STABILIZATION OF SUB GRADE SOIL BY USING DIFFERENT MATERIALS WITH NEW ASPHALT TECHNIQUES AND FLEXIBLE PAVEMENTS

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ABSTRACT

Highway and pavement design plays an important role in the DPR projects. The satisfactory performance of the pavement will result in higher savings in terms of vehicle operating costs and travel time, which has a bearing on the overall economic feasibility of the project. This paper discusses about the stabilization of sub grade soil by using different materials bitumen, Cement, desirable sand and black cotton soil with new asphalt techniques and flexible pavements methods that are traditionally being followed and examines the "Californian bearing ratio method by flexible pavements". The stabilization in sub grade soil strength is to growth of the pavement to conducting different materials. This study is prepare to use of new asphalt techniques and flexible pavements.

Flexible pavement are preferred over cement concrete roads as they have a great advantage that these can be strengthened and improved in stages with the growth of traffic and also their surfaces can be milled and recycled for rehabilitation. The flexible pavements are less expensive also with regard to initial investment and maintenance. It can be done by drawing comparisons with the standard way and practical way.

Keywords – Soil Stabilization, New Techniques in Pavement, Geometric design of pavement**.**

1. INTRODUCTION

1.1 GENERAL

Expansive soils are found in arid and semi arid regions of the world and, hot climate and poor drainage conditions are usually associated with the formation of these soils. In INDIA, these soils are generally called as black cotton soils and cover about 20% of the total land area. The primary problem that arises with regard to expansive soils is that deformations are significantly greater than the elastic deformations and they cannot be predicted by the classical elastic or plastic theory..

1.2 Classification of Indian roads as per IRC:

In Nagpur road classification, all roads were classified as follows:

1) National highways
2) State highways
3) District roads
4) Major district roads
5) Other district roads
6) Village roads.

1.2.1 National highways:

They are main highways running through the length and breadth of India connecting major ports, foreign highways, capitals of large states and large industrial and tourist centers including roads required for strategic movements, they are financed by the central government.

- All the national highways are assigned the respective numbers.
- For example the highway connecting Delhi-Ambala-Amritsar is denoted as NH-1 (Delhi-Amritsar), where as a bifurcation of this highway beyond Fullundar to Srinagar and Uri is denoted as NH-1 A.

1.2.2 State highways:

They are the arterial roads of a state, connecting up with the national highways of adjacent states, district head quarters and important cities within the state, they also serve as main arteries to and from district roads. They are financed by the State Government Roads and Buildings department of the state Government constructs and maintains these roads. Total length of all State highways in the country is 1, 37,119Kms.

1.2.3 District roads:

These are the roads with in a district. They are financed by Zillaparishads with the helpofngrants given by the State government.

(a) Major district roads:

Important roads with in a district serving areas of production and markets, connecting those with each other or with the major highways. India has a total of 4, 70,000kms.ofmajor district roads

(b) Other district roads:

Roads serving rural areas of production and providing them with outlet to market centers or other important.

(c) Village roads:

They connect villages with each other and to nearest district roads highway of railways. They are financed by panchayats with the help of Zillaparishads and state government.

1.3 TYPES OF PAVEMENT STRUCTURE

Based on the structural behavior, pavement are generally classified into two categories

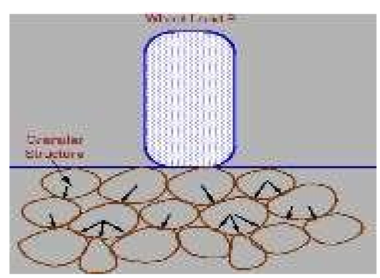
1. Flexible pavement
2. Rigid pavement

The cement concrete pavement slab can very well serve as a wearing surface as well an effective base course. Therefore usually the rigid pavement structure consists of a cement concrete slab, below which a granular base or sub-base course may be provided.

1.4 Flexible Pavements:

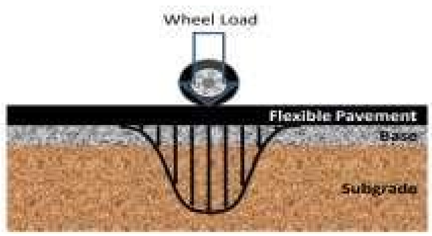
Flexible pavements are those having negligible flexural strength and are flexible in structural actions under the loads. The term flexible is associated with those pavements which reflect the formation of sub grade and of subsequent layers on to the surface. The design of flexible pavement is based on load distributing characteristics of the component layers.

Flexible pavements will transmit wheel load stresses to the lower layers by grain-to-grain transfer through the points of contact in the granular structure.



Load transfer in granular structure

Flexible pavement layers reflect the deformation of the lower layers on to the surface layer. In the case of flexible pavement, the design is based on overall performance of flexible pavement, and the stresses produced should be kept well below the allowable stresses of each pavement layer.



Load applying on a flexible pavement

The lowest layer is prepared surface consisting of the local soil itself, called the sub grade. Interpretation and recording

C.B.R. of specimen at 2.5 mm penetration

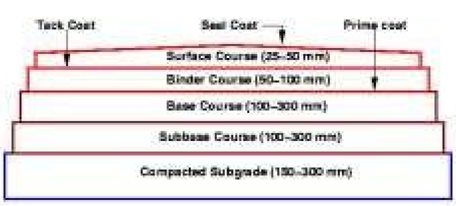
C.B.R. of specimen at 5.0 mm penetration

1.5 Typical layers of a flexible pavement

Typical layers of a conventional flexible pavement includes seal coat, surface course, tack coat, binder course, prime coat, base course, sub-base course, compacted sub-grade, and natural sub-grade (Figure).

A typical flexible pavement consists of four components namely:

1. Soil sub-grade
2. Sub base
3. Base course Surface course
4. Pavement surface



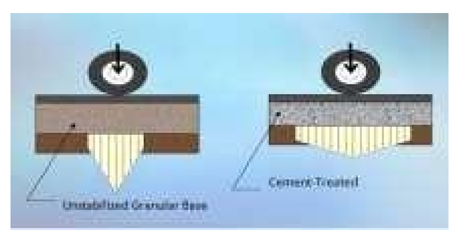
Typical cross section of a flexible pavement

1.6 Soil Sub grade And Its Construction:

The soil sub grade is a layer of natural soil prepared to receive the layers of pavements materials placed over it. The loads on the pavement are ultimately received by the soil sub grade for dispersion to the earth mass. It is essential that at no time the soil sub grade is overstressed.

Shows a sub grade of NH-1

The stabilization of naturally-occurring or native soil has been performed by millennia. The Mesopotamians and Romans separately discovered that it was possible to improve the ability of pathways to carry traffic by mixing the weak soils with a stabilizing agent like pulverized lime stone or calcium. This was the first chemical stabilization of weak soils to improve their load-carrying ability.



Shows a Load Distribution

1.7 Materials and general requirements Physical requirements:

The materials used in embankment, sub grades, earthen shoulders and miscellaneous backfills shall be soil, moorum, gravel, mixture of these of any other materials approved by the Engineer. Such ingredients likely to deteriorate of affect the stability of the embankment/sub grade.

1.8 The following types of materials shall be considered unsuitable for embankment:

Material from swamps, marches and bogs peat, log, stump and perishable materials; any soil that classifies as OL,OI,OH or Pt in accordance with IS:1498; materials susceptible to spontaneous combustion; materials in a frozen conditions; clay having liquid limit exceeding 70 and plasticity index 45 materials with salts resulting in the embankment.

1.9 NEW TECHNIQUES IN PAVEMENT

- **ASPHALT CHIP SEALS**

Chip seals are applied in a three-part process. The asphalt emulsion binder is first sprayed onto the pavement. This process is more appropriate for use on roads than on parking lots. Service life is usually 5 to 7 years.

- **ASPHALT EMULSION SEALCOATS**

Emulsion sealcoats are the familiar pre-mixed products often seen in shopping center parking lots or on driveways. Emulsion sealcoats are brushed on over existing pavements to seal small cracks and protect the surface. When used properly they're expected to last 3 to 5 years.

- **ASPHALT SLURRY SEALS**

Slurry seals combine an asphalt emulsion with graded aggregate (rocks of special, even sizes). This mixture is then applied to existing pavement using a squeegee-like drag. Slurry seals are expected to last 3 to 5 years.

- **ASPHALT SURFACE COATINGS**

Asphalt surface coatings are painted or sprayed directly over clean asphalt. These coatings are decorative, while also serving to protect the asphalt underneath. They come in many colors, but the lightest colors have the highest solar reflectivity and stay coolest.

- **PAVEMENT TEXTURING**

Pavement texturing is a process that uses standard asphalt to produce a decorative pavement in a variety of colors and patterns. These pavements are used in street paving, traffic calming, pedestrian areas, medians & boulevards, parking lots, playgrounds, and other applications.

- **ROLLER COMPACTED CONCRETE AND SOIL-CEMENT PAVEMENT**

Roller Compacted Concrete (RCC) combines cement with natural or graded aggregate to create a pavement suitable for heavy loads at low speeds. Soil-cement pavements combine cement with sand or alluvium material to construct pavement suitable for low-speed, low volume uses like hiking trails and bike paths.

1.10 Geometric design:

Geometric design is defined as the design or proportioning of the visible elements of the street or highway. The geometry of the roadway is of central importance since it provides the framework for the design of other highway elements. In addition, the geometric design establishes the basic nature and quality of the vehicle path, which has a primary effect upon the overall safety characteristics of the street or highway.

1.11 Objectives:

The major objective in geometric design is to establish a vehicle path and environment providing a reasonable margin of safety accommodation for the motorist, transit, bicyclist, and pedestrian under the expected operating conditions and speed. It is recognized that Florida's design driver is aging and tourism is our major industry.

The achievement of this objective may be realized by meeting certain specific objectives, which include the following:

- Provide the simplest geometry attainable, consistent with the physical constraints.
- Provide a design that has a reasonable and consistent margin of Safety accommodation at the expected operating speed.
- Provide a design that is safe at with consideration for night and under adverse weather conditions.
- Provide a facility that is adequate for the expected traffic conditions and pedestrian, bicyclist and transit needs.

1.12 Scope of the work:

In our project we select the National highway 9 which is to be construct from Vijayawada to machilipatnam of a length of 64.11kms.

The main components that will be include in our project are traffic volume capacity, highway surveys, highway alignment, road classification, pavement surface characteristics, cross-section elements including cross slope, sight distance elements and the horizontal alignment which includes features like super elevation, transition curve, extra widening and set back distance, sight distance and the length of curves.

2. LITERATURE REVIEW

Khan (1998) describes the Group Index Method and California Bearing Ratio Method for design of flexible pavements. In Group Index Method the thickness is obtained by first determining the Group Index of soil. In California Bearing Ratio Method, the curves are plotted between California Bearing Ratio Percent and depth of construction.

Punmia et. al (2005) have reported stresses in homogeneous mass; elastic deformation under circular load and Burmister analysis for flexible pavement. Charts for vertical deflections have been developed. The design curves by Group Index Method and California Bearing Ratio Method have been developed. In Group Index Method, the curves are plotted between Group Index and thickness. In California Bearing Ratio Method curves are plotted between thickness of construction and California Bearing Ratio.

3. MATERIALS

3.1 MATERIALS

The materials used shall comply with the following requirements:

We are using these materials Bitumen, Cement, Black Cotton Soil, Sand and Fly Ash Also Used to Stabilization for the Soil.

WATER

Water used in mixing or curing shall be clean and free from injurious amounts of oil, salt, or other deleterious substances. Where the source of water is relatively shallow, it shall be maintained at such a depth and the intake so enclosed as to exclude grass, vegetable matter, or other foreign materials.

CEMENT

Fly ash may be used as a partial replacement for the cement. Replacement amounts, not exceeding 25% by weight, shall be determined through trial batch investigations using the specific materials proposed for the project. Mixtures with fly ash shall meet the same requirements as mixtures without fly ash.

3.2 CONSTRUCTION REQUIREMENTS

Sufficient equipment shall be available so that the work may proceed in proper sequence to completion without unnecessary delay. Equipment, tools, and machinery used shall be maintained in a satisfactory working condition.

3.3 CENTRAL PLANT METHOD

When a central plant is used, the soil aggregate, cement, and water shall be mixed in a pug mill either of the batch or continuous flow type. The plant shall be equipped with feeding and metering devices that will add the soil aggregate, cement, and water into the mixer in accurately proportioned amounts as determined by the laboratory design. Aggregate and cement shall be dry-mixed sufficiently to prevent cement balls from forming when water is added. Mixing shall continue until a uniform mixture of aggregate, cement, and water has been obtained. The mixture shall be hauled to the roadway in trucks equipped with protective covers. Immediately before spreading the mixture, the sub-grade or foundation course shall be moistened and kept moist, but not excessively wet, until covered by the mixture. The mixture shall be placed on the roadbed in a uniform layer by an approved spreader or spreaders. No more than 60 minutes shall elapse between adjacent spreader runs and not more than 60 minutes shall elapse between the time of mixing and the beginning of compaction.

3.4 COMPACTION AND SURFACE FINISH

The moisture content of the mixture during compaction shall not vary more than ±5% from the optimum moisture. The surface of the treated roadway shall be reshaped to the required lines, grade, and cross section after the mixture has been compacted. It shall be scarified lightly to loosen any imprints left by the compacting or shaping equipment and rolled thoroughly. The operation of final rolling shall include the use of pneumatic tired rollers.

3.5 JOINTS

As soon as final compaction and finishing of a section has been completed, the base shall be cut back perpendicular to the centre line to a point where uniform cement content with proper density has been attained and where the vertical face conforms to the typical section shown on the plans. When the road mix method is used, a header shall be placed against the vertical face of the finished section and securely staked in place.

3.6 SURFACE TEST

The finished surface of the treated base course shall conform to the general surface provided for by the plans. It shall not vary more than 6 mm (¼") from a 3 m (10') straightedge applied to the surface parallel to the centre line of the roadway, nor more than 12 mm (½") from a template conforming to the cross section shown on the plans. Excess material shall be disposed of as directed.

3.7 PROTECTION AND COVER

Finished portions of the roadway adjacent to construction that is travelled by equipment used in constructing an adjoining section shall be protected by means satisfactory to the Engineer. If earth covering is used on fresh bases, straw, hay, building paper or similar material shall be placed under the earth so that the covering may be removed without damage to the base.

3.8 USE OF FLY ASH IN CONCRETE

Fly ash is one of the residues generated in combustion, and comprises the fine particles that rise with the flue gases. Ash which does not rise is termed bottom ash. In an industrial context, fly ash usually refers to ash produced during combustion of coal. Fly ash is generally captured by electrostatic precipitators or other particle filtration equipments before the flue gases reach the chimneys of coal-fired power plants, and together with bottom ash removed from the bottom of the furnace is in this case jointly known as coal ash.

Shows a Fly Ash in Concrete

3.9 Stabilization For Sub Grade Layers:

The stabilization of naturally-occurring or native soil has been performed by millennia. The Mesopotamians and Romans separately discovered that it was possible to improve the ability of pathways to carry traffic by mixing the weak soils with a stabilizing agent like pulverized lime stone or calcium. This was the first chemical stabilization of weak soils to improve their load-carrying ability.

3.9.1 STABILIZATION WITH BITUMEN

The basic principles in bituminous stabilization are water proofing and binding. By water proofing the inherent strength and other properties of the soil could be retained. In case of the cohesion less soils the binding action is also important. Generally both binding and water proofing actions are provided to soil.

Shows Soil stabilization with bitumen

3.9.2 FLY ASH IN SOIL STABILIZATION

Soil stabilization is the permanent physical and chemical alteration of soils to enhance their physical properties. Stabilization can increase the shear strength of a soil and/or control the shrink-swell properties of a soil, thus improving the load bearing capacity of a sub-grade to support pavements and foundations. Stabilization can be used to treat a wide range of sub-grade materials from expansive clays to granular materials.

3.9.3 Stabilization of Black Cotton Soil

Modification of black cotton soils by chemical admixtures is a common method for stabilizing the swell-shrink tendency of expansive soils. Advantages of chemical stabilization are that they reduce the swell-shrink tendency of the expansive soils and also render the soils less plastic. Among the chemical stabilization methods for expansive soils, lime stabilization is most widely adopted method for improving the swell-shrink characteristics of expansive soils.

3.9.4 STABILIZATION OF DESERT SAND

There are large deposits of the desert sand in the regions of Rajasthan and other places in India. It is really a great problem to construct roads across the desert mainly because of non-availability of other suitable materials. There is also acute scarcity of water in the desert regions.

3.9.5 STABILIZATION WITH CEMENT

CTB (CEMENT TREATED BASE)

The advantages of cement stabilization are several:

1. Cement stabilization increases the base material strength and stiffness, which reduces deflection due to the traffic loads. This delays surface distresses such as fatigue, cracking and extends pavement structure life.

2. Cement stabilization provides uniform and strong support, which results in reduced stresses to the sub-grade. Testing indicates a thinner cement-stabilized layer can reduce stresses more effectively than a thicker un-stabilized layer of aggregate. This reduces sub-grade failure, pot-hole formation and rough pavement surface.

3. Cement stabilized base has greater moisture resistance to keep water out; this maintains the higher strength of the structure.

4. Cement stabilization reduces the potential for pumping of sub-grade fines.

5. Cement stabilized base spread loads and reduces sub-grade stress.

3.9.6 WHITE-TOPPING

The white-topping construction process consists of four steps: 1) coring the existing asphalt to determine its depth, type and condition, 2) preparing the road surface by water or abrasive blasting, or milling and cleaning, 3) placing the concrete, and 4) finishing and texturing the surface, and curing and sawing its joints. The proper joint spacing is critical to control cracking of the concrete surface.

4. EXPERIMANTAL PROCEDURESA

FLEXIBLE PAVEMENT DETAILS:

4.1 TRAFFIC:

The recommended method considers traffic in terms of the cumulative number of standard axles (8160 kg) to be carried by the pavement during the design file. For estimating design traffic, the following information is needed:

(i) Initial traffic after construction in terms of number of commercial vehicles per day (CVPD)

(ii) Traffic growth rate during the design life in percentage

(iii) Design life in number of years

(iv) Vehicle damage factor (VDF)

Distribution of commercial traffic over the carriageway

4.2 TRAFFIC GROWTH RATE:

Traffic growth rates should be estimated:

(i) By studying the past trends of traffic growth and by establishing econometric models, as per the procedure outlined in IRC: 108 “guidelines for traffic prediction on rural highways”.

(ii) In adequate data is not available, it is recommended that an average growth of 7.5% may be adopted.

4.3 DESIGN LIFE:

(i) For the design of pavement, the design life is defined in terms of the cumulative number of standard axles that can be carried before strengthening of the pavement is necessary.

(ii) It is recommended that pavements for National Highway and State Highway should be designed for a life of 15 years. Expressways and urban roads may be designed for a longer life of 20 years. For other categories of roads, a design life of 10 to 15 years may be adopted.

(iii) Very often it is not possible to provide the full thickness of pavement right at the time of initial construction techniques should be resorted to in such cases.

4.4 VEHICLE DAMAGE FACTOR:

The vehicle damage factor (VDF) is a multiplier to cover the number of commercial vehicles of different axle loads, axle configuration to the number of standard axle load repetitions. It is defined as equivalent number of standard axles per commercial vehicles.

Indicative VDF Values

Initial traffic volume in terms of number of commercial vehicles per day	Terrain	
	Rolling/Plain	Hilly
0-150	1.5	0.5
150-1500	3.5	1.5
More than 1500	4.5	2.5

4.5 DISTRIBUTION OF COMMERCIAL TRAFFIC OVER THE CARRIAGEWAY:

A realistic assessment of distribution of commercial; traffic by direction and by lane is necessary as it directly affects the total equivalent standard axle load application used in the design. In the absence of adequate and conclusive data for Indian conditions, it is recommended that for the time being the following distribution may be assumed for design until more reliable data on commercial vehicles on the carriage Lanes Are Available.

4.6 STANDARDS FOR MULTIPLE LANE ROADS:

- Single Lane Roads
- Two-Lane Single Carriageway Roads
- Three Lane Roads
- Four-Lane Single Carriageway Roads
- Six Lane Or Wider Roads
- Dual Carriageway Roads

4.7 PRESTRESSED CONCRETE PAVEMENT

The prestressing technique has been applied to the highway pavements in recent years. The prestressed pavement can be built in continuous length up to 120 m without joints. Elimination of joints without inducing cracks in the pavement could be considered advantageous, in view of the maintenance problems associated with the joints.

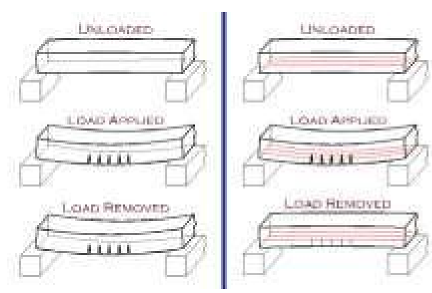
Following are few observations for the design:

a) Length: A length up to about 120 m can be prestressed for the pavement.

b) Width: A width of 3.6 m for prestressed pavement is desirable and a longitudinal a joint therefore should be provided.

c) Thickness: Because of the need to provide a required cover for tendons, the minimum recommended thickness is 15 cm.

d) Stress magnitude: A minimum value of 22 kg/cm^2 of prestress is recommended for 120 m long prestressed pavement slabs. A transverse prestress if required should be of 3 to 4 kg/cm^2.



Shows a Pre-stressing Concrete Process

5. EXPERIMENTAL PROCEDURES

5.1 LABORATORYEXPERIMENTATION

Atterberg Limits

Liquid Limit

Plastic Limit

Shrinkage limit

Compaction Properties

Differential Free Swell (DFS

Strength Tests

5.2 CALIFORNIA BEARING RATIO TEST

The California bearing ratio tests (as per IS: 2720 (part-16)-1979) were conducted on all the combinations listed in table. . At the end of the curing period (all the samples were cured for 3 days and later soaked for 4 days).

Showing the California bearing apparatus

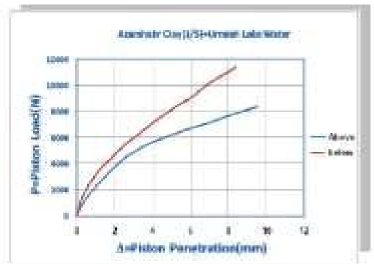
5.2.1 Sample Preparation

Both treated and untreated samples were prepared by compacting different mixes to the maximum dry density of the soil. The initial moisture content for these samples was maintained at optimum moisture content of the untreated soil. The amount of chemical to be added to the amount of water was arrived at based on the optimum moisture content of the natural soil and the chemical solution was prepared. This solution was added to the dry soil and the mixture was thoroughly mixed.

Preparation of Specimen

5.2.2 CBR TEST

The California bearing ratio (CBR) is a penetration test for evaluation of the mechanical strength of road sub-grades and base-courses. To determine the California bearing ratio by conducting a load penetration test in the laboratory. The California bearing ratio test is penetration test meant for the evaluation of sub grade strength of roads and pavements. The results obtained by these tests are used with the empirical curves to determine the thickness of pavement and its component layers. This is the most widely used method for the design of flexible pavement.



Graph for cbr test

5.2.3 California bearing ratio test:

It is the ratio of force per unit area required to penetrate a soil mass with standard circular piston at the rate of 1.25 mm/min. to that required for the corresponding penetration of a standard material. The California Bearing Ratio Test (CBR Test) is a penetration test developed by California State Highway Department (U.S.A.) for evaluating the bearing capacity of sub grade soil for design of flexible pavement.

5.2.4 Apparatus Used:

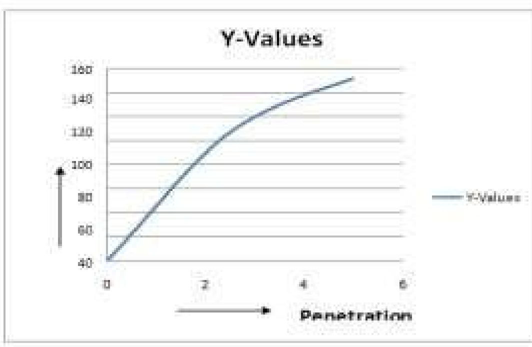
- Mould
- Steel Cutting collar
- Spacer Disc
- Surcharge weight
- Dial gauges
- IS Sieves
- Penetration Plunger
- Loading Machine

5.2.5 Test procedure:

A highway is a public road, especially a major road connecting two or more destinations. Any interconnected set of highways can be variously referred to as a "highway system", a "highway network", or a "highway transportation system”. The history of highway engineering gives us an idea about the roads of ancient times. Roads in Rome were constructed in a large scale and it radiated in many directions helping them in military operations. Thus they are considered to be pioneers in road construction.

CBR Readings

S.no	Dial gauge reading (mm)	Penetration (2)=(1)×0.01	Proving ring reading (3)	Corrected load (Kg)	Load on plunger (3)×1kg/div
1.	0	0.0	0	0	0
2.	50	0.5	26	26	26
3.	100	1.0	57	57	57
4.	150	1.5	76	76	76
5.	200	2.0	96	96	96
6.	250	2.5	107	107	107
7.	300	3.0	119	119	119
8.	350	3.5	128	128	128
9.	400	4.0	137	137	137
10.	450	4.5	145	145	145
11.	500	5.0	152	152	152



Graph Relation between penetration vs load

5.2.6 Uses and significance of California Bearing Ratio Test:

The CBR test is one of the most commonly used methods to evaluate the strength of a sub grade soil, sub base, and base course material for design of thickness for highways and airfield pavement.

5.2.7 EFFECT OF ADDITIVES (CHEMICALS) ON CBR

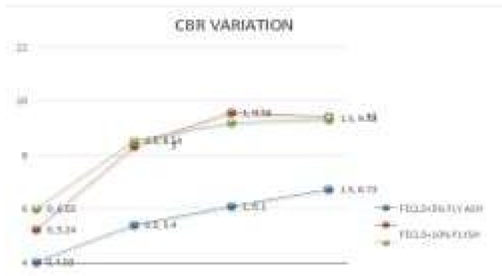
Fig. shows the variation of CBR of stabilized expansive clay with addition of different percentages of chemicals. It is can be seen that the CBR is increasing with increasing percentage of chemical added to the expansive soil. Significant increase in CBR is recorded in stabilized expansive clay with addition of chemical up to 1%, beyond this percentage the increase in CBR is marginal. The increase in CBR values of stabilized expansive clay with addition of 1% chemical are 80%, 99% and 116% for KCl, $CaCl_2$ and $FeCl_3$ respectively compared with the expansive clay.

5.2.8 EFFECT OF ADDITIVES (FeCl3 and Fly Ash) and ON CALIFORNIA BEARING RATIO

Soaked CBR test was carried on a specimen prepared at Modified Proctors maximum dry density and optimum water content. Different values of Soaked CBR are shown in Table 4.4 for different compositions of chemical. Fig 4.11 depicts the variation of soaked CBR values with increasing percentages of chemical $FeCl_3$.

Effect of Chemical with fly ash on CBR of Expansive Soil

Chemical	Fly ash	CBR Values
		$FeCl_3$
0	0%	2
0.5	0%	4.85
1	0%	5.25
1.5	0%	5.68
0	5%	4.03
0.5	5%	5.4
1	5%	6.1
1.5	5%	6.73
0	10%	5.24
0.5	10%	8.34
1	10%	9.58
1.5	10%	9.41
0	15%	6.02
0.5	15%	8.54
1	15%	9.2
1.5	15%	9.32



Graph for CBR expansive soil

6. CONCLUSIONS

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

1. From the laboratory studies, it is observed that the percentage reduction in CBR values are of the order of 1% addition of KCL, $CACl_2$, $FECl_3$ respectively and the CBR values Increased respectively.
2. Optimum and higher values observed from ferric chloride
3. CBR value of the untreated expansive soil observed as 2.0 only, but with the treatment of $CACl_2$, KCL and $FECl_3$ values reached to 3.9, 4.25 and 5.25 to the initial value. But further addition of fly ash up to 10%, the CBR values reached to 8.87, 9.58 respectively.
4. Based on results and as per IRC 2001, the pavement thickness 540mm at CBR 9.58%.

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