to 300 kN/m^2 or more. This characteristic of swelling and the swelling pressures of black cotton soils is predominantly attributed to the presence of 'Montmorillonite' clay mineral.

Properties of BC Soils

BC soil deposits can be ascribed to continuous weathering of igneous rocks, mainly of basaltic origin. The soil strata varies in depth from about one to 15 m in depth. The black colour of the soil is presently known to be due to presence of titanium existing in small quantities. The BC soils are highly argillaceous and somewhat calcareous. Such soils have a high percentage of iron oxide, Mg and Ca-Carbonates and organic matter. The clay fraction of BC soil (particles below 0.002 mm) is very rich in silica, sometimes to the extent of 60 to 70 per cent, the remaining being iron and alumina. At many locations, BC soils have appreciable percentage of calcium carbonates which get accumulated in the lower layers of the soil due to leaching and form hard nodules called 'Kankar'. The pH value of these soils varies from 7 to 9. The higher swelling and shrinkage characteristics is due to more sodium (Na) and calcium (Ca) contents in soils.

In India, BC soils have liquid limit values ranging from 50 to 100 per cent and plasticity index ranging from 20 to 65. Hence, BC soils are highly sensitive to moisture changes. The amount of swell generally increases with increase in the plasticity index. Black cotton soils are very hard in dry state and possess high bearing capacity. In summer, it is very common to see shrinkage cracks with hexagonal columnar structure, with vertical cracks as wide as 10mm, extending up to a depth of 3m or more. The swelling potential depends on the type of clay mineral, crystal lattice structure, cation exchange capacity, ability of water absorption, density and water content. The swelling pressure and free swell index tests should be done in accordance with IS 2720 (Part 40) and IS 2720 (Part 41). Expansive soil met within the road site has to be analysed for swelling pressure before deciding the type of treatment. Typical properties of BC soil are given below in Table 1.

Table 1 Typical Geotechnical Properties of BC soil

Sample No.		1	2	3	4
Specific Gravity		2.71	2.70	2.68	2.70
FSI (%)		33	94	124	100
Swelling pressure (kPa)		60	170	200	170
Atterberg's limits	Liquid Limit (%)	53	74	74	80
	Plasticity Index	33	47	45	49
Grain Size Distribution	Gravel (%)	0	0	0	0
	Sand (%)	7	18	3	2
	Silt (%)	74	44	60	58
	Clay (%)	19	38	37	40
IS classification		CH	CH	CH	CH
Modified Proctor test	MDD, kN/m^3	18.3	17.1	17.0	16.0
	OMC, %	16.0	16.5	16.0	16.0
CBR (%)		1.2	0.8	1.3	1.3

Road Pavements in BC Soil Areas

Several investigations over past 50 years have established many reliable techniques for construction of roads in BC soil areas. Brief details of such techniques are given in following paragraphs:

Sand Cushion Method

Several researchers have concluded that sand cushion acts as a effective restraint against swelling of BC soil. IRC 37 suggests that a blanket course of at least 225 mm thickness and composed of coarse/medium sand or non-plastic moorum having PI less than five should be provided on the expansive soil subgrade as a sub-base to serve as an effective intrusion barrier. The blanket course should extend over the entire formation width. The basic advantage of the sand cushion method is its ability to adapt itself to volume changes in the soil. Shri Natarajan after field performance observation of sand blanket course vis-a-vis other types of remedial measures like lime stabilisation, Moorum blanket, etc for BC soil subgrade, concluded as given below:

(a) In-spite of some amount of subgrade intrusion and consequent reduction in effective thickness, specifications incorporating sand blanket courses gave the best performance as compared to others, serving both as an effective filter and capillary cut-off.

(b) Recurring cost on maintenance measures was a minimum with regard to sand blanket courses. The surface provided a good riding quality without cracking up or developing potholes.

(c) The soling stones or the oversize metal making up the sub-base overlying the sand blanket course disturbed the sand layer and penetrated somewhat during placement and rolling. Hence a minimum of 23 cm thickness of sand blanket would seem preferable.

(d) Sand blanket of 23 cm thickness appears to have performed better than 15 cm thick sand blanket course. This can be attributed to intrusion of subgrade soil (BC soil) into sand layer which further reduces the thickness of sand blanket course.

Providing CNS Layer

Replacement by soils with relatively impervious but non swelling in nature, may offset to a great extent, the disadvantages of BC soil subgrade. Katti (1978) developed a technique where by removal of about 1m of expansive soil and replacement by cohesive non-swelling soils (CNS) layer beneath foundations yielded satisfactory results. Katti has successfully adopted it for prevention of heave and resultant cracking of canal beds and linings and recommends it for use in foundations of other infrastructure also. According to Katti cohesive forces of significant magnitude are developed with depth in an expansive soil system during saturation which is responsible for reducing heave and counteracting swelling pressure. The behaviour is mainly attributed to the influence of electrical charges present on the surface of clay particles on the dipolar nature of water molecules, producing absorbed water bonds that give rise to cohesion.

Moorum is a typical example of CNS material. The cohesive bonds develop around the particles at a faster rate than the ingress of water molecules into the interlayer of the expanding lattices of Montmorillonite, thereby reducing heave. The heave of expansive soil underlying a CNS layer reduces exponentially with increase in thickness of the CNS layer and attains a value of no heave around a thickness of 1.0m. IS 9415 suggests following cushion thickness for different swell pressures (Table 2). Similar kind of cushion can be adopted for road works also. IRC 37 suggests the following: There is a definite gain in placing the pavement on a non-expansive cohesive soil cushion of 0.6-1.0 m thickness. It prevents ingress of water in the underlying expansive soil layer, counteracts swelling and secondly even if the underlying expansive soil heaves, the movement will be more uniform and consequently more tolerable. However, where provision of non-expansive buffer layer is not economically feasible, a sand blanket course can be provided.

Table 2 Thickness of CNS Layer Depending on Swelling Pressure

Swelling Pressure of soil kN/m^2	Minimum Thickness of CNS layer required (cm)
50 to 150	75
150 to 300	85
300 to 500	100

As per IS 9415, most moorums of laterite, laterite type and siliceous sandy clays exhibit CNS characteristics, however some moorums may be of swelling type. Unlike swelling soils, they do not exhibit cracking during summer, nor heaving and stickiness during rainy season. Structures constructed on such soil do not exhibit heave though they may sometimes settle. The CNS are generally red, reddish yellow, brown, yellow, white, whitish grey, whitish yellow, green and greenish grey in colour. Although, several soils containing non-expanding type clay mineral exhibit CNS properties, the following range helps in locating such types (Table 3):

Table 3 Properties of CNS Material

Clay Content	15 to 20%
Silt content	30 to 40%
Sand content	30 to 40%
Gravel content	0 to 10%
Liquid limit	Greater than 30%, but less than 50%
Plasticity index	Greater than 15 but less than 30

Fly Ash Cushion

Each one of the above methods has one limitation or the other, in terms of its efficacy or economy. The studies have been carried out using fly ash as a cushioning material. Developments of cohesive bonds in a lime-stabilised fly ash cushion, when stabilized with lime, is expected to produce an environment similar to the one obtained in CNS material following saturation and consequently arrest heave. The results of the study showed a new solution to the problem heave of expansive soil in the form of "Fly ash cushion method." It also solves the problem of fly ash utilisation and disposal to some extent. If at a site containing black cotton soil, the depth of the active zone is 3m, it would be sufficient if 1.5m of expansive clay is removed and replaced with fly ash cushion to get the heave reduced significantly.

Lime Stabilisation

Lime stabilisation has been used successfully on many road projects to minimise swelling of the expansive soil. Generally, 3 to 8 per cent by weight hydrated lime is added to the BC soil, mixed well and then compacted at moisture content slightly higher than OMC. Lime continues to be widely used additive for modification of expansive clays in view of its cost effectiveness. The hydration of Portland cement is a complex pozzolanic reaction that produces a variety of different compounds and gels. The results of mixing cement with clay soil are similar to that of lime. It reduces liquid limit, the plastic index and the potential of volume change, it increases the shrinkage limit and shear strength. For highly plastic clay, it is not effective like lime in stabilization. Addition of 2 to 6% cement content can produce a soil that acts as a semi rigid slab (John). Some investigators have tried and succeeded in minimizing the swelling of expansive soil using chemicals like calcium chloride ($CaCl_2$), calcium sulphate ($CaSo_4$), potassium chloride (KCl), aluminum chloride ($AlCl_3$), etc.

The cement requirement for BC soil stabilisation is always very high (15 to 25 per cent) so it is never advocated alone. By adding suitable proportion of lime to BC soil, and allowing it to react for a day or two, following changes occur in BC soils:

(a) Plasticity index decreases drastically and soil may even become non-plastic. Also soil becomes friable in nature and it becomes easy to pulverise the lumps.

(b) The affinity for water decreases and there are less changes in volume and stability with changes in moisture content.

(c) Soaked CBR value increases.

(d) Lesser shrinkage of BC after compaction.

(e) Cement requirement of lime treated soil is considerably lesser than untreated BC soils.

Two stage stabilisation can be adopted to effectively deal with BC soils. As a first stage, pre-conditioning of BC soil is carried out by using about 2 to 3 per cent of lime. As a result of lime addition, BC soil becomes friable, i.e., easier to pulverise. BC soil is then powdered and remaining percentage of lime is then added along with required water and BC soil is compacted. This process is called two stage stabilisation. In the second stage, instead of lime, cement can also be used.

Lime Fly ash Stabilisation

Pozzolanic industrial wastes like fly ash, slag etc can be used for stabilisation of BC soils. Soil-lime fly ash stabilised layer develops enough strength to be used as a pavement layer. Pozzolanas which are essentially siliceous materials devoid of cementing properties of their own react with lime at ordinary temperature and in the presence of moisture, resulting in the formation of cementitious compounds. Among pozzolanic materials, fly ash has the greatest potential and lime fly ash mixes have been used to stabilise BC soils. The ratio of lime to pozzolana and lime-pozzolana to soil are the important factors determining the strength properties of stabilised soil mix. Usually the ratio between lime and pozzolana varies from 1:1 to 1:9. Increasing the lime pozzolana percentage beyond a certain limit does not bring in commensurate strength gain of the soil. The behaviour of lime-soil and lime-pozzolana soil are identical in many respects. Both reduce the plasticity, increase the strength and reduce volume change in soil and enhance durability.

Moisture Barriers

Swelling and shrinkage of BC soils occur as a result of moisture variations. In case, moisture ingress is prevented, the BC soil would not suffer from swelling and shrinkage. Various techniques like use of geomembrane, polythene sheets, ferrocement, etc have been used with varying degree of success. With great improvement in geosynthetic manufacture and testing process, geomembrane is emerging as an effective alternative.

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