ANALYSIS OF CONCRETE PAVEMENTS ON STABILIZED COLLAPSIBLE SOILS

Thesis Submitted in Fulfillment of the Requirement for the award

Of

Master of Technology

Under the guidance of

Prof. Kongan Aryan

By

HARPREET SINGH

2K16/GTE/08

Delhi Technological University

Shahbad Daulatpur Village

Delhi 110042

Delhi Technological University

Department of Civil Engineering

CANDIDATE’S DECLARATION

I certify that the all analytical or experimental work presented in this thesis entitled “Analysis of concrete pavements on stabilized collapsible soils” in the partial fulfillment for the requirement of the award of the degree of “Master of Technology in Geotechnical Engineering” Civil Engineering Department, Delhi Technological University, Delhi is an authentic record of our own work carried out from January to July under the guidance of Prof. Kongan Aryan, Department of Civil Engineering.

I have never submitted or presented the work present in this thesis for the award of any other degree or diploma.

Date 28-06-2018

HARPREET SINGH
(2K16/GTE/08)

Delhi Technological University

Department of Civil Engineering

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To the best of my knowledge this work have never been submitted or presented anywhere for the award of any other degree or diploma.

Prof. Kongan Aryan

Department of Civil Engineering

Delhi Technological University

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Harpreet Singh
Master of Technology
Geotechnical Engineering Branch
Roll No - 2K16/GTE/08
Civil Engineering Department
Delhi Technological University, Delhi

ABSTRACT

Collapsible soils are susceptible to volume changes or volume shrinkage as moisture content in the soil varies or changes by various natural or man-made occurrences. Rigid pavements construction is a constant and significant source of problem in the design and construction of foundations of buildings and highways. Collapsible soil are the specific type of soil which occurs mainly in African countries like Egypt, Iran, Iraq, Syria, Asian countries like India, mainly north and north-west part of the country i.e., regions of Rajasthan, Ladakh, some regions of Maharashtra, Some regions of Punjab and Haryana, Asian countries like Afghanistan, Kazakhstan, American states like California, Nevada, Itaho and European countries like some parts of Spain, Blue Nile regions and White Nile regions and Valley Region of the Great Rift, Middle east countries including Dubai, Saudi Arabia, Qatar, Sharjah and other parts of the world. These countries are constructing structures like buildings, highways, bridges, etc. on such soils and adopting various methods for soil improvement for safety purposes.

Before starting construction of any type of structure like buildings or highways, peak consideration factor is safety, economy and durability. There is a need and demand of higher value of the strength criteria parameter along with equivalent controlled decrease in cost of the foreign material leading to overall economy and decrease in the gross construction cost which are the sure signs of progress and development.

Collapsible soils present problems to engineers in the construction of durable roads. The two main concerns are shrinking and losses of shear strengths of soils and changes in materials properties under a wide ranges of moisture contents. Volumes changes in collapsible soil can be signification and occurs as the moistures contents changes. Rigid pavements or flexible pavements constructions has been a particular challenge to engineers because of the volumetric changes reasons which is causing roads instability, causing pavements surfaces unevenness and cracking, severe cracking and then finally early and premature deteriorations and then reconstructions or replacements. As the moisture contents of the soils increases above a certain level, strengths as well as dry densities of the soils decreases and the plasticities of the soils increases. As a result, there will be requirements of maintenances and early and premature roads replacement will become necessary.

For improvising the engineering properties of soils, a kind of materials are used called soil

stabilizers such as waste products and metallic elements and Geosynthetics etc. are put into use. These products normally have a large life span and they also don't undergo biological degradation but they can create environmental issues and problems. That is why the demand of waste materials and biodegradable natural fibers are getting popularity.

Using waste materials as a construction materials has always been an attraction and huge opportunity in business world. Nowadays, companies have started to examine various ways of saving wastes products in their every-day activities for both economies as well as hygiene purposes. According to CEST (Centre-of-Exploration-of-Science-and-Technology), costs of waste materials are generally about 6 times higher than what it is expected. Reduction of waste materials also cause improved hygienic conditions of the surrounding areas by reducing leaching into the ground water table.

Concrete or rigid pavements are generally constructed of Portland cement concrete. They generally consist of three layers which are PCC slab as surface layer, base layer as intermediate layer and the soil sub grade. The concrete pavements have high flexural strength and are these are capable of resisting very high tensile stresses. Rigid pavements possess also have very high flexural stiffness or flexural rigidity. These pavements can transfer load through slab action but not by grain to grain transfer which is in the case of flexural pavements. They are made of Portland cement concrete either plain or reinforced or pre –stressed concrete. The plain cement concrete are expected to take up approx. 4 MPa of flexural stress. Rigid pavements constructed on soils of collapsing nature generally suffers by cracking, huge differential settlements which ultimately causes the loss of resources, money, and time of the constructing authorities. Hence there is a need to properly investigate the mitigation and prevention of the collapse of the soil.

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LIST OF SYMBOLS AND ABBREVATIONS

AASHTO - American Association of States Highways & Transportation official

WBM - Water Bounds Macadam

ALS - Axle Loads Survey

WMM - Wet Mixes Macadam

ESP - Electrostatic Precipitator

ADT - Average Daily Trafficking

CBTM - Concrete Beams Testing Machinery

CVC - Classified Volumes County

FHWA - Federal Highways Administration

IRC - Indian Roads Congress

TWT - Thin White Toppings

MORTH - Ministry Of Road Transport and Highways

NCHRP - National Highway Research Programme (United States)

OMC - Optimum water content

PQC - Pavements Quality Concrete

UCS - Unconfined Compressives Strength

INTRODUCTION

1.1 Collapsible Soils

Collapsible soils are the soils which exhibit a large volume change on saturation, without or with addition loading, hence posing significant challenges to the geotechnical practice and profession. Numerous soil types fall in the category of collapsible soils, including aeolian deposites, alluvial deposites, colluvial deposits, residual deposits, and volcanic tuff. Most common collapsible soil is loess, a yellow to reddish brown silt size soil, which is characterized by relatively low density and cohesion, but appreciable strength and stiffness in the dry state. Aeolian deposits with significant tendency to collapse are often found in arid regions where the water table is low.

These soils are defined as any unsaturated soil that goes through a radical rearrangement of particles and forms a Meta stable state and greatly decreases in volume upon wetting. Most widely these soils are found in dry and arid or semiarid regions and have a loose soil structure a large void ratio and water content far less than saturation.

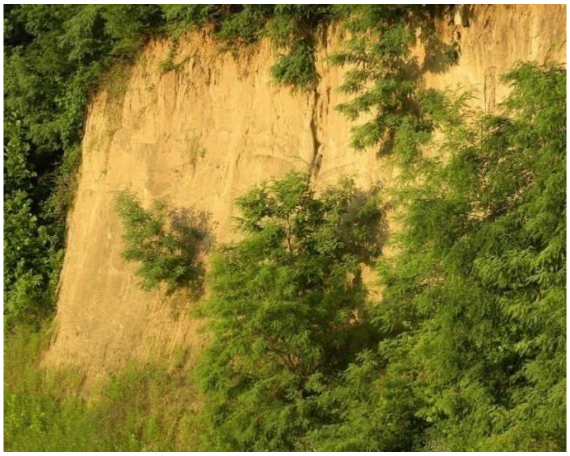


Fig 1.1 View of Collapsible soil

Source - https://upload.wikimedia.org/wikipedia/commons/thumb/8/86/LoessVicksburg.jpg/220px-LoessVicksburg.jpg

The blank spaces called voids seen between soil particles generally consist of water, air, or both. The soil particles may have containing dead and decayed organic matter. The soil particles maybe separated by each of the particles by such mechanical and geological means as agitation and water. Soils deposits in nature exist in an extremely erratic manner producing thereby an infinite variety of possible combination which will affect the strength of the soil and the procedures to make it grateful.

In case of coarse particulated soil, the mineralogical composition of the particles barely affects the engineering properties of the soils perhaps the grain to grain friction is influenced to some little degree or have a little variation. Is such soils, inter-particle-forces other than those due to gravity are of no use or consequence, but the finer and smaller particles, the more significant becomes the forces associated with the surface area of the grains. The chemicals characteristics and properties of the individual particles assumes importance especially when the surfaces areas are directly or indirectly related to the size of the particle - a condition which is associated with the fine grained soil. Thus, inter-particle attraction holding the grains together with each other makes constantly important as the size of the grain or particle decreases. The soil structures means the modes of arrangements of soil particles related to each other and the forces that are acting between soil particles for holding them together in their positions. The concepts are also further extended to include the other basic 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.

Soil collapse due to wetting can cause severe damage to dams, canals, roads, buildings, pumping plants, pipelines, fields and other structures related with irrigation projects and have been identified as one of the most destructive forms of land subsidence.

Collapse condition can be so much disastrous as it can trigger many structure failures and highway failures in major cities, lead to landslides in hilly areas, cause Tsunamis if collapse occur under the oceans or other water bodies.

Houston et al stated the formation of collapsible soil occurs in the dry or arid climate where rainfall is much exceeded by potential evaporation. In these conditions, water near to the surface start drying so, the remaining water is withdrawn by capillary tension into the narrow spaces near to soil-grain interface bringing with them soluble salts and silt particles and clay colloids. As the drying of the soil is continued salts, silt and clay particles come out of solution and bigger soil particles are tack weld together at the interface of these particles.

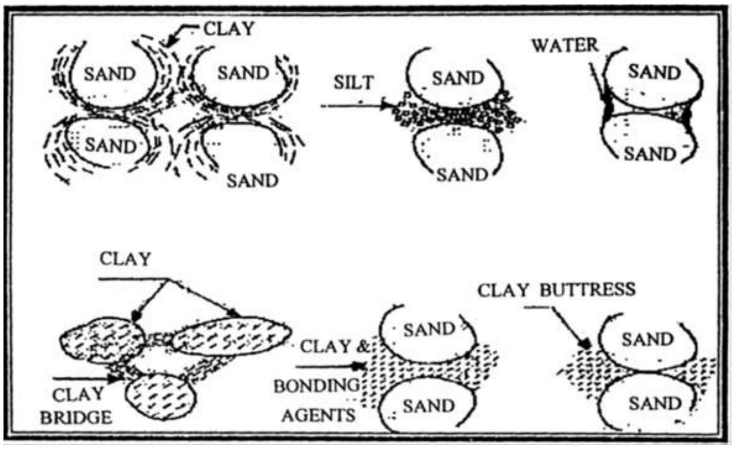


Fig 1.2 Main forms of collapsible soil structure

Source - http://www.ijser.org International - Journal of Scientific & Engineering Research Volume 8, Issue 8, August-2017 125 ISSN 2229-5518 IJSER © 2017 Soil Improvement Techniques of Collapsible Soil.

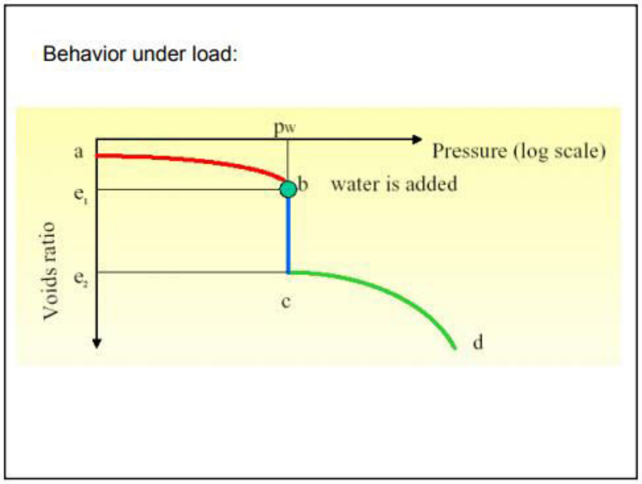


Fig 1.3 Behavior of collapsible soil under load

Source - http://www.abuildersengineer.com/2012/12/collapse-potential-and-settlement.html

‘ab’ part is determined by conducting consolidation test on soil sample at its natural moisture content.
‘e1’ part is the equilibrium void ratio before soil water saturation.
‘e2’ part is the equilibrium void ratio after soil water saturation.
‘cd’ part is the curve that is ensured from additional loading after saturation. Also called Virgin compression curve.

1.2 Problems in collapsible soils and their characteristics

a. Main geotechnical problem associated with these soils is the significant loss of shear strength and volume reduction occurring when they are subjected to additional water from rainfall, irrigation, broken water or sewer lines, moisture increase due to capillarity or ‘‘pumping’’ as a result of traffic loading, ground water rise, etc.

b. Main challenge related to road construction is differential settlements are encountered. Differential collapse settlement across roadway sections comes from two major factors.
c. First, non-homogenous subgrades that encompass materials with different degree of collapse potential and Second, non-uniform distribution of wetting in subgrades materials.
d. Differential settlements causes a rough and uneven and bumpy surface which directly or indirectly reduces the serviceability, and raise the frequency and cost of rehabilitation.

Source - https://civil-engg-world.blogspot.com/2012/04/how-to-identify-collapsible-soils.html

Source - https://www.burgsimpson.com/practice-areas-construction-defects-collapsing-expansive-soils

Fig 1.4 Failure-of-pavements-on-collapsible-soil

Collapsible soil characteristics

a. High void ratio,
b. Less initial dry or bulk density and water content,

c. Very high dry strength and stiffness,
d. High percentage of fine grained particles and zero or slight plasticity.
e. Mostly they contain over 60% of fines and have a porosity of 50% to 60%,
f. Liquid limit of about 50 %.
g. Plastic limit ranging from 0 to 20%.
h. Open structure formed by sharp grains,
i. Low plasticity,
j. Relatively high stiffness and strength in the dry state,
k. Particle size in the silt to fine sand range.

1.3 Objective of Study

a. Improvement of soil properties by addition of Lime and Cement.
b. To design concrete pavement as per IS 58 – 2002.
c. Calculate the stresses in concrete pavement.

LITERATURE REVIEW

2.1 SOIL STABILIZATION

Generally when a project site comes in the areas of difficult ground conditions examples of which are collapsible soils, swelling soils and organic soils and soft soil, possible alternative solutions may be 1.) Design the planned structure by enabling the cost effective design of foundation, 2.) Remove and replace previous unsuitable soil, 3.) Prewetting, 4.) Dynamic Compaction, 5.) Stone columns, 6.) Chemical stabilization, 8.) Decrease the effect of contaminated soils 7.)Modify the existing ground by adding stabilizers, and 8.) Promote sustainability in construction works and 9.) Decrease the effect of contaminated soils.

a.) Soil compaction using Rollers

There are various types of rollers and their selection is done on the basis of water content of the soil and on the basis of type of soil. These rollers are:

Static smooth wheeled rollers

These are generally suitable for soils such as well-graded sand, well-graded gravel and crushed rocks etc. They can be used where we require crushing. These are used on soils which does not require great pressure for compaction. These rollers are generally used for finishing the upper surface of the soil. These roller are not used for compaction of uniform sands. Their gross weight is about 8 to10 tonnes.

Fig 2.1 Static smooth wheeled roller

Source - https://theconstructor.org/geotechnical/soil-compaction-equipments-roller-types/9389/

Vibratory smooth wheeled rollers

These are generally smooth wheeled rollers but with a single difference which is they are employed with a rotating mass or reciprocating mass which is helpful in achieving higher level of compaction. Its output is more than the normal static roller and compaction also reaches to higher depth. Their gross weight is about 8 to10 tonnes same as that of static smooth wheeled rollers.

Fig 2.2 Vibratory smooth wheeled roller

Source - https://theconstructor.org/geotechnical/soil-compaction-equipments-roller-types/9389/

Pneumatic--tyred or rubber-tyred rollers

These are generally used for the purpose of compaction of granular soils having some fines such as silty sands but these are unsuitable for hard rocks and uniform coarse-grained soils. They are mostly used for subgrade of the pavement. Their gross weight is about 200 tonnes. These rollers have a heavily-loaded wagon which is attached with many rows of wheels. All these tires have close spacing and they are almost 4 - 6 in a row. Their coverage is about 70 - 80% and the under tires contact pressure is approximately 600 - 700 KPa.

Fig 2.3 Pneumatic tyred roller

Source - https://theconstructor.org/geotechnical/soil-compaction-equipments-roller-types/9389/

Sheepfoot rollers

These are generally used for the purpose of compaction of fine grained soils like silty clays and heavy clays. Their common application is their use in compaction of soils in works like dams, Highway embankments and highway subgrade layer and in railway formations. These rollers contains steel drums over which there are fixed projecting lugs which are capable of applying a contact pressure of approx.1.4 MPa. Different types of lugs can be of various types such as spindle shaped provided with widened base and clubfoot type and prismatic type.

Fig 2.4 Sheepfoot roller

Source - https://theconstructor.org/geotechnical/soil-compaction-equipments-roller-types/9389/

b.) Dynamic compaction

This is generally used for densification and compaction of granular or sandy soil deposits. Heavy rollers can be used to compact the soil by heavy tamping process by removing air voids present in the soil. Rollins and Rogers performed various in-situ tests in which concrete block was used with a specified weight and then dropped using a cranes from a specified height on the soil. Approximate weight of the hammer is kept from 8-35 metric tons and height of free fall of drop of hammer is kept in between 7.5 - 30.5 m. The conclusion was indicated as that the final collapse settlement was decreased to approximately 1% of the initial value i.e., value of the previous untreated soil. After the compaction of soil up to 95% of its dry unit weight, the bearing capacity is increased by approx. 23–30 % and there is a decrease in the collapse potential of approx. 0.15–0.23 from its previous value for untreated soil.

c.) Prewetting

Prewetting is the technique in which the soil which is expected to show collapsing behavior on flooding or wetting by water or upon saturation before the structure is built, soil collapse can be reduced after the structure is built, Prewetting can be used as it is easiest and least expensive treatment but it is completely unable to reduce collapse potential of the soil.

d.) Stone Columns

Stone column method is suitable for collapsible soil with low fines. In this we use a vibrating unit which vibrates horizontally with an inside eccentric weight and it also has two water jets one at the top and other at the bottom of the unit. Generally the subgrade is improved with compaction and Prewetting prior to the placing the get better results of high bearing capacity and much lower settlement.

e.) Chemical Stabilization

Soil properties are modified by improving the engineering properties of soil using addition of chemical substances called stabilizers. Generally adopted methods are lime stabilization in which lime is used as a stabilizer and cement stabilization in which cement is used as a stabilizer, other than that we can use various chemical additives such as soil treatment with salts like ammonium sulphate

$(NH_4)_2SO_4$ and potassium chloride KCL. Sometimes, fly ash is also added to the soil-lime mix and soil-cement mix for enhancing the properties of the stabilized soil. As the lime or cement content is increased, compression of the soil is decreased and collapse potential is also decreased to negligible for these treated soils. In the foundation trenches, we flood these trenches with solution of sodium silicate and $CaCl_2$ (calcium chloride) and cause stabilization of the soil. Stabilized soil will approx. behave like a soft sandstone and soil collapse will be resisted considerably. But these solutions must reach to desired depth if the results need to be obtained as per requirement.

Fig 2.5 Chemical Stabilization

Source - http://civilengineersforum.com/chemical-stabilization/

2.2 EXPERIMENTAL TESTS

2.2.1 Liquid Limit and Plastic Limit Tests:

Objective: - To determine liquid limit and plastic limit of the soil.

Apparatus: - Casagrande's liquid limit device ASTM, BS grooving tool, Glass plate 20 x 15 cm, 425 micron I.S. Sieve, 3 mm diameter rod, Balance (0.01gm sensitivity), Drying oven, Measuring cylinder.

Precautions:

a. Use distilled water in order to minimize the possibility of iron exchange between the soil and any impurities in the water.
b. Soil used for liquid and plastic limit determinations should not be oven dried prior to testing.
c. The groove should be closed by a flow of the soil and not by slippage between the soil and the cup.
d. After mixing distilled water to the soil sample, sufficient time should be given to permeate the water throughout the soil mass.

e. Wet soil taken in the container for moisture content determinations should not be left in the air even for some time, the containers with soil samples should either be placed in desiccators or immediately be weighed.
f. For each test, cup and grooving tool, should be clean.

Fig 3.1 Liquid Limit apparatus with grooving tool

Plastic Limit determination

2.2.2 Compaction Test (Proctor Test):

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

Apparatus:-

Cylinder Mould (Capacity 1000 c.c., internal dia.100 mm, effective ht. 127.3 mm), Rammer for light compaction (face dia. 50 mm. mass of 2.6 kg, free drop 310 mm), Rammer for heavy compaction (face dia50 mm, mass4.89 kg, free drop 450mm), Mould accessories (detachable base plate removal collar)

I.S. Sieves (20 mm, 4.75 mm), Balance (Capacity 200 gm sensitivity 0.01 gm), Drying oven (temperature 105°C to 11°C), Desiccators, Graduated jars , Straight edge, Spatula, Scoop.

Fig 3.2 Standard proctor apparatus with hammer

2.2.3 UCS TEST:

Object: To determine the unconfined compressive strength of soil.

Apparatus: UCS apparatus with proving ring, Dial gauge, Weighing balance, Oven, Mould (3.8 cm Dia, 7.6 cm long), Knife.

Procedure**:**

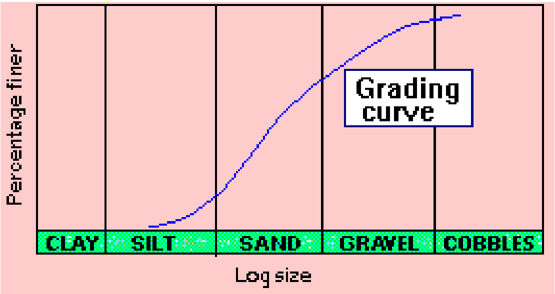
a. Prepare the sample of soil mixed at desired water content.
b. Compact the soil in mould in three layers by compaction rod.
c. Take out the sample from sampler and trim the two ends of soil specimen
d. Place specimen at bottom of UCS machine.
e. Adjust dial gauge and proving ring to zero.
f. Apply the load through compression machine and record proving ring reading at equal interval of dial gauge reading up to failure of sample.

Fig 3.3 Unconfined compressive strength apparatus

2.2.4. Particle size distribution:

It is used to classify coarse grained soils as gravel or sand as well as their gradation, and it is also very helpful in understanding the chemical and physical properties of hard rocks and given soils.

For fine grained soils, we use hydrometer method and pipette method. In both methods basic principle and procedure is same but the method of measuring observations are different. In this Indian soil classification system is used.



Classification of soil according to Collapse potential

Based on Clonjer criterion (1959)

Dry density (g/cm3)	Collapse potential
≤ 1.27	High C.P.
1.27 – 1.44	Medium C.P
≥ 1.44	Low C.P.

Based on Jenninger criterion (1975)

Severity of Problem	Collapse potential (%)
No Problem	1.0 – 0.0
Relatively Problematic	5.0 – 1.1
Average	10.0 – 5.1
Relatively high	20.0 – 10.1
High	20.0 <

Based on ASTM based Collapse Index classification

Severity of Problem	Collapse potential (%)
No Problem	0.0
Relatively Problematic	2.0 – 0.10
Average	6.0 – 2.1
Relatively high	10.0 – 6.1
High	10.0 <

Analysis of Collapsible Soil

The soil used in the present study is Silty Sand obtained from the field of Leh (Ladakh) of Jammu & Kashmir state of India. Laboratory tests were conducted to determine various engineering properties and index properties of Silty Sand according to Indian Standards methods of testing.

Fig 4.1 Untreated Collapsible soil sample

3. Experimental Work

3.1. Index Properties (For Untreated Soil Sample)

3.1.1. For Bulk density:

Weight of mould (m_m) = 4250 g, Volume of mould (V) = 960 cm^3

S.No	% Water added	Mass of Water added	Mass of mould + Mass of soil (M_m + M_s) (gm)	Mass of soil In mould (gm)	Bulk density (ρ) = (M_s / V)
1.	4	130	6034	1774	1.648
2.	7	220	6066	1806	1.682
3.	10	310	6178	1918	1.718
4.	13	380	6274	2024	1.808
5.	16	470	6196	1946	1.927

Table 2.1 Bulk density calculation

For water content:

S. No.	Mass of sampler (m_m in gm)	Mass of sampler+ moist soil	Mass of Sampler+ dry soil	Mass of moist soil (m_m)	Mass of dry Soil(m_s)	Mass of water (m_w)	Water content (w %) $(m_w/m_s)*100$
1.	6.37	14.73	13.84	8.362	7.472	0.89	8.91
2.	6.69	17.04	15.92	10.35	9.226	1.12	10.14
3.	16.46	28.44	26.66	11.98	10.20	1.78	17.45
4.	6.97	19.28	17.23	12.31	10.26	2.05	11.03

Table 2.2 water content calculation

From curve we found, Water content (w) = 9.7 %

Dry density determination:

S. No.	Bulk Density (Υ)	Water content (w %)	Dry density $\Upsilon_d = (\Upsilon/(1+w))$g/cm^3
1.	1.848	11.91	1.651
2.	1.882	14.23	1.678
3.	1.998	16.78	1.702
4.	2.108	21.03	1.731
5.	2.027	22.35	1.657

Table 2.3 Dry density calculation

From curve we found, $\Upsilon_d = 1.731$ gm/cm^3 or 17.31 kN/m^3, O.M.C = 21 %

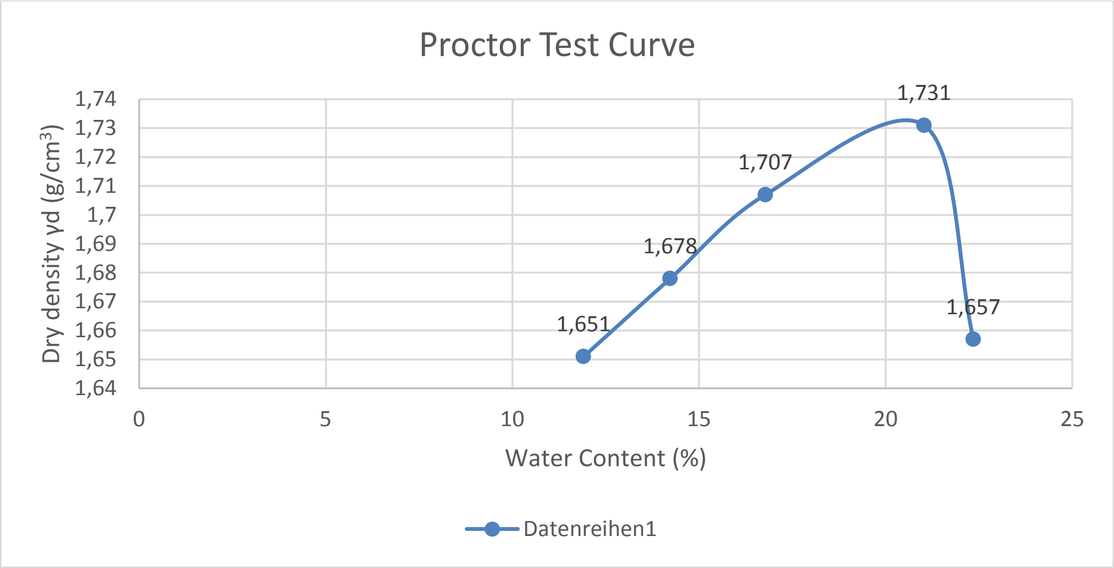


Fig 4.2 Proctor Test curve

3.1.2. Liquid Limit determination:

S. No.	No. of blow	Mass of sampler (M_e) in gm	Mass of sampler + Moist soil (M_e + M_m) in gm	Mass of sampler + Dry soil ($M_e + M_s$)	Mass of moist soil (m_m) in gm	Mass of Dry soil (m_s)	Water content (w in %)
1.	14	5.46	11.79	9.98	6.39	4.58	54.52
2.	21	5.39	11.51	9.90	6.12	4.51	51.48
3.	29	15.63	26.17	23.77	10.54	8.14	42.37
4.	41	5.36	13.84	12.39	8.48	7.63	32.67

Table 2.4 Liquid limit calculation

No. of blow	% water content
14	57.35
21	51.48
29	42.37
41	32.67

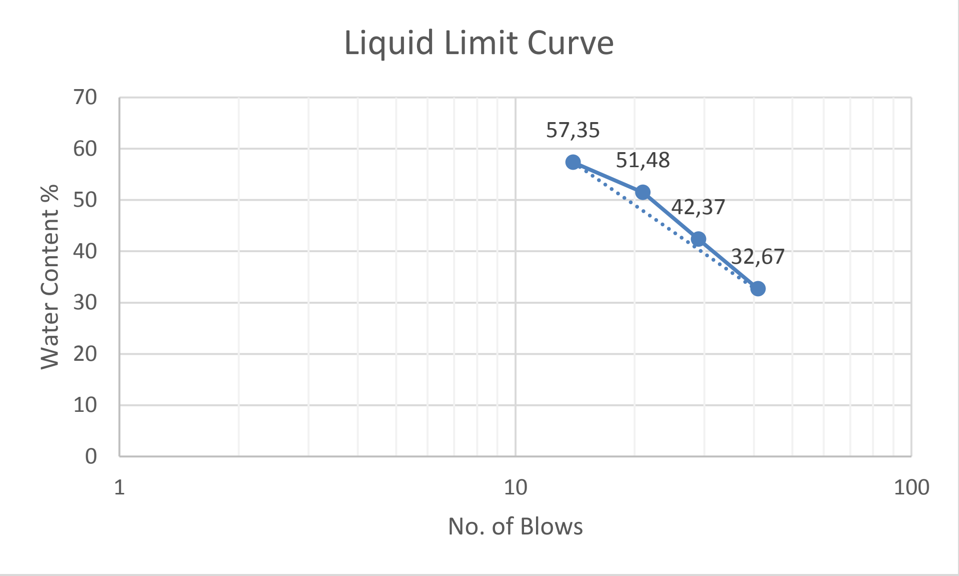


Fig 4.3 Liquid limit curve

Liquid Limit of soil sample = 45 %.

Plastic limit determination:

S. No.	Mass of sampler (m_e) in gm	Mass of sampler + moist soil in gm ($m_e + m_m$)	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)	Mass of water (m_w) in gm	Water content w = (m_w/m_m)*100 %
1.	5.79	9.73	9.09	4.52	3.57	0.96	22.54
2.	5.98	9.61	8.91	3.43	2.63	0.68	23.11
3.	5.67	9.47	8.78	3.61	2.79	0.73	24.41

Table 2.5 Plastic limit calculation

Plastic Limit = 23.5 %, Plasticity Index = 21.5 %

Plasticity Index of A-Line = 0.73(w_L-20) = 0.73(45-20) = 18.25%

So, P.I of the sample is above A-LINE, Hence, Soil is CL-ML.

3.1.3. Specific gravity calculation:

m_1 = Mass of empty bottle = 694.97 gm

m_2 = Mass of empty bottle + mass of dry soil = 856.45 gm

m_3 = Mass of empty bottle + mass of water + mass of dry soil = 1665.31 gm

m_4 = Mass of empty bottle + mass of water = 1567.53 gm

Specific gravity is given by

$G = (m_2 - m_1)/ (m_4 - m_3 + m_2 - m_1) = 161.48/ (161.48 - 101.87) = 2.71$

3.1.4. Grain Size Distribution:

S.No.	Sieve size	Mass of soil retained in each sieve in gm	Percentage retained (%)	Cumulative percentage retained on each sieve	% finer
1.	4.75 mm	4.1	0.41	0.41	99.59
2.	2.36 mm	7.9	0.79	1.56	98.44
3.	1.18 mm	13	1.3	2.86	97.14
4.	600µ	57.9	5.79	8.65	91.35
5.	300µ	47.3	4.73	13.38	86.62
6.	180µ	98.7	9.87	23.25	76.75
7.	75µ	178.1	17.81	41.06	58.94
8.	Pan	589.4	58.94	100	0.00

Table 2.6 Grain-size-distribution-table

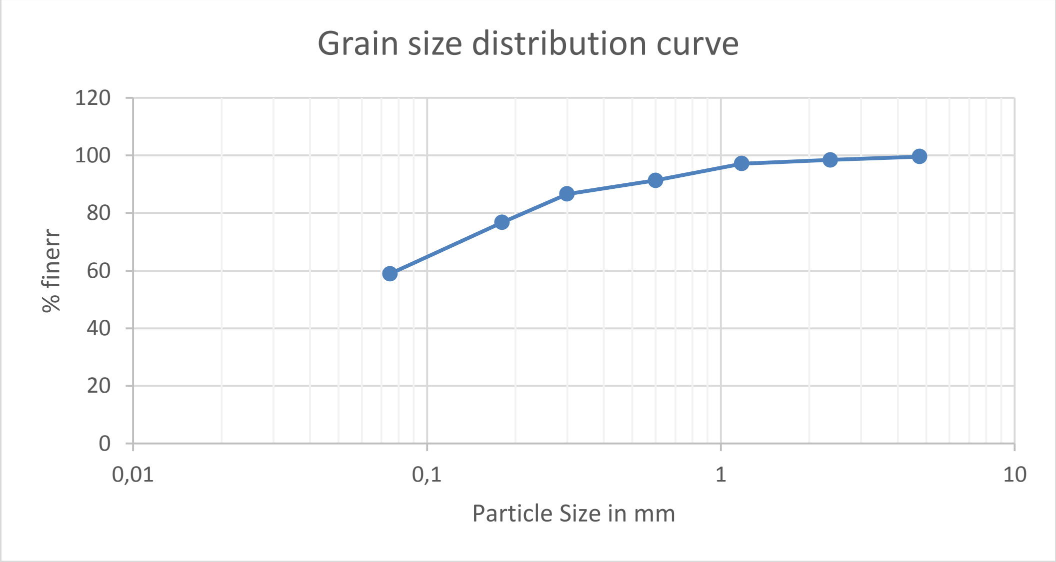


Fig 4.4 Grain-size-distribution-curve

3.1.5. Unconfined compressive strength (UCS) calculation

Fig 4.5 Soil specimen for unconfined compressive strength of soil

S.No.	Dial gauge reading	Strain (€) reading	Proving Ring reading	Corrected Area(in mm^2)	Load(in N)	Axial Stress (MPa)
1.	25	0.0032	67	19.68	78.12	0.0651
2.	50	0.0063	79	19.77	89.33	0.0748
3.	75	0.0097	91	19.85	105.61	0.0797
4.	100	0.0121	99	19.96	113.53	0.0829
5.	125	0.0153	105	20.03	119.32	0.0865
6.	150	0.0178	97	20.11	111.87	0.0813
7.	175	0.0201	92	20.18	107.46	0.0802

Table 2.6 unconfined-compressive-strength-of-the-soil

3 day UCS Value = 73 KPa = 0.073 MPa

Characteristics of untreated soil

Properties	Observed Values

Colour	Yellowish Brown
Natural water content (w %)	9.7
Dry unit weight (kN/m^3)	16.7
Specific gravity	2.7
Clay content (%)	18
Liquid limit (%)	45
Plastic limit (%)	23.5
Plasticity index (%)	21.5
Optimum moisture content (%)	21
Maximum dry unit weight (kN/m^3)	17.31

Table 2.7 Characteristics-of-the-untreated-soil

Soil Stabilization

4.1 Effect of addition of stabilizers in Untreated Collapsible Soil

4.1.1 Effect on Liquid limit, Plastic Limit and Plasticity Index of the soil

Proportion	Liquid limit (%)	Plastic limit (%)	Plasticity Index (%)
US + 0% Lime + 0% Cement	45	23.5	21.5
US + 3% Lime + 0% Cement	42.5	24.7	17.8
US + 3% Lime + 3% Cement	41.1	26.2	14.9
US + 3% Lime + 5% Cement	38.7	27.3	11.4
US + 5% Lime + 0% Cement	41.8	25.6	16.2
US + 5% Lime + 3% Cement	39.8	27.1	12.7
US + 5% Lime + 5% Cement	37.4	28.7	8.7

Table 3.1 Variation in Liquid limit, Plastic Limit and Plasticity Index of the soil

where,

US = Untreated Soil

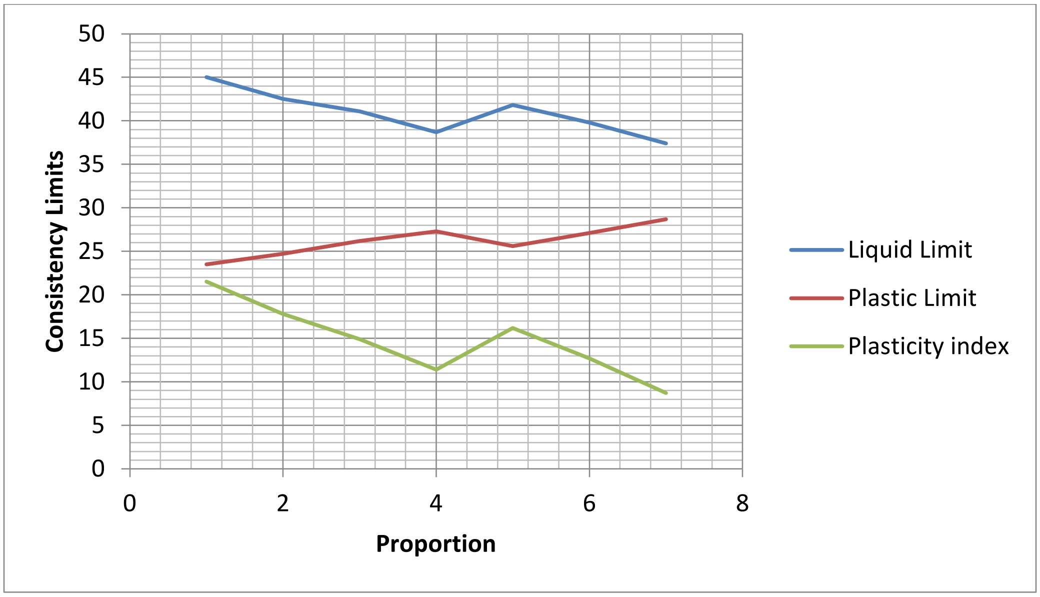


Fig 5.1 Variation of Consistency limits with soil proportion

4.1.2 Effect on Max. Dry density and Optimum water content of the soil

Proportion	Max. Dry density (KN/m^3)	Optimum water content (%)
US + 0% Lime + 0% Cement	17.31	21.1
US + 3% Lime + 0% Cement	17.33	22.3

US + 3% Lime + 3% Cement	17.51	21.7
US + 3% Lime + 5% Cement	17.63	21.4
US + 5% Lime + 0% Cement	17.45	24.1
US + 5% Lime + 3% Cement	17.79	23.9
US + 5% Lime + 5% Cement	17.98	23.2

Table 3.2 Variation in Max. Dry density and Optimum water content of the soil

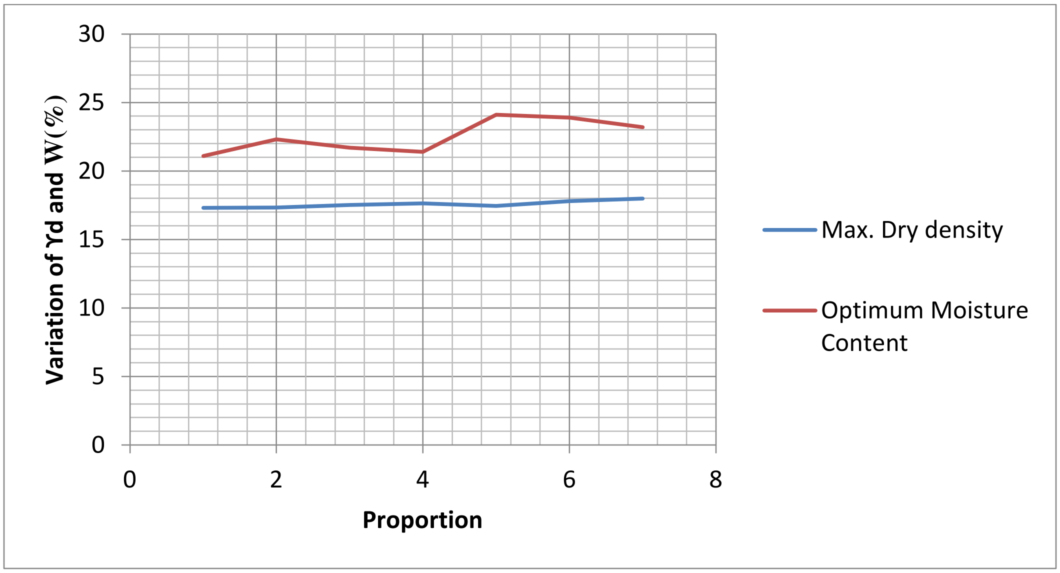


Fig 5.2 Variation of Maximum dry density and optimum moisture content with soil proportion

4.1.3 Effect on unconfined compressive strength of the soil

Proportion	UCS (3 days in KPa)	UCS (7 days in KPa)
US + 0% Lime + 0% Cement	74	135
US + 3% Lime + 0% Cement	79	149
US + 3% Lime + 3% Cement	231	278
US + 3% Lime + 5% Cement	342	429
US + 5% Lime + 0% Cement	81	157
US + 5% Lime + 3% Cement	351	453
US + 5% Lime + 5% Cement	427	491

Table 3.3 Variation-in-Unconfined-compressive-strength-of-the-soil

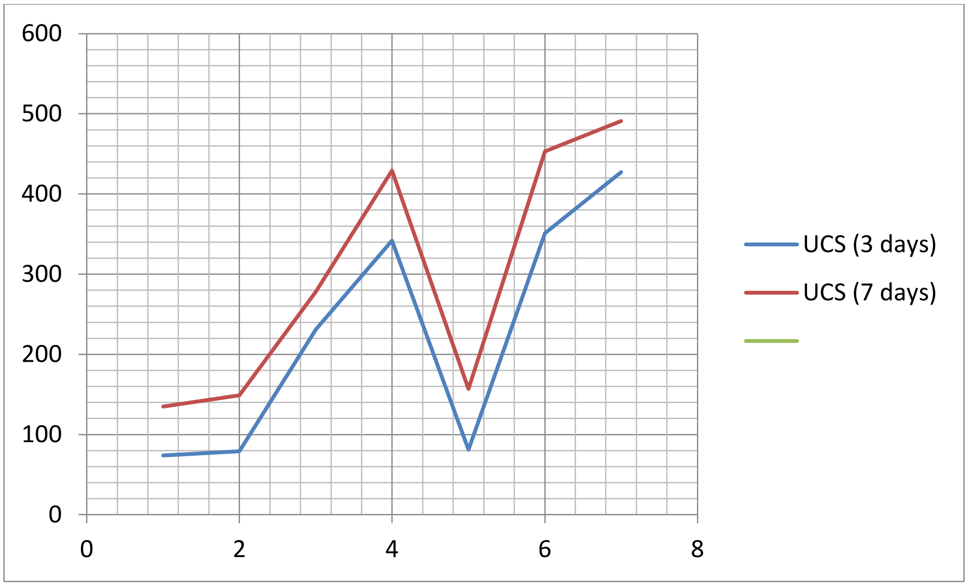


Fig 5.3 Variation of Unconfined compressive strength with soil proportion

Analysis of Concrete Pavement

There have been a huge change in the design methods for concrete pavements. Earlier there were purely empirical methods and now there are modern mechanistic empirical methods. As high speed micro-computers and complex testing methods are nowadays available, the trend is shifting towards mechanistic methods is apparent.

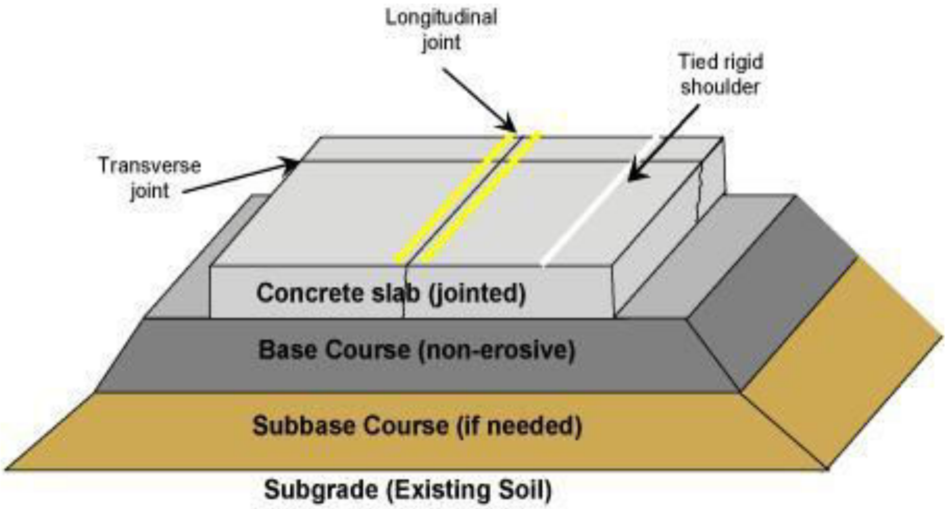
5.1. Basic structural parts of concrete pavements:

Rigid pavements are made up of Portland cement concrete. The first concrete pavement was built in Bellefontaine, Ohio in 1893.These consist of three layers i.e. surface layer, base layer and the subgrade. The rigid pavements have very high flexural strength and can be resist very high tensile stresses. Rigid pavements possess noteworthy 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, Soil sub grade.

They are made of Portland cement concrete either plain, reinforced or pre – stressed. The plain cement concrete (PCC) are expected to take up about 4 N/mm^2 flexural stress.

Fig.6.1 Concrete pavement cross sectional view



Source - https://theconstructor.org/transportation/types-of-pavement-flexible-and-rigid-pavement/9570/

Rigid pavements are analyzed by the Westergaard's plate theory since 1920, instead of the layered theory. Plate theory is a simplified version of the layered theory. We assume that the concrete slab like a medium thick plate with a condition of plane before bending remaining plain after bending. Layered theory can be used for flexible pavements but not on rigid pavements because Plain cement concrete is stiffer and also distribute load to a much wider area. Also, concrete pavements have joints making it unsuitable for layered theory.

First subgrade is prepared and then concrete slab is placed directly on that or on a single or double layer of granular stabilized material. Because there is only one layer of the material under the concrete and above the sub grade, we can call it as a base course.

The most extensive theoretical studies on the stresses and deflections in concrete pavements were made by Westergaard, who developed equations due to temperature curling as well as three cases of loading: load applied near the corner edge of a large slab, load applied near the edge of a large slab but at a considerable distance from any corner, and load applied at the interior of a large slab at a considerable distance from any edge. The analysis was based on simplifying assumption that the reactive pressure between the slab and the sub grade at any given point is proportional to the deflection at that point, independent of the deflections at any other points. This type of foundation is called as a liquid or Winkler foundation. Westergaard also assumed that the foundation and the subgrade were in full contact.

5.2. Important Terms

Modulus of sub-grade reaction (k)

Modulus of sub-grade reaction is denoted by ‘K’ and is defined as the stress sustained by the rigid plate of diameter of about 75mm – 125mm deflection, the reaction is assumed to be proportional to deflection. The rigid pavement slab acts as very thin elastic plate which is resting on soil sub-grade which is in the form of dense liquid.

Relative stiffness of slab (l)

As some resistance is also offered by sub-grade soil against slab deflection therefore we consider the deformation of sub-grade soil to be same like the deformation or deflection of slab therefore the deflection of slab is direct measurement of the sub-grade pressure. This radius of relative stiffness is also responsible in relating the slab deflection with the stress in the sub-grade.

$$l = \sqrt[4]{\frac{Eh^3}{12k(1-\mu^2)}}$$

Equivalent radius of resisting section (b)

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.

$$b = \left\{ \sqrt{1.6a^2 + h^2} - 0.675h \quad if\ a < 1.724h, (other\ wise\ a) \right.$$

a = wheel load radius of load distribution (in cm)

h = thickness of slab (in cm)

Westergaard’s analysis

Load stresses in the corner (S_c) in kg/cm^2 can be calculated as per Westergaard analysis by

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

P = wheel load (in kg)

a = radius of equivalent circular contact area (in cm)

r = radius of relative stiffness

As corners are relatively free to warp, temperature stresses at the corners are almost negligible and hence they are ignored.

Load stresses in the edge region (S_e) in kg/cm^2 can be calculated by

$$S_e = \frac{0.572P}{h^2}\left[4\log_{10}\frac{l}{b} + 0.359\right]$$

P, a, l have their usual meanings.

Load stresses due to interior loading (S_i) in kg/cm^2 are

$$S_i = \frac{0.316P}{h^2}\left[4\log_{10}\frac{l}{b} + 1.069\right]$$

P, a, l have their usual meanings.

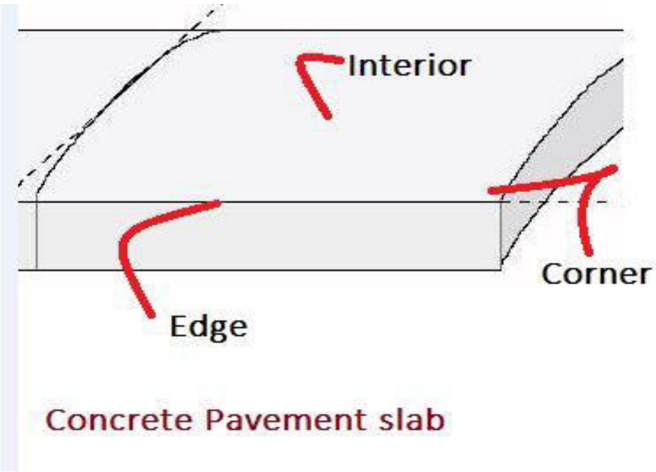


Fig.6.2 Critical stress regions

Source - http://transportationengineering2012onwards.blogspot.com/2014/02/critical-stress-combination-for-rigid.html

Temperature stresses

Variations of temperature of surroundings of road leads to the acting of temperature stress in the concrete pavements. Main reasons are:

- Daily temperature variation such as in morning and in afternoon and in evening which causes the gradient along the thickness of cement concrete pavement. This contributes in warping stresses.
- Seasonal temperature variation such as in summer and in winter and in rainy season which causes homogeneous change of temperature of slab. This contributes in frictional stresses.
- Combined effect of many stresses like wheel load stress etc. stresses results in to 3 critical cases.

Warping stress at the corner, interior and edge are represented as σ_{tc}, σ_{ti}, σ_{te} equation are:

$$\sigma t_{\iota} = \frac{E\epsilon t}{2}\left(\frac{C_{x+\mu C_y}}{1-\mu^2}\right)$$

$$\sigma\dot{t}_e = max\left(\frac{C_{xE\epsilon t}}{2}, \frac{C_{yE\epsilon t}}{2}\right)$$

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

ϵ = coefficient of thermal expansion for concrete in 10^{-7} °C.

$C_{x,}$ C_y = coefficients based on L_x/l and L_y/l in corresponding direction.

μ = Poisson’s ratio = 0.15

a = contact area in mm^2

Frictional stress σ_f (in kg/cm^2) is

$$\sigma_f = \frac{\dot{}Wlf}{2x10^{24}}$$

f = friction coefficient

W = unit weight of concrete = 24 kN/m^2

Design of Rigid Pavement

6.1. IRC Recommendation for Design

Limits of legal axle load

Single Axle	102 kN = 10200 kg
Tandem Axle	190 kN = 19000 kg
Tridem Axle	240 kN = 24000 kg

Table 5.1 Limits of legal axle load

Fig 6.3 Load representation

Safety factors for load

National highways (NH) and state highways (SH)	1.2
Highways having low truck traffic	1.1
Residential area streets	1.0

Table 5.2 Safety factors for load

Traffic Design

$$C=\frac{365[(1+r)^n-1]}{r}A \qquad \text{(where, } A=P(1+r)^x\text{)}$$

A = Number of axles /day after the road use starts put into function.

r = Growth rate of commercial traffic per year.

n = Design period which is usually in years about 20 to 30.

x = Number of years spent or required for the completion of construction of the highway.

Tyre pressure = 7 - 10 kg/cm^2 and 8 kg/cm^2 (if thickness of pavement $\geq$20cm).

Design of a rigid pavement mainly has two stages which are:

1. Design of the concrete material i.e. designs mix of the concrete.
2. Design of the slab.

6.2. Design of the concrete Mix

Design of concrete mix used in the concrete slab construction process is done using IS 10262-2009 and guidelines of design followed for concrete are as per guidelines of IRC 58-2002:

For cement

Grade of cement = OPC 43 (conforming to IS 8112)

Min. cement-content = 330 kg/m^3

Max. Cement-content = 440 kg/m^3

Maximum water-cement ratio = 0.45

Specific gravity of cement = 3.15

Initial setting time of cement = 45 min

Final setting time of cement = 10 hours

Compressive strength of cement = 43 MPa

Assume water cement ratio = 0.40 <0.45 (From table 5 of IS 456:2000)

For concrete

Grade of concrete = M45

Degree of workability = 95 mm

Characteristic compressive strength = 45 MPa

Maximum size of aggregates = 20 mm

Corrected proportion of volume of coarse aggregate = 0.59

Volume of coarse aggregate = 0.59 x 0.91 = 0.537

Volume of fine aggregate = 1 - 0.537 = 0.463

For Mix

Volume of concrete = 1 m^3

Volume of cement = mass/specific gravity of cement = 350/ (3.15x1000) = 0.109 kg/m^3

Volume of water = mass/specific gravity of water = 140/1000 = 0.137 kg/m^3.

6.3. Compressive strength of concrete or cube testing

We can use two sizes of cubes either of 15 cm x 15 cm x 15 cm or 10cm x 10 cm x 10 cm depending upon the sizes of aggregates used. We are using cubes of size 15 cm x 15cm x 15cm.

Procedure:

a. Cement and fine aggregates are mixed on water tight and non - absorbent base until the mixture is thoroughly blended and attains uniform colour.
b. Then coarse aggregates are added and mixed with mix until they are uniformly distributed throughout the batch.
c. Then water is added to the mix until the concrete appears to be homogeneous and of the desired consistency.
d. Now Moulds are cleaned and on its inner surface oil is applied.
e. Concrete is poured in the mould in layers of thickness of 5cm approx. and to remove voids temper it properly.
f. Each layer is compacted with at least 35 strokes per layer using a tamping rod (steel bar 16mm dia and 60cm long).
g. Then level the top surface using a trowel.
h. After 24 hours these test specimens are removed and put in water for curing.
i. Temperature of water bath must be about 27°C.
j. After curing of 7 days or 28 days these specimens are tested on compression testing machine.
k. Load must be applied gradually at the rate of 140 kg/cm^2 per minute till the failure of the specimens.
l. Load at the failure divided by area of specimen gives the compressive strength of concrete.

Calculations (for prepared plain concrete)

S.No.	Size of cube	Curing time	Rate of load applied	Failure load	Compressive str. In MPa
1.	15 x 15 cm	7days	140kg/cm^2/min	305	13.33N/mm^2
2.	15 x 15 cm	7days	140kg/cm^2/min	320	13.55 N/mm^2
3.	15 x 15 cm	28days	140kg/cm^2/min	785	34.44 N/mm^2
4.	15 x 15 cm	28 days	140kg/cm^2/min	795	34.88 N/mm^2

Table 5.3 Compressive strength test results

Fig 6.4 Compression testing machine and vibrator in concrete laboratory

<u>6.4. Design of the slab (IRC 58-2002)</u>

6.4.1. Thickness calculation of concrete pavement

- Concrete flexural strength, (f_{ck}) in MPa =4.41N/mm^2
- Effective modulus of Subgrade reactions (k) = 9.6 Kg/cm^2
- Elastic modulus of concrete = 300000 Kg/cm^2
- Poisson ratio (μ) = 0.15
- Tyre pressure (p) = 0.784 MPa
- Coefficient of thermal expansion, (α) = 0.00001 per ^{o}C
- Traffic growth rate increase, r = 7.5 % = 0.075
- Contraction joints spacing, L = 4.5m

- Slab width, B = 3.5m
- Value of present traffic = 3600cv/day
- Design life in years = 30 years
- Difference in temperature in degree Celsius =21^{o}C
- Cumulative repetitions of vehicles in design life = 135867810
- Value of design traffic = 33967103

  We assume the thickness of pavement = 33cm.

  Load safety factor = 1.2.

  Thickness is safe and acceptable as cumulative fatigue life ≤ 1.

6.4.2. Temperature stress calculations

- Length of slab (L) = 4.50 m
- Width of slab (B) = 3.50 m
- Radius of relative stiffness (l) = 1.03 m
- Ratio (L/l) = 4.38
- Bradbury's coefficient © = 0.55
- Edge warping stress = 1.699 MPa

  Now as the value of total temperature warping stress + highest axle load stress (40.325 Kg/cm^2) ≤ 45 Kg/cm^2 (4.41 MPa),, Therefore. Thickness assumed is safe.

6.4.3. Corner, edge and interior of the pavement stress calculations

- Single axle Wheel load in kg (P) (according to IRC) = 102 KN
- Modulus of elasticity of concrete pavement(E) = 300000 kg/cm^2
- Trial thickness of pavement in cm (h) = 0.33 m
- Poisson ratio (μ) = 0.15
- Modulus of sub-grade reaction of soil (k) = 8.3
- Radius of area of contact surface (a) = 0.14 m
- Radius of relative stiffness (l) = 102.48 cm
- Radius of area of contact surface(a)/Thickness of pavement (h) = 0.42
- Equivalent radius of resisting section(b) = 0.15 m
- Stress at corner (S_c) = 16.74 kg/cm^2 = 1.674 MPa
- Stress at edge (S_e) = 7.367 kg/cm^2 = 0.737 MPa
- Stress at interior (S_i) = 14.98 kg/cm^2 = 1.498 MPa

Assumed thickness of pavement = 33cm is safe as flexural strength of cube ≥ (temperature stress +corner) stresses.

Conclusions and Results

Various experimental tests were performed on the soil and many index properties were found as:

Properties	Observed Values
Colour	Yellowish Brown
Natural water content (w %)	9.7
Dry unit weight (kN/m^3)	16.7
Specific gravity	2.7
Clay content (%)	18
Liquid limit (%)	45
Plastic limit (%)	23.5
Plasticity index (%)	21.5
Optimum moisture content (%)	21
Maximum dry unit weight (kN/m^3)	17.31

On addition of Lime and Cement the effect on Liquid limit, Plastic Limit and Plasticity Index of the soil

Proportion	**Liquid limit (%)**	**Plastic limit (%)**	**Plasticity Index (%)**
US + 0% Lime + 0% Cement	45	23.5	21.5
US + 3% Lime + 0% Cement	42.5	24.7	17.8
US + 3% Lime + 3% Cement	41.1	26.2	14.9
US + 3% Lime + 5% Cement	38.7	27.3	11.4
US + 5% Lime + 0% Cement	41.8	25.6	16.2
US + 5% Lime + 3% Cement	39.8	27.1	12.7
US + 5% Lime + 5% Cement	37.4	28.7	8.7

On addition of Lime and Cement the effect on Max. Dry density and Optimum water content of the soil

Proportion	**Max. Dry density (KN/m^3)**	**Optimum water content (%)**
US + 0% Lime + 0% Cement	17.31	21.1
US + 3% Lime + 0% Cement	17.33	22.3
US + 3% Lime + 3% Cement	17.51	21.7
US + 3% Lime + 5% Cement	17.63	21.4
US + 5% Lime + 0% Cement	17.45	24.1
US + 5% Lime + 3% Cement	17.79	23.9
US + 5% Lime + 5% Cement	17.98	23.2

On addition of Lime and Cement the effect on unconfined compressive strength of the soil

Proportion	**UCS (3 days in KPa)**	**UCS (7 days in KPa)**
US + 0% Lime + 0% Cement	74	135

US + 3% Lime + 0% Cement	79	149
US + 3% Lime + 3% Cement	231	278
US + 3% Lime + 5% Cement	342	429
US + 5% Lime + 0% Cement	81	157
US + 5% Lime + 3% Cement	351	453
US + 5% Lime + 5% Cement	427	491

Calculated values for the concrete pavement are:

Edge warping stress = = 1.699 MPa = 17.325 kg/cm$^{2.}$

Highest axle load stress = 40.325 kg/cm^2.

Stress at corner (S_c) = 16.74 kg/cm^2 = 1.674 MPa

Stress at edge (S_e) = 7.367 kg/cm^2 = 0.737MPa

Stress at interior (S_i) = 14.98 kg/cm^2 = 1.498 MPa

Assumed thickness of pavement = 0.33 m

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