ANALYSIS OF CONCRETE PAVEMENT ON EXPANSIVE SOIL

A Thesis
Submitted in Fulfilment of the Requirements for The
award of the Degree of
MASTER OF TECHNOLOGY

In
GEOTECHNICAL
ENGINEERING

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CANDIDATE'S DECLARATION

I do hereby certify that the work presented is the report entitled "**ANALYSIS OF CONCRETE PAVEMENT ON EXPANSIVE SOIL"** in the partial fulfilment of the requirements for the award of the degree of "Master Of Technology in Geotechnical Engineering" submitted in the department of Civil Engineering, Delhi Technological University, is an authentic record of our own work carried from Jan 2018 to June 2018 under the supervision Prof Kongan Aryan, Department of Civil Engineering.

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Date- 30/6/2018

CERTIFICATE

I hereby certify that the Project Dissertation titled “ANALYSIS OF CONCRETE PAVEMENT ON EXPANSIVE SOIL” which is submitted by Ankur Chaudhary, 2K16/GTE/05 (Department of civil engineering), Delhi Technological University, Delhi in partial fulfillment of the requirement for the award of the degree of Master of Technology, is record of the project work carried out by the students under y supervision. To the best of my knowledge this work has not been submitted in part or full for any Degree or Diploma to the University or elsewhere.

Place - Rohini, Delhi

Date -

Prof. KONGAN ARYAN

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ABSTRACT

Analysis of concrete pavement on expansive soil susceptible to expansion and shrinkage with chance of different moisture content is a constant source of trouble in the design and construction of foundations such soils popularly known as black cotton soil and collapsible soil occur extensively in countries like India. In India there are various states like Maharashtra, Madhya Pradesh, Andhra Pradesh and Tamil Nadu.

Expansive soils are susceptible to volume change, and thus for the construction of rigid pavement as well flexible pavements over them, they need to be stabilized to increase load carrying capacity without undergoing excessive volume change, which can be catastrophic in nature.

Economy has always been a top consideration factor before carrying out construction of any kind. Achieving higher values of the strength parameters, with a controlled increase in cost of the foreign material leading to an overall decrease in the net construction cost, are always a sign of development.

To improve the mechanical properties of soils, a variety of materials are used for reinforcement e.g. metallic elements, geo synthetics etc. the products generally have a long life and do not undergo biological degradation, but are liable to create environmental problems from their manufacture till the end use. In effecting this use of biodegradable natural fibers is gaining popularity.

Now days, waste material are produces in abundance. These waste materials can be utilized in the stabilization of soils. Waste materials like fly ash, plastic waste, slag comes from iron ore industries and other manufacturing plants. Various researches have been conducted on soil stabilization using these foreign materials. In the present study, the expansive soil is treated using mixtures of lime and fly ash in different proportion to achieve the best mixture. In our study mixtures of treated are tested for liquid limit, plastic limit, optimum moisture content, maximum dry density, free swell index and unconfined compressive strength.

Soil sub-grade. Rigid pavements are constructed of Portland cement concrete. The first concrete pavement was built in Bellefontaine, Ohio in 1893.they consist of three layers i.e. surface layer, base layer and the sub grade.

The rigid pavements have high flexural strength and can resist very high tensile stresses. Rigid pavements possess note worthy flexural stiffness or flexural rigidity.

These pavements transfer load through slab action but not grain to grain transfer as in case of flexural pavements. These consist of three layers namely-cement concrete slab base course

They are made of Portland cement concrete either plain, reinforced or pre –stressed. The plain cement concrete are expected to take up about 40kg/cm^2 flexural stress. These are designed using elastic theory, assuming pavement as an elastic plate resting over elastic or a viscous foundation.

Expansive soils present problems to engineers in the construction of durable roads. The

two main concerns are shrinking, swelling of clays and changes in material properties under a range of moisture conditions. Volume changes in expansive soil can be signification and occur as the moisture content changes. Low volume roads constructed on clay sub grades are a particular challenge to engineers because the volumetric changes cause instability of the road, resulting in an uneven pavement surface, detrimental cracking and ultimately, premature deterioration and replacement. However, as the moisture increases, the plasticity of the clay increases and strength decreases. Hence, significant maintenance or premature road replacement would be often necessary.

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LIST OF SYMBOLS AND ABBREVATIONS

AASHTO	American Association of State Highway and Transportation officials
ALS	Axle Load Survey
ADT	Average Daily Traffic
BC	Bituminous Concrete
CBTM	Concrete Beam Testing Machine
CVC	Classified Volume County
DBM	Dense Bituminous Macadam
DWS	During Winter And Summer
ESP	Electrostatic Precipitator
FHWA	Federal Highway Administration
FSIT	Free Swell Index Test
IRC	Indian Road Congress
MORTH	Ministry Of Road Transport and Highways
NCHRP	National Highway Research Programme (USA)
OMC	Optimum Moisture Content
PQC	Pavement Quality Concrete
SDBC	Semi Dense Bituminous Concrete
TWT	Thin White Topping

UWT	Ultra Thin White Topping
WBM	Water Bound Macadam
WMM	Wet Mix Macadam
UCS	Unconfined Compressive Strength
USS	Unconfined Strength of Swelling Soil

CHAPTER 1

INTRODUCTION

1.1 Expansive Soil

Soils which in unsaturated condition can high values of load applied on them with undergoing large changes in volume but collapses totally when fully saturated are known as expansive soil and expansive soil occur extensively in countries like India. Expansive soils are susceptible to volume change, and thus for the construction of rigid pavement as well flexible pavements over them, they need to be stabilized to increase load carrying capacity without undergoing excessive volume change, which can be catastrophic in nature. The soil particles in this case, can be separated by any mechanical methods such as agitating with water. The particles of solid can also contain some organic matter. Soils deposits present in nature exist in totally erratic manner giving rise to thus an infinite number of possible combinations which obviously will have different effects on the strength of the soil and the procedures to make it purposeful.. In case of coarse grained soil, the mineralogical composition of the grain hardly affects the engineering properties of the soils perhaps the grain to grain friction is influenced to a degree. Is such soils, inter particle forces other than those due to gravity are of no consequence, but the finer particles, the more significant becomes the forces associated with the surface area of the grains. The chemical character of the individual grain assumes importance especially when the surface area is large related to the size of the grain - a condition which is associated with the fine grained soil. Thus, inter-particle attraction holding the grain together becomes increasingly important as the size decreases. The soil structure means the mode of arrangement of soil particles related to each other and the forces that are acting between soil particles to hold them together in their positions. The concept is further extended to include the mineralogical composition of the grains, the electrical properties of the particle surface, the physical characteristics, ionic composition of pore water, the interactions among the soil particles, pore water and the adsorption complex.

It becomes very important for the engineers to find the means of improving soil rather than replacing the unusable soil at the construction site. Soil stabilization was earlier used but then because of the obsolete methods and also because of presence of improper technique, the method of soil stabilization gradually reduced its charm. In present times, since there is an increase in the need for the infrastructure, fuels and raw materials, the method of stabilizing the soil has begun to take a new form. With the presence of improved and furnished research, equipments and raw materials, it has emerged as the most popular, in demand and price-effective methods for improvement of soil. Soil is the indispensable element of this nature. It is attached to everyone in one or another way. All of the basic needs of life, whether it is related with food, clothes or shelter, have been fulfilled by this soil .Without the soil it is just nearly impossible to give a thought to life on this planet. The word soil in the term “soil engineering” is meant to be an unconsolidated material which is composed primarily of solid particles generated due to mechanical disintegration of rocks.

Objective of Study:

To achieve the following objective the soil is mixed with fly ash and lime as these are considered to enhance properties of soil. Liquid limit test, plastic limit test, unconfined compressive test and hydrometer test are conducted on untreated and treated soil. Study of variation in bearing capacity liquidity, plastic behaviour and compaction behaviour

- Variation of Atterberg limit with different soil proportion.
- Improvement of compressive strength on addition of lime and fly ash.
- Effect of fly ash and lime on maximum dry density.
- Variation of soil's optimum moisture content at different fly ash and lime content.
- Variation of UCS value with different content of lime and fly ash in black cotton soil.
- Variation of free swell index with different proportion of fly ash and lime

CHAPTER-2

LITERATURE REVIEW

2.1 Soil stabilization

The construction of highway requires the soil to behave in almost similar manner under various adverse conditions. However not all soil suitable for this purpose Since the soil in such a large amount that it cannot entirely replaced with another ideal soil, so the only option left to somehow stabilize the soil by suitable methods so that it can be purposely made ideal for the construction of highway or any other structure. Following various types of methods are used for soil stabilization.

a. Mechanical methods

The most common mechanical method for soil stabilization is compaction of soil with rollers and vibrators used specifically for different soils e.g vibratory rollers are most suitable for granular soil and sheep foot roller is suitable for cohesive soils. But the extent of stabilization of these soils by mechanical method is limited. To compact the soil and to achieve maximum dry density, the soils are compacted at laboratory determine optimum moisture content

Fig 2.1 Various types of mechanical compactors a.) Vibratory roller b.) Smooth wheel roller c.) Sheep foot roller d.) Pneumatic tyre roller

b. Chemical method

These methods of soil stabilization includes mixing of various industrial waste like fly ash, slag waste and other pozzolanic materials like lime and cement to enhance the volume change and pressure resisting characteristics and make the soil suitable for constructing structure upon them. In the present case the soil is stabilized using fly ash and lime. The fly ash and lime are mixed with soil in plenty of number of proportion and it is tested for index properties, unconfined compressive strength value and proctor values to get the best proportion of stabilized soil.

Fig.2.2 Chemical stabilisation of soil

2.1.2 Advantage and need of stabilization

The pressure resisting of soil is dependent on the cohesion between soil particles in case of cohesive soil. The stabilization of soil increases the shear strength. The volume change characteristics are greatly reduce which is important from the safety point of view of structure as excessive settlement can lead to permanent damage in structure. The greatest advantage of chemical method over mechanical method is cheaper, convenient and uses waste material from industry which also helps in recycling. The soil stabilization using admixtures is done from very long time since it is locally available. By using of soil stabilization we can improve the overall properties of soil to make it suitable for the construction of any structure. Various researchers have used fly ash and lime separately to stabilize the soil in the present study both are used in proportion to arrive at a proper conclusion. The fly ash brought from nearby industry while the lime was purchased from nearby shop. It is proven by various researchers that stabilization of soil by chemical and mechanical method is very important to build expansive structure.

2.2 Soil properties

2.2.1 Atterberg limit

a. Liquid limit

The minimum water content at soil offers a resistance to flow against applied shear stress. It is also defined as the water content at which soil requires exactly 25 number of blows on Casagrande's apparatus to close the groove of 12mm. ASTM tool in Casagrande's apparatus is used for soils with low plasticity. Soil passing 425 micron sieve is used to determine liquid limit in casagrande's apparatus.

b. Plastic limit

It is the water content at which the behaviour of soil shifts from liquid to plastic. It is moisture content at which soil of diameter 3mm starts to crumble when rolled in thread. Soil passing 425 micron sieve is used to determine plastic limit.

c. Shrinkage limit

It is boundary moisture content after which further reduction does not leads to decrease in overall volume. It is determined in laboratory using oven. For cohesive soil either paraffin coating or mercury displacement method is used instead of water displacement method to determine volume of oven dried soil.

d. Plasticity index

It is measure of soil plasticity. It is a range of water content in which soil behaves in plastic manner. Mathematically it is the numerical difference between liquid limit and plastic limit.

e. Shrinkage ratio

It is the change in volume expressed as percentage of dry volume per unit change in the corresponding water content where both water content are greater than shrinkage limit. Mathematically it is the ratio of dry unit weight of soil to the unit weight of water

2.2.2 Specific gravity

Specific gravity of grain is the mathematical ratio of weight of solids to the weight of water of same volume. Specific gravity of mass/apparent is the bulk weight of soil to the weight of water same volume. It is determine by using pycnometer.

Sand specific gravity	2.63-2.67
Sand specific gravity	2.65-2.70
Clay and Silty clay specific gravity	2.67-2.90
Specific gravity of organic soil	<2.0

Table 2.1

2.2.3 Particle size distribution

For coarse grained soil sieve analysis is used to classify soil as gravel, sand, and it is very useful for understanding physical and chemical properties of rocks and soils. It affects the solids reactivity while participating in various chemical reaction for fine grained soils hydrometer method and pipette method is used. In both methods only the method of taking observation is different. We use Indian soil classification system.

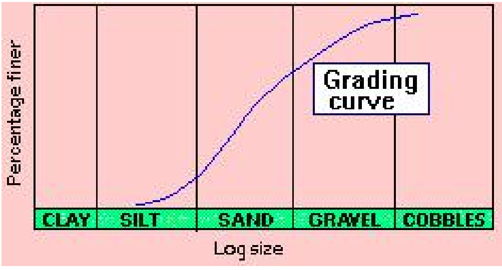

Fig.2.3 Gradation curve

2.2.4 Shear strength

Shear strength of soil is the resistance to the applied shear stress. Shear stresses are the destabilizing stress which is induced in soil due to external loading, seismic forces and seepage forces. They tends to make the soil fail along a certain surface which can be straight as in case of transitional slides or circular/log spiral as in case of rotational slides. Shear strength of soil can be improved by compacting the soil, reinforcing the soil, making the slopes flatter and improving the drainage condition.

Fig.2.4 Direct shear apparatus

CHAPTER 3

ANALYSIS OF EXPANSIVE SOIL

3.1 Expansive Soil:

The soil used in our study is Black cotton soil obtained from the field of Madhya Pradesh from the city Gwalior. Laboratory tests is done to determine various index and engineering properties of Black cotton soil were conducted according to Indian Standard methods of testing.

3.2 Occurrence of lime

Lime is obtained from minerals and rock which are derived from chalk or limestone, mainly composed of calcium carbonate. They are usually pulverised crushed, cut or altered chemically. Calcinations is a burning process which converts it into a material which is highly caustic known as quick lime or calcium oxide. By addition of appropriate amount of water, it is turned into less caustic material know as hydrated lime, slaked lime or calcium hydroxide and this process is known as slaking of lime. The burning and slaking of lime is done in kilns knows as lime kiln.

3.3 Generation of lime:

Limestone is generally referred to rocks which contain more than 80 percent of calcium and/or magnesium carbonate including marl, chalk, iolite and marble. Some of the uncommon sources of lime are coral, calcite, ankerite and sea shells. Limestone is extracted from mines and quarries. The stone extracted are calcinated at around 1000^{o}C in various types of lime kiln.

$$CaCO_3 \longrightarrow CaO + CO_2$$

Calcium carbonate → Calcium oxide + Carbon dioxide

Quick lime is mixed with water to form hydrated lime or slaked lime according to following reaction

$$CaO + H_2O \longrightarrow Ca(OH)_2$$

Water → Calcium hydroxide

3.4 Industrial waste:

Solid and semi-solid constituents that are unwanted by the community are known as solid waste. Improper disposal of these wastes causes negative impact on the ecology which may lead to cause possible outbreak of diseases, epidemics, ecological misbalance or pollution. Solid wastes are divided in to three group's namely Industrial waste, Agricultural waste, and Municipal waste.

These industrial wastes may be used as source of substitute material for stabilization or dumping purpose which are cheaply available, by using these wastes as construction material will provide solution for problems of pollution and disposal of these wastes. Some of the waste material which are being used for road construction now a days are presented in table below with their relative advantages and disadvantages.

WASTE PRODUCT	**SOURCE**	**POSSIBLE USE**
Blast furnace slag	Steel industry	Base/Sub-base material, Binder in soil stabilisation (Ground slag)
Waste tyre	Automobile industry	Rubber modified bitumen aggregate
Cement kiln dust	Cement industry	Stabilization of base, binder in bituminous mix
Used engine oil	Automobile industry	Air entraining of concrete
Fly ash	Thermal power plant	Bulk fill, filler in bituminous mix, artificial aggregates
Marble dust	Marble industry	Filler in bituminous mix

Table 3.1

MATERIAL	**ADVANTAGES**	**DISADVANTAGES**
Blast furnace	More strength, can be used as Aggregates granular base	Ground water pollution Due to leachate formation, used as unbound aggregates
Fly ash	Lightweight, used as binder in stabilized base/ sub-base due to pozzolanic properties	Lack of homogeneity, presence of sulphates, strength development
Cement kiln dust	Hardens when exposed to moisture, can be used in soil	Corrosion of metals (used in concrete roads) in contact

	stabilization	because of significant alkali percentage
Rubber tires	Enhances fatigue life	Requires special techniques for fine grinding and mixing with bitumen, sometimes segregation occurs
demolition waste	More strength, can be used as Aggregates granular base	Ground water Pollutiondue to leachate formation, used as unbound aggregates
Used engine oil	Good air entertainer, can be used in concrete work	Requires well organized used oil collection system

Table 3.2: Advantages and disadvantages of using specific industrial was

3.5 Black cotton soil and fly ash

- Fly ash produces during combustion of coal in industries to get heat; mainly it is generated from thermal power plants. Fly ash is collected from electrostatic precipitator when flue gases reach to top of chimney. Bottom ash is the ash which cannot fly with flue gas while ash which goes with flue gas is known as flue ash or fly ash, combined fly ash and bottom ash is termed as coal ash. Elemental composition of fly ash depends upon source and type of coal used but all fly ash contain silicon dioxide and calcium oxide. In past it was released to atmosphere But to control pollution it collected by some means and disposed carefully, now these days it is used as stabilizing agent due to virtue of pozzolanic reactions.

3.6 Index properties of black cotton soil

3.6.1 Liquid limit and plastic limit test

Object: - To determine liquid limit and plastic limit.

Apparatus: -

- Casagrande liquid limit device
- ASTM and BS grooving tool
- Glass plate 20 x 15 cm
- 425 micron I.S. Sieve
- mm diameter rod
- Balance (0.01gm sensitivity)
- Oven drying
- Distilled water
- Measuring cylinder

Precautions:

- Distilled should be used to avoid the possible situation of any ion exchange between soil particles and impurities if any present in water
- Prior to testing, the soils which are to be used for determination of liquid and plastic limit must not be dried in oven..
- The groove in cassagrande’s apparatus used for liquid limit determination must close only by the flow of the soil and not due to the slippage between the cup and the soil.

- Sufficient time must be given for the water to seep through mass of soil from the instant soil sample is mixed with distilled water.
- The soil wet sample present in container to determine water content must never be left in air, not even for small amount of time. It should either be put in the desiccators or if possible immediately weighed.
- For every different test, cups and grooving tools, must be clean.

SI. No.	No of blows	Mass of sampler(Mc) in gm	Mass of sampler +Moist soil(Mc + Mm) in gm	Mass of sampler +Dry soil (Mc +Ms) in gm	Mass of moist soil(Mm) in gm	Mass of Dry soil (Mm) in gm	Mass of water (Mw) in gm	Water content=(Mw/Mm)*100%
1	14	5.46	12.87	9.98	7.41	4.52	2.89	63.94
2	21	5.39	12.6	9.90	7.21	4.51	2.7	59.87
3	29	5.63	17.43	13.77	11.8	8.14	3.66	44.97
4	41	5.36	15.86	12.39	10.5	7.63	2.89	37.86

Table 3.3

No. of blows	% water content
14	63.94
21	59.87
29	44.97
41	37.86

Fig.3.2 Casagrande’s apparatus and BCS

Liquid Limit Graph

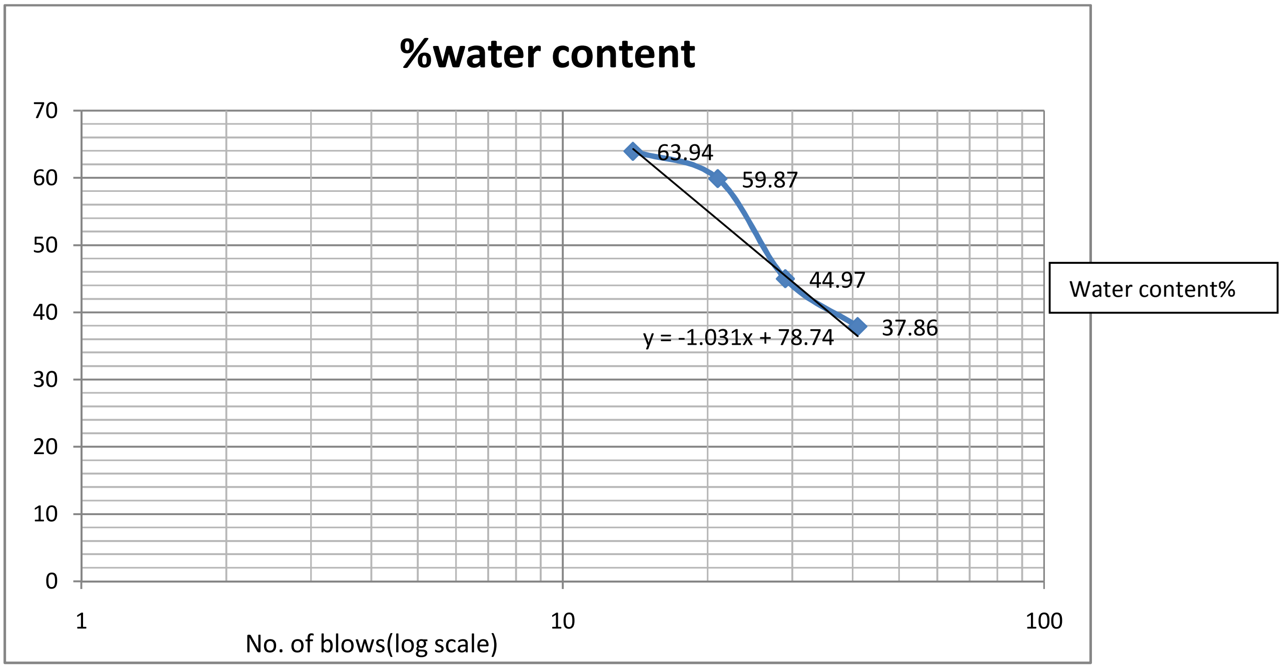

Fig.3.3 Liquid limit corresponding to 25 no of blows is 52.50

Black cotton soil Liquid limit is 52.60%

Black cotton soil Plastic limit is 24.90%

Plasticity Index is 27.6%

Plastic limit

Sl. No.	Mass of sampler (M_e) in gm	Mass of Sampler + Moist soil (M_e + M_m) in gm	Mass of Sampler + Dry soil (M_e + M_s) in gm	Mass of moist soil (M_m) in gm	Mass of Dry soil (M_m) in gm	Mass of water (M_w) in gm	Water content W= (M_w/M_m)*100 %
1	5.39	9.89	8.95	4.417	3.56	0.937	23.5
2	6.04	9.924	8.69	3.884	2.65	0.754	24.1
3	5.61	9.165	8.64	3.555	2.73	0.825	25.3

Table 3.4

Result for plastic limit is 24.90%

Plasticity index is difference of liquid limit and plastic limit which is 27.6%

Degree of expansion	Plasticity index (%)		
	IS1498	Chen	Holtz and Gibbs
Low	<12	0-15	<20
Medium	12-23	10-35	12-34
High	23-32	20-55	23-45
Very high	>32	>35	>32

Table 3.5 Soil expansiveness prediction on the basis of Plasticity Index

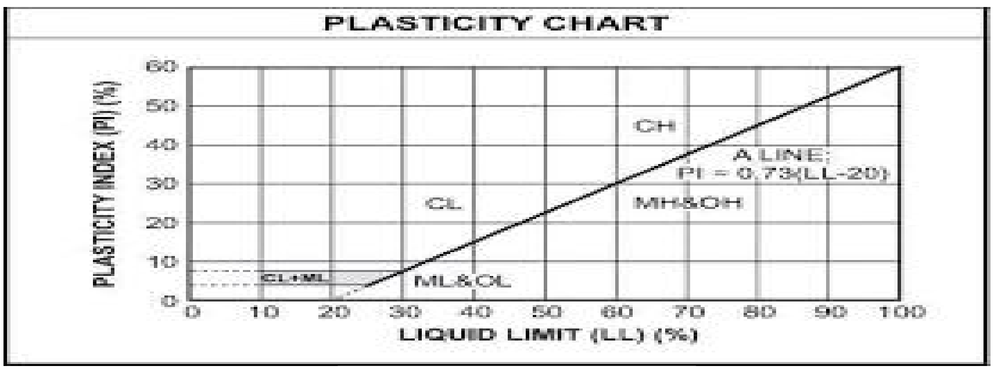

Fig.3.4 Plasticity chart

According to above results of plasticity index and liquid limit the soil is classified as **CH** Which is highly compressible clay

3.6.1 Determination of specific gravity of soil

Specific gravity of grain is the mathematical ratio of weight of solids to the weight of water of same volume. Specific gravity of mass/apparent is the bulk weight of soil to the weight of the water same volume. It is determine by using density bottle. It is required for calculation of soil grain and bulk properties like void ratio, degree of saturation etc. It is determined on soil passing through IS 4.75mm sieve using density bottle.

Apparatus required

a. 50ml density bottle with inbuilt stopper having a capillary hole.
b. Weigh balance with accuracy of 10gm
c. Distilled water and wash bottle
d. Alcohol and ether

Procedure

Take around 10 to 20gm oven dried soil after cooling in desiccators find its weight along with the density bottle. Next, find the weight of the bottle with distilled bottle. Now find the weight of the soil and corresponding weight of water of same volume

$$G = \frac{W_1 - W_2}{(W_2 - W_1) - (W_3 - W_4)} \tag{3.1}$$

W1 weight of density bottle

W2 weight of density bottle with dry soil

W3 weight of density bottle with dry soil plus water

W4 weight of density bottle with waters

Mass of empty bottle (W_1) in gm	696.63
Mass of bottle + mass of dry soil (W_2) in gm	858.22
Mass of bottle + mass of dry soil + mass of water (W3) in gm	1669.42
Mass of bottle + water (W_4) in gm	1567.53
Specific gravity of soil	2.709

Table 3.7 Specific gravity

Result of Specific gravity of black cotton soil is 2.709

6.2 Compaction test (standard proctor):

Object:-To find out the optimum moisture content and maximum dry density of a soil by proctor test

Apparatus:-

1. Cylindrical mould (of capacity - 1000 cm^3., internal dia. - 100 mm and effective ht - 127.3 mm)
2. Rammer or tamping rod for light compaction test (face dia. - 50 mm., mass of 2.6 kg, freefall of rod from 310 mm)
3. Rammer for heavy compaction (face dia50 mm, mass4.89 kg, free drop 450mm)
4. Mould with accessories (detachable - base - plate - removal collar)
5. I.S. Sieves (20 mm,4.75 mm)
6. Weigh balance (of capacity of 200 gm with sensitivity of 0.01 gm)
7. Drying oven (temperature 105°C to 11°C)
8. Desiccators
9. Graduated jars
10. Straight edge
11. Spatula
12. Scoop

Fig 3.5 Standard proctor apparatus

Precautions:-

1. Adequate period is allowed for mixing the water with soil before compaction.
2. The blows should be uniformly distributed over the surface of each layer.
3. Each layer of compacted soil is scored with spatula before placing the soil for the succeeding layer.
4. The amount of soil used should be just sufficient to fill the mould i.e." at the end of compacting the last layer the surface of the soil should be slightly (5 mm) above the top rim of the mould.
5. Mould should be placed on a solid foundation during compaction.

Standard Proctor test result (Compaction curve)

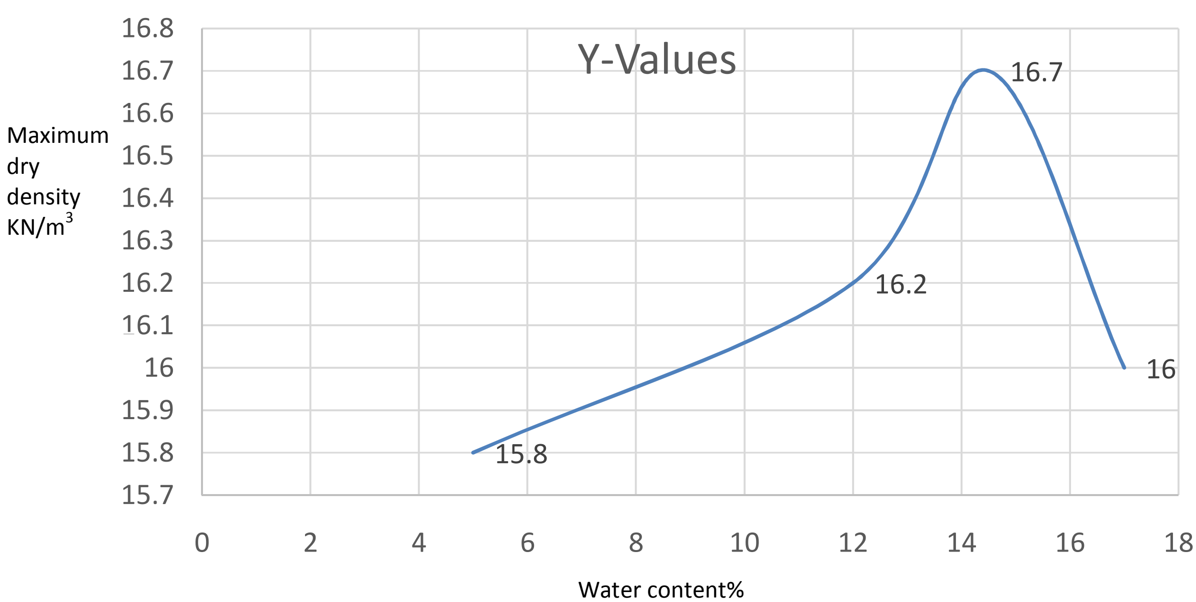

Fig.3.6

Optimum moisture content of Black cotton soil =14.50%

Black cotton soil Maximum dry density =1.68gm/cc

3.6.3. Differential Free Swell Test:

Two samples of dried soil weighing 10gm each passing through 425 micron sieve are taken.

- One 10gm soil sample is put in a 50cc graduated glass cylinder containing kerosene.
- Other sample is put in a similar cylinder containing distilled water.

Both the samples are left undisturbed for 24 hours and then there volumes are noted. The differential free swell is expressed by.

$$F = \frac{V_d - V_k}{V_k} \tag{3.2}$$

Initial volume of soil in Water is 6.4cc

Final volume of soil in Water after 24hrs V_d is 9.4cc

Initial volume of soil in Kerosene is 6.4cc

Final volume of soil in Kerosene after 24hrs V_k is 6.4cc

On calculation Free swell index is $\frac{9.4-6.4}{6.4}$ *100 = 46.88%

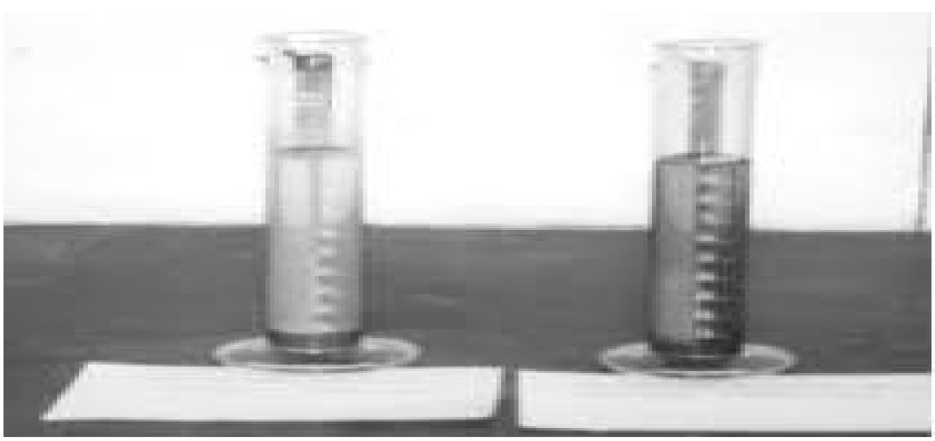

Fig 3.7 Free swell test

3.6.4.UCS test:

Object: To find out the unconfined compressive strength of cohesive soil.

Apparatus:

1. Unconfined apparatus , with proving ring
2. Dial gauge
3. Weighing balance
4. Oven
5. Mould(38 mm dia,76 mm long)
6. Knife

Procedure:

1. Prepare the soil and mix at desired water content.
2. Compact soil in mould with three layers by compaction road.
3. Saturate the sample.
4. Take out the sample from sampler.
5. Trim the two ends of soil specimen
6. Place specimen at bottom of compression machine
7. Proving ring of dial gauge adjusted to zero.
8. Apply the load through compression machine and record proving ring reading at equal interval of dial gauge reading upto failure of sample.

Fig 3.8 Unconfined compression test

UCS Result:

UCS for 1 day	79.29 KPa
UCS for 7 day	118.94 KPa
UCS for 28 day	135.32 KPa

Table 3.8

CHAPTER 4

4.1 Soil stabilisation:

During the process of stabilization we alter the property of parent material by adding some admixtures in optimum dose so that they can get modify their engineering property economically. In my study I use lime and fly ash as a stabilizing material to stabilize black cotton soil and compare the result with stabilization of black cotton soil with lime and fly ash, properties of materials are as given as

FOR EXPANSIVE SOIL

1. LIQUID LIMIT - 53.53%
2. PLASTIC LIMIT - 25.6%
3. SPECIFIC GRAVITY - 2.71
4. MAX. DRY DENSITY - 16.8 KN/m^3
5. OPTIMUM MOISTURE CONTENT - 14.50%
6. UCS VALUE - 0.12 Mpa

FLY-ASH

1. LIQUID LIMIT - 32%
2. PLASTIC LIMIT - Non-plastic
3. SPECIFIC GRAVITY - 2.13
4. MAX. DRY DENSITY - 13.5KN/m^3
5. OPTIMUM MOISTURE CONTENT - 19.0%

LIME

1. BULK DENSITY = 6-9 KN/M^3
2. SPECIFIC GRAVITY = 2
3. INSOLUBLE MATERIAL < 1%
4. MAJOR INGREDIENT CAO > 83%
5. OVER 90 µM < 10%
6. OVER 630 µM = 0%

4.1. Effect of fly ash and lime on consistency limit and free swell test of black cotton soil:

PROPORTION	LIQUID LIMIT %	PLASTIC LIMIT%	PLASTICITY INDEX%	FREE SWELL INDEX %
BS+ 5% FA + 0% lime	52.50	24.90	27.90	46.88
BCS+ 5% FA + 2% lime	54.20	26.2	28	28.13
BCS+ 5% FA + 4% lime	55.4	26.8	28.6	21.88
BCS+ 5% FA + 6% lime	56.7	27.7	28.6	22.58
BCS+ 5% FA + 8% lime	57.3	28.4	28.9	25.8
BCS+ 10% FA + 0% lime	51.6	24.3	27.3	33.33
BCS+ 10% FA + 2% lime	52.2	24.7	27.5	21.22
BCS+ 10% FA + 4% lime	52.9	25.5	27.4	18.75
BCS+ 10% FA + 6% lime	53.7	26.2	27.5	18.75
BCS+ 10% FA + 8% lime	54.6	26.8	27.8	21.88
BCS+ 15% FA + 0% lime	47.2	22.8	24.4	27.27
BCS+ 15% FA + 2% lime	48.4	23.2	25.2	18.75
BCS+ 15% FA + 4% lime	49.7	23.4	26.3	15.63
BCS+ 15% FA + 6% lime	50.3	23.8	26.5	12.9
BCS+ 15% FA + 8% lime	50.1	24.3	25.8	15.63
BCS+ 20% FA + 0% lime	42.6	21.4	21.2	38.24
BCS+ 20% FA + 2% lime	43.2	21.3	21.9	29.41
BCS+ 20% FA + 4% lime	43.7	21.6	22.1	26.78
BCS+ 20% FA + 6% lime	42.5	22.02	20.48	26.78
BCS+ 20% FA + 8% lime	45.2	22.7	22.5	26.78

Table 4.1

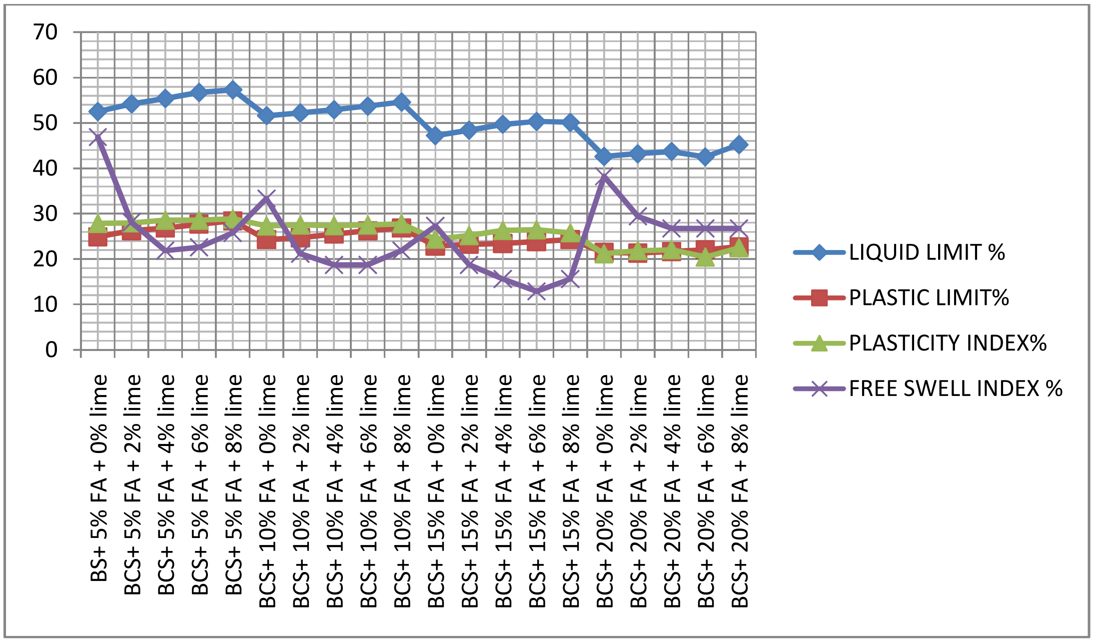

Fig.4.1 Variation of Consistency limits with soil proportion

4.2. Effect of fly ash and lime on maximum dry density and optimum moisture content of black cotton soil.

PROPORTION	**MAXIMUM DRY DENSITY (KN/m^3)**	**OPTIMUM MOISTURE CONTENT (%)**
BCS+ 5% FA + 2% lime	16.1	16
BCS+ 5% FA + 4% lime	15.2	18.5
BCS+ 5% FA + 6% lime	14.4	22.5
BCS+ 5% FA + 8% lime	14	24
BCS+10% FA +0% lime	16.3	17.5
BCS+ 10% FA+2% lime	15.9	18.6
BCS+ 10% FA+4% lime	15.4	20.2
BCS+ 10% FA+6% lime	14.8	22.4
BCS+ 10% FA+8% lime	14.2	24.5
BCS+15% FA +0% lime	15.6	17.2
BCS+ 15%FA +2% lime	15.1	19.4
BCS+ 15% FA+4% lime	14.7	21.3
BCS+ 15% FA+6% lime	14.1	23.2
BCS+ 15%FA +8% lime	13.7	24.8
BCS+ 20% FA+0% lime	14.9	20.3
BCS+ 20% FA+2% lime	14.3	21.6
BCS+ 20% FA+4% lime	13.8	22.8
BCS+ 20% FA+6% lime	13.4	24.2
BCS+ 20% FA+8% lime	13.2	25.6

Table 4.2

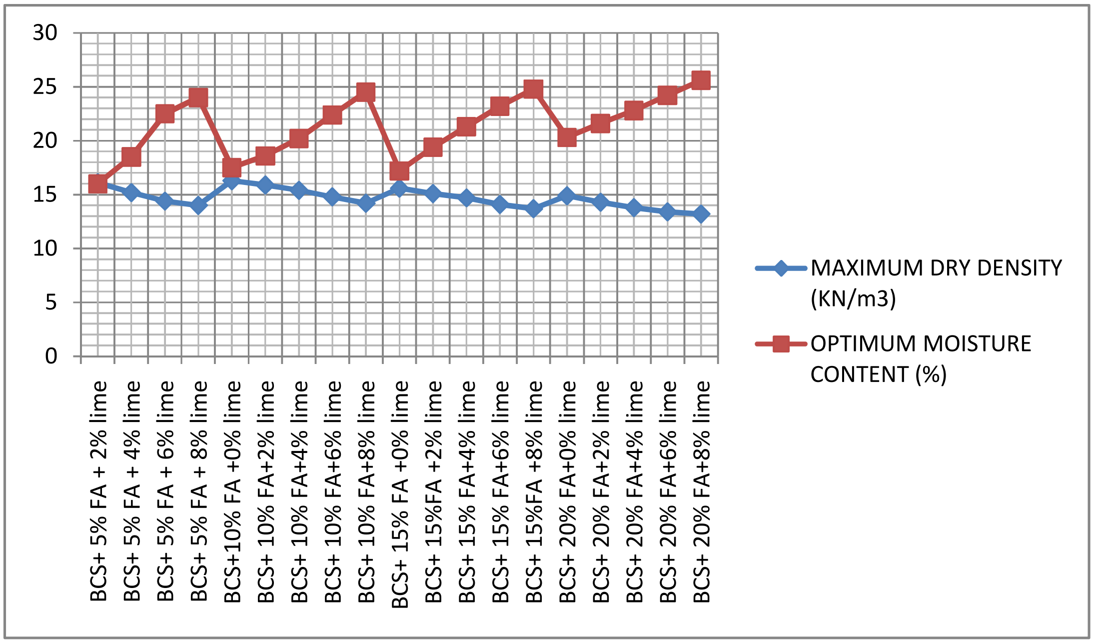

Fig.4.2 Variation of Maximum dry density and optimum moisture content with soil proportion

4.3. Effect of fly ash and lime on unconfined compressive strength of black cotton soil

PROPORTION	UCS (1DAY), KPa	UCS (7DAY) , KPa	UCS(28DAY), KPa
BCS+ 5% FA + 2% lime	84.08	149.77	187.7
BCS+ 5% FA + 4% lime	71.76	135.32	192.95
BCS+ 5% FA + 6% lime	79.29	101.32	158.59
BCS+ 5% FA+8% lime	67.28	84.85	136.56
BCS+ 10% FA+0% lime	80.37	123.34	158.58
BCS+ 10% FA+2% lime	88.51	114.9	171.02
BCS+ 10% FA+4% lime	83.70	170.24	192.95
BCS+ 10% FA+6% lime	92.51	153.48	184.18
BCS+10%FA+8% lime	75.57	115.06	166.64
BCS+15%FA + 0% lime	80.73	133.34	172.59
BCS+ 15% FA+2% lime	84.08	137.8	189.43
BCS+ 15% FA+4% lime	92.51	162.9	215.86
BCS+ 15% FA+6% lime	88.15	149.78	184.18
BCS+ 15%FA+8%lime	75.91	128.33	157.87
BCS+ 20% FA+0% lime	66.68	131.55	149.77
BCS+ 20% FA+2% lime	71.45	148.42	178.97
BCS+ 20% FA+4% lime	75.91	152.08	183.33
BCS+ 20% FA+6% lime	71.76	132.15	145.37
BCS+20%FA+8% lime	63.06	116.09	137.18

Table 4.3

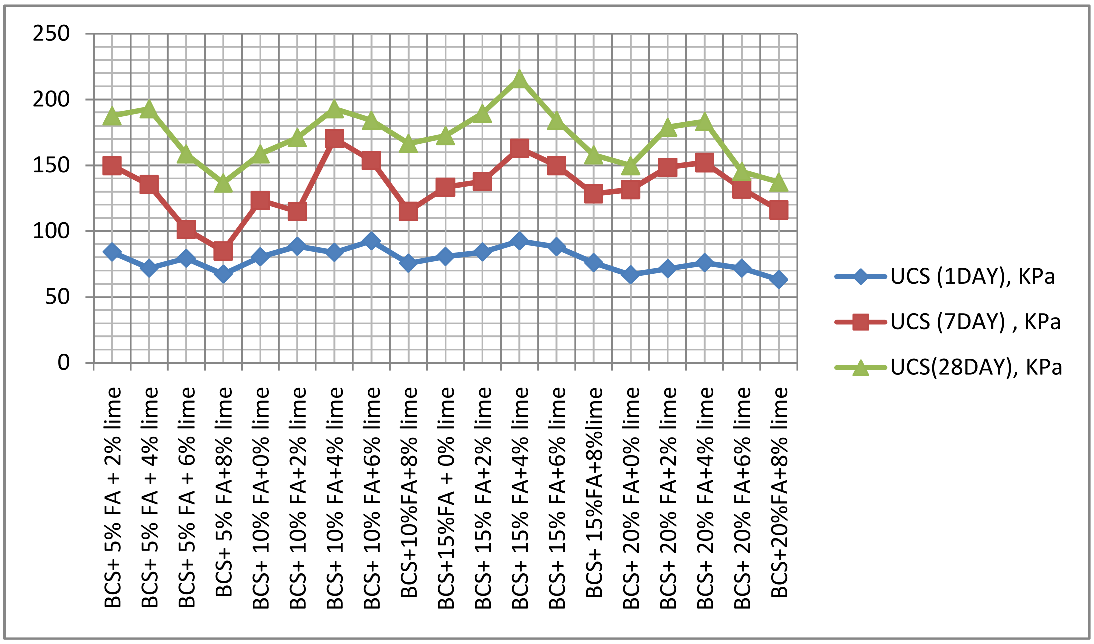

Fig.4.3 Variation of Unconfined compressive strength with soil proportion

CHAPTER 5:
ANALYSIS & DESIGN OF RIGID PAVEMENT

5.1. Introduction:

Rigid pavements do not bend under wheel load like flexible pavements the load is carried due to the stiffness and high concrete modulus of elasticity of slab. Analysis of rigid pavement is usually done by Westergaard's equation.

5.2 Modulus of sub-grade reaction

The modulus of sub-grade reaction is defined as the sustained pressure by rigid plate of diameter 75mm at 0.125cm deflection the reaction is assumed proportional to deflection. The rigid pavement slab acts as thin elastic plate which is resting on dense liquid in form of soil sub-grade.

5.3 Relative stiffness of slab

The sub-grade soil also offers some resistance to slab deflection. The deformation of sub-grade soil is considered to the same as the deflection of slab therefore deflection of slab is direct measurement of the pressure of sub-grade. The radius of relative stiffness relates the slab deflection and sub-grade pressure

$$l = \sqrt[4]{\frac{Eh^3}{1\ \ k(1-\mu^2)}} \qquad (5.1)$$

E- Modulus of elasticity of concrete (300000 kg/cm^2)

μ-Poisson's ration of concrete 0.15

h -Thickness of slab in cm

k- Modulus of soil sub-grade kg/cm^3

5.4 Critical load position

Westergaard's defines three positions namely the corner, edge and interior where the conditions of slab continuity exist differently. The maximum stress intensity is dependent on load location on pavement because pavement is finite in length and width.

5.5 Equivalent radius of resisting section

Equivalent radius of resisting section is the small finite are on the pavement only which is assumed to resist the bending moment when it is loaded with interior point load

$b = \{\sqrt{1.6a^2 + h^2} - 0.675h \quad i\; a < 1.724h, (o\ he\ \ w \quad a)$
(5.2)

Where a is wheel load radius of load distribution in cm

h is thickness of slab in cm

5.6 Westergaard's wheel load stresses

Westergaard's gives equation for determination of stress at corner, edge and interior regions in which Westergaard's assumed the rigid concrete slab to be homogeneous and having elastic properties which are uniform and deflection being proportional to the vertical reaction of sub-grade. Stress equation are σ_i, σ_e, σ_c in kg/cm^2 at interior, edge and corner regions.

$$\sigma_i = \frac{0.3\quad P}{h^2}\left[4lo\quad 1\left[\frac{l}{b}\right] + 1.069\right]$$
(5.3)

$$\sigma_e = \frac{0.5\quad P}{h^2}\left[4lo\quad 1\left[\frac{l}{b}\right] + 0.359\right]$$
(5.4)

$$\sigma_c = \frac{3P}{h^2}\left(1 - \left(\frac{a\sqrt{2}}{l}\right)^{0.6}\right)$$
(5.5)

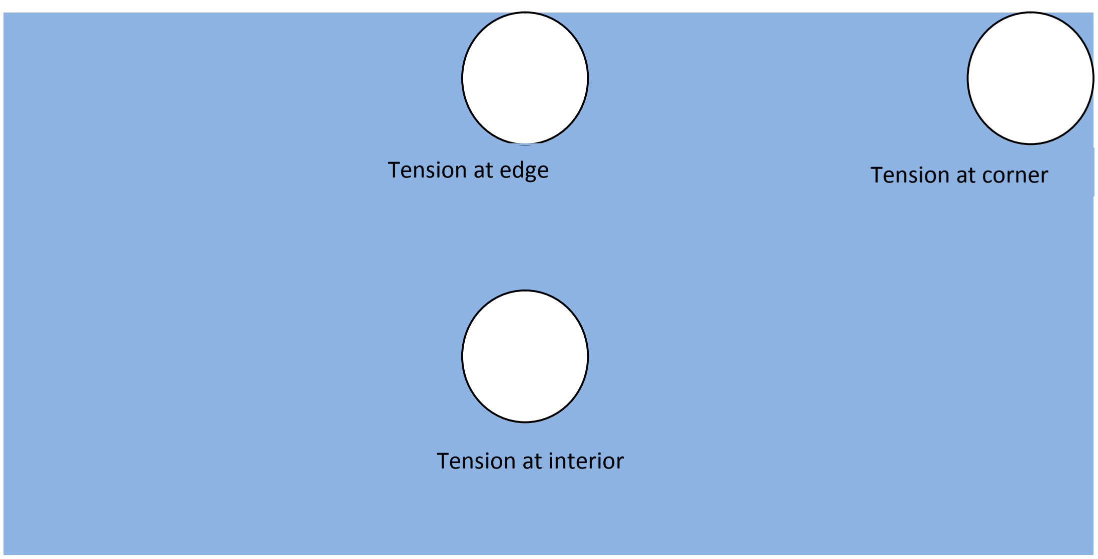

Fig.5.1 Critical stress region

5.7 Temperature stress

The variation of slab temperature leads to development of temperature stress in concrete pavements. This is due to

- Daily variation of temperature resulting in gradient across the thickness of cement concrete pavement. This results in warping stresses.
- Seasonal variation of temperature leading to homogeneous change of slab temperature. This results in frictional stresses.
- Combined effect of various stresses lead to three critical cases
    - Summer-mid day
    - Winter-mid day
    - Mid nights

Warping stress at the corner, interior and edge are represented as σt_c, σt_i, σt_e equation are:

$$\sigma t_i = \frac{E}{2}\left(\frac{C_x+\mu C_y}{1-\mu^2}\right) \quad (5.6)$$

$$\sigma t_e = m \left(\frac{C_x}{2}, \frac{C_y}{2}\right) \quad (5.7)$$

$$\sigma t_c = \frac{E}{3(1-\mu)}\sqrt{\frac{a}{l}} \quad (5.8)$$

Where ϵ is the coefficient of thermal for concrete °C ($1x10^{-7}$)

Elasticity modulus of concrete is E

C_x and C_y are the coefficient based on L_x/l and L_y/l in desired direction

μ is poisson's ratio which is 0.15

a is contact area and l is relative stiffness radius

The frictional stress σ_f in kg/cm^2 is given by

$$\sigma_f = \frac{W}{2x1^{\ \ 2}} \quad (5.9)$$

W is unit weight f concrete 2400 kg/cm^2
f is friction coefficient

5.8 Basic structure of rigid pavement

Portland cement concrete is use for the construction of rigid pavement. The rigid pavements have high flexural strength and can resist very high tensile stresses. Rigid pavements possess note worthy flexural stiffness or flexural rigidity.

These pavements transfer load through slab action but not grain to grain transfer as in case of flexural pavements. These consist of three layers namely-

1. Cement concrete slab
2. Base course
3. Soil sub grade.

1. Cement concrete slab

   Cement concrete slab is the top most layer of rigid pavement if bitumen is not used for the topping of slab. In cement concrete slab reinforcement steel also use for the better stability of rigid pavement. Expansion joint and contraction joint are also provided, expansion joints are provided for expansion of concrete due to increase in temperature while contraction joints are provided for contraction of concrete due decrease in temperature. Expansion joints are provided across full depth while contraction joints are provided across 25 to 30 percent of depth from the top. Construction joints are provided at the end of the day to continue the slab on next day.

2. Base course

   Base course is laid below concrete slab to absorb the wheel load stresses transferred from surface layer and transmits to sub-grade soil, hence it acts as a medium of link between surface layer and sub-grade soil. It is generally laid by a method of attentive spreading with relative compaction value of more than 95 percent. The usually size of aggregate used is 20 mm.

3. Soil sub-grade

   Soil sub-grade function is to transmit the wheel load into earth. For this the soil must be free from any undesirable volume change characteristics. The soil sub-grade must be properly compacted to achieve maximum strength but at the same time it should be permeable enough to allow the water to drain through it. The strength of the soil sub-grade is find out by using CBR test. The stabilization of soil is usually done on soil sub-grade. The soil should also be resistant to temperature changes otherwise freezing and thawing can occur. Soils like expansive and collapsible soil are stabilizing using foreign material to be used as soil sub-grade for construction of pavement.

Portland cement concrete plain, reinforced or pre–stressed is used for the construction of rigid pavement and for their stability concrete gives better performance. The plain cement concrete are suitable to take up about 49kg/cm^2 flexural stress. These are designed using elastic theory in which it is assumed that pavement is an elastic plate laid over viscous or elastic type of foundation.

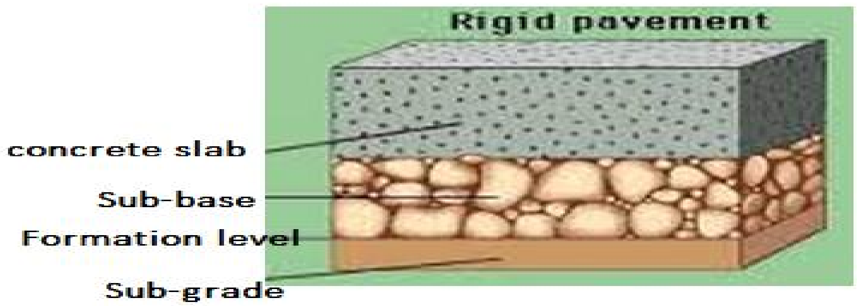

Fig.5.2 Basic structure of pavement

5.9 Recommendation of IRC for Design of rigid pavement

5.9.1 Limits of legal axle load

Single	10200 kg
Tandem	19000 kg
Tridem	24000 kg

Table 5.1

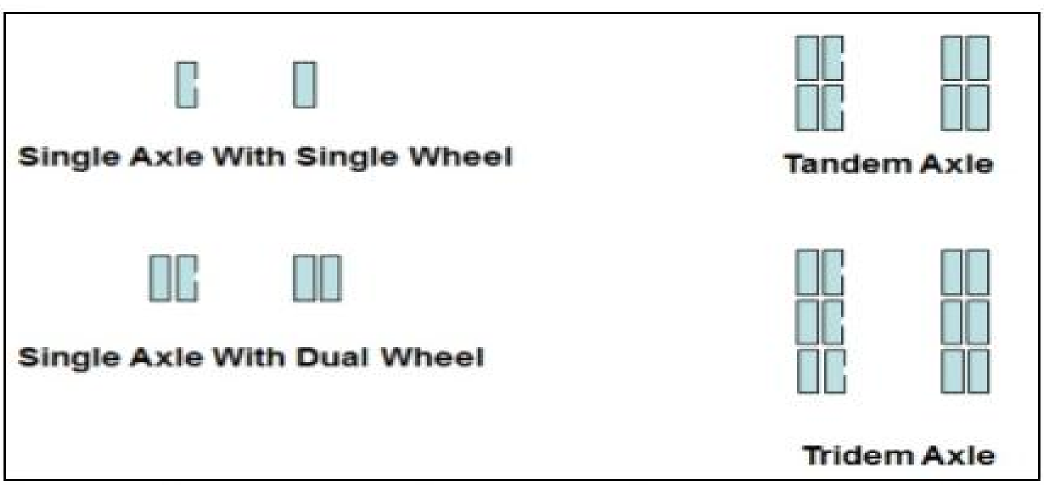

Fig.5.3 Legal axle load

5.9.2 Safety factors for load

National highway and state highway	1.2
Road with lower truck traffic	1.1
Street in residential area	1.0

Table 5.2

5.9.3 Tyre pressure

Range 7 kg/cm^2 to 10 kg/cm^2

When thickness of pavement is > 20cm than tyre pressure 8kg/cm^2 is adopted

5.9.4 Traffic Design

According to IRC

On two-way+ two-lane design traffic is taken as 25% of the total fatigue design while on four or more lane road the design traffic is taken as 25% of total predominant traffic in the desired direction.

For the design of newly build highways for which there is no availability of data, data is taken equal to data for similar roads with similar roads with same classification and equal importance.

Rate of annual average growth is taken as 7.5%

$$C = \frac{3 \quad [(1+r)^n - 1]}{r} A \qquad (5.10)$$

$$A = P(1 + r)^x \qquad (5.11)$$

A No of axles per day after the road is put in function

r commercial traffic growth rate per year

n Design period (years 20 to 30)

x no. years for the completion of highway construction

5.9.5 Sub-grade characteristics

Modulus of sub-grade reaction

a. ratio of pressure to deflection
b. computed by plate bearing test

c. deflection taken for design 0.125cm
d. k(75cm)=0.5k(30cm)
e. Only one test conducted /lane/km

5.9.5 Modulus of soil sub-grade

It is pressure sustained per unit deflection. The value of k can obtain experimentally by using plate load test in field. In plate load test we note the pressure at 1.25mm deflection and the plate used in this test is 30, 45, or may be 75cm.

In our analysis we use the modulus of soil sub-grade on the basis of literature review

Soil proportion	k- value in kg/cm^2 for 30cm plate
Black cotton soil	7.6
Black cotton soil and fly ash	7.9
Black cotton soil with fly ash and lime	8.3

Table 5.3

5.10 Design of concrete mix

5.10.1) Design of concrete mix (M50 grade of concrete with OPC43)

a.) Design stipulations

- Characteristic mean compressive strength at 28 days: 50 N/mm^2
- Type of cement conforming IS8112 : OPC grade 43
- Aggregates maximum size : 20 mm
- Minimum content of cement : 320 kg/m^3
- Maximum ratio of water cement : 0.45
- Degree of workability : 100mm
- Type of quality : Very good
- Type of exposure : Severe
- Type of admixtures used :Super plasticizer
- Maximum cement content : 450 kg/m^3

b.) Concrete ingredients

Cement’s specific gravity	3.15
Fly ash Specific gravity	2.09
Admixture Specific gravity o	1.145
Initial setting time of cement	40mm
Final setting time for cement	10 hours
Compressive strength of cement	43
Coarse aggregate Specific gravity	2.73
Fine aggregate Specific gravity	2.73

Table 5.4

Coarse aggregate

Sieve size (mm)	Coarse aggregate fraction (%passing) I	II	Percentage of different fraction I	II	III	
20	100	100	60	40	10	Conforming to IS 383:1970
10	0	71.2	0	28.5	28.5	
4.75		9.4	-	3.7	3.7	
2.36						

Fine aggregate

Sieve sizes	Fine aggregate (%passing)	Remark
4.75 mm	90 – 100	Conforming to grading zone 2 of table 4 of IS383:1970
2.36 mm	75 – 100	
1.18 mm	55 – 90	
600 µ	34 – 58	
300 µ	7 – 29	
150 µ	1 – 10	

Table 5.5

5.10.2 Sampling and testing of cubes

6 cubes of 15cm is used for testing of M50 grade. In rigid pavement minimum M40 garde of concrete is used or above.

- Cement and othet material like coarsed and fine aggeregate are mixed throughly.
- Whole mixture of concrete would be in same colour.
- Water is added to the mixture and make sure that it will mixed up correctly.
- Moulds used for casting are clean and oil is applied for safely removal of cubes.
- Concrete fill into the mould in layers wise approx 5cm and make sure that no air voids present in the concrete mix.
- 35 strokes is used to compact each layer.
- Top surface should be lavelled with a trowel.
- Each cube is curing for 24 hrs in moist air.

S.no	Size of cube	Curing time	Rate of load applied	Failure load	Compressive str.
1	15cm	7days	140kg/cm^2/min	375	16.67N/mm^2
2	15cm	7days	140kg/cm^2/min	380	17.2 N/mm^2
3	15cm	28days	140kg/cm^2/min	1005	44.44 N/mm^2

4	15cm	28 days	140kg/cm^2/min	1020	45.33 N/mm^2

Table 5.6

Fig.5.4 Compression testing machine and vibrator

5.10.3) Calculation of thickness of cement concrete pavement

- Cement concrete flexural strength, = 45.14 Kg/cm^2
- Sub-grade reactions effective modulus, k = 8.3 Kg/cm^2
- Elastic modulus of concrete = 300000 Kg/cm^2
- Poisson ratio, (μ) = 0.15
- Tyre pressure, p = 8 Kg/cm^2
- Coefficient of thermal expansion, (α) = 0.00001/^{o}C
- Traffic growth rate increase, r = 0.075
- Contraction joints spacing, L = 4.5m
- Slab width, B = 3.5m
- Value of present traffic = 3000cvpd
- Design life = 30 years
- Difference in temperature = 21^{o}C
- Cumulative repetitions of vehicles in design life = 121714021.7
- Value of design traffic = 30428505.42

Assuming the thickness of pavement be 33cm

Load safety factor according to IRC 58: 2002 is 1.2

For the following case the cumulative fatigue life comes out to be less than unity. Therefore the thickness is acceptable and design is safe.

5.10.4) Calculation of temperature stress

- Length of slab, L = 450 cm
- Width of slab, B = 350 cm
- Relative stiffness radius , l = 102.58 cm
- Ratio, L/l = 4.38
- Coefficient of Bradbury's, C = 0.55
- Warping stress at Edge = 17.345 Kg/cm^2

Since the value of total warping stress and the axle load stress (40.325 Kg/cm^2) is lesser than 45 Kg/cm^2, so the assumed thickness is safe in the combination of temperature and wheel load.

5.10.5) Calculation of stress on pavement at corner, edge and interior

- Single axle Wheel load(P) according to IRC on pavement = 10200 Kg
- Modulus of elasticity of concrete pavement(E) = 300000 Kg/cm^2
- Trial thickness of pavement(h) = 33 cm
- Poisson ratio(µ) = 0.15
- Soil subgrade reaction modulus (k) = 8.3
- Radius of area of contact surface(a) = 14cm
- Relative stiffness radius(l) = 102.58 cm
- Radius of area of contact surface(a)/Thickness of pavement(h) = 0.42
- Equivalent radius of resisting section (b) = 15.15 cm

The following are the results that were comes from the study:

- The thickness of the pavement was calculated as 33cm using load-safety factor of 1.2, traffic increase rate of 7.5% and 30 years design life with reference to IRC 58:2002.
- Stress at corner(S_c) = 17.62 kg/cm^2
- Stress at edge(S_e) = 19.69 kg/cm^2
- Stress at interior(S_i) = 12.98 kg/cm^2

Assume thickness of pavement 33cm is safe flexural strength of cube is greater than (temperature stress + edge stress).

CHAPTER 6:

RESULT AND CONCLUSION

6.1) Results

6.1.1) Results for un-stabilized expansive soil, fly-ash and lime

	LIQUID LIMIT	PLASTIC LIMIT	SPECIFIC GRAVITY	MAX. DRY DENSITY	OPTIMUM MOISTURE CONTENT
EXPANSIVE SOIL	53.53%	25.6%	2.71	16.8 KN/m^3	14.50%
FLY-ASH	32%	Non-plastic	2.13	13.5KN/m^3	19.0%

Table 6.1

6.1.2) Results for stabilized soil

	SOIL PROPOTION	**BEST RESULT**
LIQUID LIMIT %	BCS+ 20% FA + 6% lime	42.5%
PLASTIC LIMIT%	BCS+ 20% FA + 2% lime	21.3%
PLASTICITY INDEX%	BCS+ 20% FA + 2% lime	21.9%
FREE SWELL INDEX %	BCS+ 15% FA + 4% lime	15.63%
MAXIMUM DRY DENSITY (KN/m^3)	BCS+ 15% FA + 4%lime	14.7 KN/m^2
OPTIMUM MOISTURE CONTENT (%)	BCS+ 15% FA + 4% lime	21.3%
UCS (1DAY), KPa	BCS+ 15% FA + 4% lime	92.51
UCS (7DAY) , KPa	BCS+ 15% FA + 4% lime	162.9
UCS(28DAY), KPa	BCS+ 15% FA + 4% lime	215.86

Table 6.2

6.1.3) Results for stresses on concrete pavement

- The value of edge warping stress is 17.325 Kg/cm^2.
- The value of highest axle load stress is 40.325 Kg/cm^2.
- The thickness of the pavement was calculated as 33cm using a load safety factor of 1.2, traffic increase rate of 7.5% and 30 years design life with reference to IRC 58:2002.

- Stress at corner(S_c) = 17.62 kg/cm^2
- Stress at edge(S_e) = 19.69 kg/cm^2
- Stress at interior(S_i) = 12.98 kg/cm^2

S.no	1	2	3	4
Size of cube	15cm	15cm	15cm	15cm
Curing time	7days	7days	28days	28days
Rate of load applied	140kg/cm^2/min	140kg/cm^2/min	140kg/cm^2/min	140kg/cm^2/min
Failure load	375 KN	380 KN	1005 KN	1020 KN
Compressive str.	16.67N/mm^2	17.2 N/mm^2	44.44 N/mm^2	45.33N/mm^2

Table 6.3

6.2) Conclusions

Analysis of Rigid pavement on expansive soil the following Results can be drawn from the study and recommendations made. Analysis of Rigid pavement on expansive soil other advantages of overlays include:

- Long life, practically maintenance- free performance, fuel saving, good riding quality, hard surface, no effect of spillage of oil, better performance under adverse conditions. Design Precision, good reflectivity lights leading to electricity savings and favourable cost economics.
- Analysis of Rigid Pavement on expansive soil Interest in concrete overlays has been seen all over the world during the past two decades mainly because of likely shortages of bitumen- a petroleum crude based product- in the coming years. India has an abundant supply of cement and will feel the bitumen shortages in the coming years. Thus, it is **in the country's interest to start immediately the switch over from** bituminous overlays to concrete overlays.
- Analysis of Rigid pavement on expansive soil International experience in Analysis of Rigid pavement on expansive and expansive soil has been encouraging, with countries like France, Britain, USA, Belgium having taken up thus option with encouraging results.
- Analysis of Rigid pavements on expansive soil rehabilitation and strengthening is a problem of immediate concern. It is expected that in the coming year's large investments on this will be made. Hence great care is needed to select the proper specifications for overlay.
- Analysis of Rigid pavement on expansive soil has initial cost of concrete overlays is slightly more than a bituminous overlay. But on a life-cycle-cost basis, it is always economical. Besides, there are additional benefits such as saving in vehicle operating costs and diesel consumed by commercial vehicles.
- Analysis of Rigid pavement on expansive soil though the usual practice is to cure the concrete for 14 days and allow traffic only **after it has attained the desired strength, "fast-track" construction cuts** down the traffic delays and the road can be opened to traffic in 3 to 4 days after concreting.

- Analysis of Rigid pavement on expansive soil good construction practices, use of machinery and strict control over the quality are needed in concrete road construction. Concrete M-40 or M-50 grade is used.
- Analysis of Rigid pavement on expansive soil conventional concrete overlays can be with plain concrete jointed slabs or Continuously Reinforced Concrete Pavements.
- Analysis of Rigid pavement on expansive soil concrete overlays can be of three types, viz., conventional concrete overlays of thickness above 200mm suitable for heavy traffic, Thin White topping(TWT) with thickness in the range of 100-200mm suitable for medium traffic and ultrathin white topping (UTWT) with thickness in the range of 50-100mm suitable for low traffic.

6.2.1) Conclusions for lime

- On mixture of lime and fly ash in soil it increase its OMC value from 14.5% to 16-24 (min-max) % .The reason of it may be the water absorbing tendency of lime is more, due to absorption of water the OMC required is more.
- On addition of lime and fly ash the MDD value of the mix decreases from 16.8 to 13.2 - 16.3 (min-max) KN/m^3.

  On addition of lime and fly ash mixture shows increase in UCs value from 0.12 MPa to 0.136 - 0.215 MPa (min-max) when 4 % lime is added after addition of fly ash does not increase.

  Best proportion of fly ash and lime in black cotton soil is 20% fly ash and 4% lime to stabilize the soil for best properties.

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