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Effect of California Bearing Ratio on the Properties of Soil

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Abstract :*Pavements Are A Conglomeration Of Materials. These Materials, Their Associated Properties, And Their Interactions Determine The Properties Of The Resultant Pavement. Thus, A Good Understanding Of These Materials, How They Are Characterized, And How They Perform Is Fundamental To Understanding Pavement. The Materials Which Are Used In The Construction Of Highway Are Of Intense Interest To The Highway Engineer. This Requires Not Only A Thorough Understanding Of The Soil And Aggregate Properties Which Affect Pavement Stability And Durability, But Also The Binding Materials Which May Be Added To Improve These Pavement Features. The Supporting Soil Beneath Pavement And Its Special Under Courses Is Called Sub Grade. Compacted Sub Grade Is The Soil Compacted By Controlled Movement Of Heavy Compactors. The Performance Of Pavements Depends To A Large Extent On The Strength And Stiffness Of The Subgrades. Among The Various Methods Of Determining The Strength Of Subgrade The CBR Test Is Very Important. The Design Of Flexible Pavement Takes Into Account Some Important Parameters Such As Traffic Load, Material Properties Of Layers And Sub Grade Soil Properties. California Bearing Ratio Is Defined As The Ratio Of Load Required To Cause 2.5mm Or 5mm Penetration To The Standard Load Which Replaced By Material. After Getting The CBR Values Analysis Is Carried Out And Relationships Are Established Between CBR And All The Fundamental Properties Of Soil In Order To Determine Which Properties Of Soil Has More Or Less Influence. Mathematical Concepts Of Linear Regression, Power Series And Linear Series Are Applied So That Proper Relationships Are Established. In Order To Test The Validation Of The Established Relationships The Chi-Squared Test Is Carried Out. Finally, For The Design Of Flexible Pavement Parameters Such As Annual Daily Traffic, Lane Distribution Factor, Vehicle Damaging Factor, Design Traffic In MSA. Using These Data The Required Thickness Is Calculated As Per IRC: 37-2001 Guidelines.*

Keywords: *Un-Soaked CBR (California Bearing Ratio), Soil Properties, Regression, Power Series, Chi Square Test*

I. Introduction

The design of flexible pavement involves several parameters such as the wheel load, traffic intensity climatic conditions, sub grade strengths and terrain conditions. Highway sub grade may be defined as "supporting layer on which pavement and it's under coarse will rest". The thickness of road pavement is a function of sub grade strength, which intern depends upon the moisture content of the sub grade. Pavement performance is a function of volume stability, which depends on the properties of sub grade and other related variables. It is therefore, obvious that pavement design should be rationally and scientifically related to all the variables that may be expected in the design under service condition from economy point of view.

The IRC: 37-2001, "Guidelines for the design of flexible pavement", recommends the use of California Bearing Ratio Method for the design of flexible pavement. CBR is an indirect measure of shearing resistance of the material under controlled density and moisture conditions. The CBR method of design is purely empirical and has several limitations. As this approach has been accepted in our country and also since most of the pavement are designed based on this method, here an attempt has been to develop the various relationships between unsoaked CBR with soil parameters such has field density, dry density, optimum moisture content, coefficient of curvature, coefficient of cohesion etc.; using regression analysis technique.

Here why we have establishing these relationships is, if at a short interval of time it is not possible to conduct the all the experiments then at that point of time using any one of the relation established using regression analysis can be used to calculate the CBR value, based on that CBR value and using traffic axle load specified in the pavement catalogue IRC: 37-2001, we can obtain the thickness required to that interval or chainage.

II. Objective Of Study

In the present work, the following objectives are fulfilled,

2.1. To establish the relationship between soaked CBR with specific gravity of soil.
2.2. To establish the relation between soaked CBR with field density obtained by core cutter method.
2.3. To establish relation between soaked CBR with bulk density.
2.4. To establish relation between soaked CBR with dry density of soil.
2.5. To establish the relation between soaked CBR with optimum moisture content.
2.6. To establish the relation between soaked CBR with cohesion.
2.7. To establish the relation between soaked CBR with angle of internal friction.
2.8. To establish the relation between soaked CBR and liquid limit of the soil.
2.9. To calculate the estimated percentage of thickness reduction of the pavement.

III. Methodology And Data Collection

For conducting the experiments we have selected 15 soil samples from the road link connecting between Dudda to Kormangala Gate (Hassan district, Karnataka, India) at every 100m interval for a distance of 1.5 Kilometer from a depth of 3 feet below the existing pavement level. Field density test has been conducted by core cutter method. The main purpose of selecting this test location is to conduct the experiments on soil properties and then obtain the relations in order to obtain the design thickness of pavement because this road is deteriorated in a short interval of time from its reconstruction work due to various failures like stripping of bitumen layer, ruts and pot holes, etc. The tests conducted for the soil samples were confined to the Indian Standards (IS). The details of the soil samples and its properties are tabulated below in the Table.1.0. There are 15 locations included in the present work. In order to facilitate the analysis at each location, samples have been designated by a notation 'S' designated as S_{100} to S_{1500} covering a total distance of 1.5 Km.

Table.4.1Showing the Sample Designation Along With the Properties of Soil.

Sample	**SOAKED CBR(%)**	**Specific gravity (G)**	**Field density (g/cc)**	**Bulk density (g/cc)**	**Dry density (g/cc)**	**OMC (%)**	**Cohesion (C) (kg/cm^2)**	**Angle of Internal friction (ϕ)**
S_{100}	1.382	2.373	1.634	1.906	1.804	10.54	0.430	33
S_{200}	2.112	2.377	1.720	1.944	1.832	8.650	0.500	33
S_{300}	2.227	2.396	1.850	2.050	1.887	8.620	0.610	33
S_{400}	3.225	2.410	1.878	2.086	1.912	7.340	0.650	33
S_{500}	3.225	2.490	1.878	2.114	1.951	7.250	0.650	32
S_{600}	3.302	2.547	1.900	2.141	2.000	7.070	0.650	32
S_{700}	3.379	2.557	1.908	2.144	2.010	6.920	0.700	31
S_{800}	3.494	2.557	1.929	2.153	2.013	6.840	0.750	31
S_{900}	3.532	2.559	1.957	2.184	2.027	6.670	0.770	28
S_{1000}	3.763	2.568	1.974	2.195	2.046	6.350	0.830	28
S_{1100}	4.646	2.620	1.977	2.227	2.085	6.330	0.850	26
S_{1200}	4.953	2.629	1.978	2.239	2.105	6.250	1.000	25
S_{1300}	5.106	2.643	2.030	2.266	2.125	6.100	1.050	23
S_{1400}	7.141	2.657	2.066	2.305	2.150	5.610	1.150	20
S_{1500}	8.101	2.708	2.105	2.334	2.220	5.100	1.250	18

Assumptions made while analyzing the data is that, for every sub location at 100m interval there is no appreciable variation in soil characteristics and the lane carriage way details and also lane distribution factor remains same for a given location and also there is no appreciable variation in terrain condition.

The sub grade strength is accessed in terms of the cumulative number of standard axles 8160 Kg. The relative severity of axle load spectra is expressed in terms of standard axles of 8160 Kg on the basis of damaging factors (VDF) derived from the **'AASHTO'** road test irrespective of legally permitted maximum axle load. The suggested VDF's have been based on R-2 study, "study of spectrum of axle loads on National Highways". The recommendations made by **IRC: 37-2001** regarding the discussion of commercial traffic over the carriageway are based on the experience gained from the practices followed in U.K. and U.S.A. The minimum value of CBR suggested for sub grade and base for minimum thickness of component layers are based on the recommendation contained in IRC 37-2001 and the experience gained in U.K. and India. The overall thickness is evaluated as a function of sub grade soaked CBR value and cumulative standard axle.

The present study employs **Regression analysis**, which is a statistical tool for the investigation of relationships between variables. Linear regression is an approach for modeling the relationship between a scalar dependent variable y and one or more explanatory variables (or independent variables) denoted x. To ascertain the established relationships and results, chi-square test is a statistical test used to examine differences with categorical variables. The chi-square test is used in two similar but distinct circumstances, i.e. for estimating how closely an observed distribution matches an expected distribution called as **goodness-of-fit** test and for estimating whether two random variables are independent. **Power series** is effectively used to accelerate the convergence and it's a powerful tool to for approximating the values of the transcendental functions.

IV. Results And Discussions

4.1. Relationship between Soaked CBR and Specific Gravity.

Table.4.1Table showing chi-squared results for specific gravity of soil.

CBR (Oj)	Specific Gravity (G)	Expected Values (E_j)	χ^2 Calculated	χ^2 Tabled	R^2
1.382	2.373	1.891	1.531	4.07	0.853
2.112	2.377	1.923			
2.227	2.396	2.079			
3.225	2.41	2.201			
3.225	2.49	3.030			
3.302	2.547	3.782			
3.379	2.557	3.930			
3.494	2.557	3.930			
3.532	2.559	3.960			
3.763	2.568	4.098			
4.646	2.620	4.987			
4.953	2.629	5.158			
5.106	2.643	5.433			
7.141	2.657	5.721			
8.101	2.708	6.892			

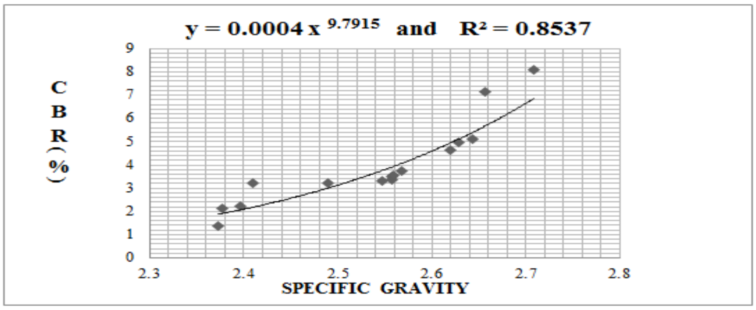

Figure.4.1 Graph plotted for specific gravity versus CBR

CBR test was conducted as per IS: 2720(Part 16)-1979 and the Specific Gravity test was done as per IS: 2720-1980. A graph is plotted between soaked CBR (%) and specific gravity and presented in above figure. It satisfies power series and the relation is having a correlation coefficient of 0.8537 which is very close to 1.0

2.5. **CBR = 0.0004(G)$^{9.7915}$**

After obtaining the required values of CBR the remaining relationships are computed. The chi-square calculated value is less than chi-square tabled value at 99.5% confidence interval which suggests that the above hypothesis is acceptable. Further as the specific gravity value increases the soaked CBR also increases.

4.2 Relationship between soaked CBR and field density.

Table.4.2 Table showing chi-squared results for Field Density of soil.

CBR (Oj)	Field Density (g/cc)	Expected Values (E_j)	χ^2 Calculated	χ^2 Tabled	R^2
1.382	1.634	1.266			
2.112	1.720	1.777			
2.227	1.850	2.878			
3.225	1.878	3.178			
3.225	1.878	3.178			

3.302	1.900	3.433	1.013	4.07	0.915
3.379	1.908	3.530			
3.494	1.929	3.795			
3.532	1.957	4.174			
3.763	1.974	4.420			
4.646	1.977	4.465			
4.953	1.978	4.480			
5.106	2.030	5.318			
7.141	2.066	5.974			
8.101	2.105	6.761			

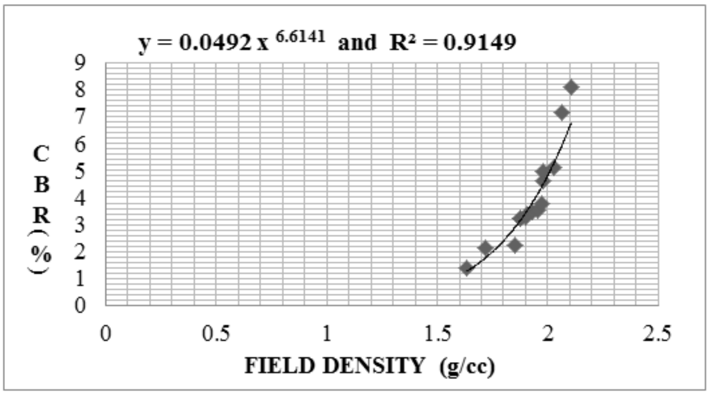

Figure.4.2. Graph plotted for Field Density versus CBR

The field density test was done as per IS: 2720-1975.A graph is plotted between soaked CBR (%) and field density and presented in above figure. It satisfies power series and the relation is having a correlation coefficient of 0.9149 which is very close to 1.0.

$$\mathbf{CBR = 0.0492}\Upsilon_f^{\mathbf{6.6141}}$$

The chi-square calculated value is less than chi-square tabled value at 99.5% confidence interval which suggests that the above hypothesis is acceptable. Further as the field density value increases the soaked CBR also increases.

4.3 Relationship between Soaked CBR and Bulk Density.

Table.4.3 Table showing chi-squared results for Bulk Density of soil.

CBR (O_j)	Bulk Density (g/cc)	Expected Values (Ej)	χ^2 Calculated	χ^2 Tabled	R^2
1.382	1.906	1.441	0.771	4.07	0.936
2.112	1.944	1.676			
2.227	2.050	2.517			
3.225	2.086	2.876			
3.225	2.114	3.186			
3.302	2.141	3.511			
3.379	2.144	3.549			
3.494	2.153	3.665			
3.532	2.184	4.089			
3.763	2.195	4.249			
4.646	2.227	4.747			
4.953	2.239	4.947			
5.106	2.266	5.422			
7.141	2.305	6.180			
8.101	2.334	6.801			

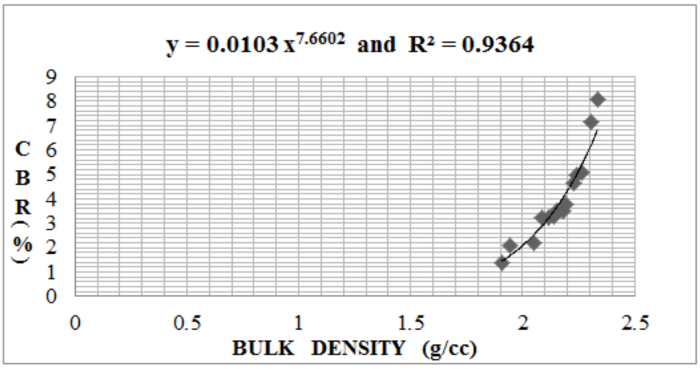

Figure.4.3. Graph plotted for Bulk Density versus CBR

The Bulk density test was done as per IS 2720:1980. A graph is plotted between soaked CBR (%) and bulk density and presented in below figure. It satisfies power series and the relation is having a correlation coefficient of 0.9364 which is very close to 1.0.

$$\textbf{CBR} = \textbf{0.0103}(\Upsilon_b)^{7.5502}$$

The chi-square calculated value is less than chi-square tabled value at 99.5% confidence interval which suggests that the above hypothesis is acceptable. Further as the dry density value increases the soaked CBR also increases.

4.4 Relationship between Soaked CBR and Dry Density.

Table.4.4Table showing chi-squared results for Dry Density of soil.

CBR (O_j)	Dry Density (g/cc)	Expected Values (Ej)	χ^2 Calculated	χ^2 Tabled	R^2
1.382	1.804	1.640	0.706	4.07	0.933
2.112	1.832	1.838			
2.227	1.887	2.289			
3.225	1.912	2.523			
3.225	1.951	2.931			
3.302	2.000	3.522			
3.379	2.010	3.655			
3.494	2.013	3.695			
3.532	2.027	3.890			
3.763	2.046	4.168			
4.646	2.085	4.794			
4.953	2.105	5.146			
5.106	2.125	5.519			
7.141	2.150	6.019			
8.101	2.220	7.632			

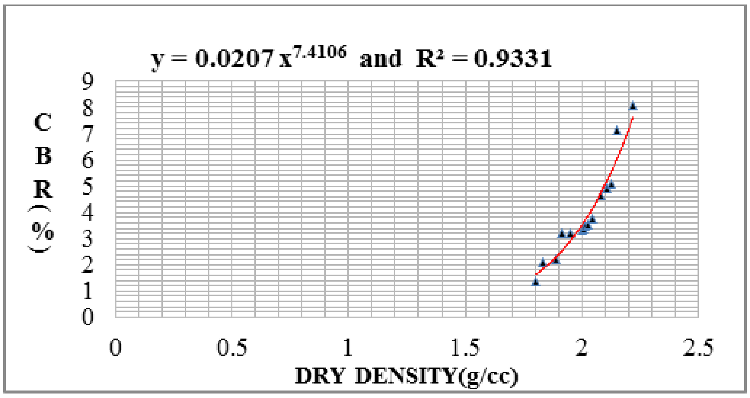

Figure.4.4. Graph plotted for Dry Density versus CBR

The dry density test was done as per IS 2720:1975. A graph is plotted between soaked CBR (%) and dry density and presented in above figure. It satisfies power series and the relation is having a correlation coefficient of 0.9331 which is very close to 1.0

$$\textbf{CBR} = 0.0207(\Upsilon_d)^{7.4106}$$

After obtaining the required values of CBR the remaining relationships are computed. The chi-square calculated value is less than chi-square tabled value at 99.5% confidence interval which suggests that the above hypothesis is acceptable. Further as the dry density value increases the soaked CBR also increases.

4.5 Relationship between Soaked CBR and OMC (Optimum Moisture Content)

Table.4.5Table showing chi-squared results for OMC of soil.

CBR (Oj)	OMC (%)	EXPECTED VALUES (Ej)	χ^2 Calculated	χ^2 Tabled	R^2
1.382	10.540	1.291	0.451	4.07	0.966
2.112	8.650	2.099			
2.227	8.620	2.117			
3.225	7.340	3.143			
3.225	7.250	3.240			
3.302	7.070	3.446			
3.379	6.920	3.633			
3.494	6.840	3.738			
3.532	6.670	3.977			
3.763	6.350	4.488			
4.646	6.330	4.523			
4.953	6.250	4.666			
5.106	6.100	4.953			
7.141	5.610	6.085			
8.101	5.100	7.692			

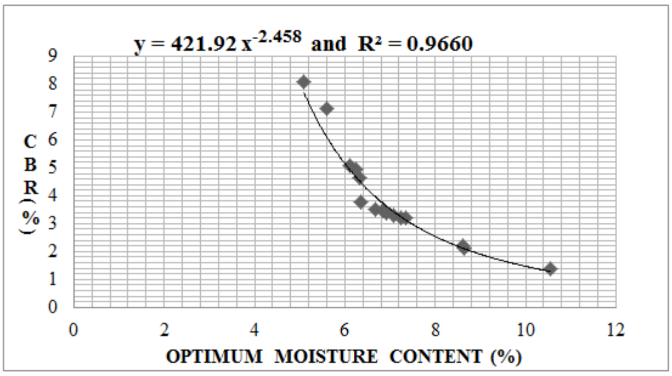

Figure.4.5. Graph plotted for OMC versus CBR

The optimum moisture content for a specific compaction effort is the moisture content at which the maximum density is obtained. A max dry unit weight would be when zero voids are in the soil. A graph is plotted between soaked CBR and OMC and presented in above figure. It satisfies power series and the relation is having a correlation coefficient of 0.966 which is very close to 1.0

$$\textbf{CBR} = 421.92(OMC)^{-2.458}$$

After obtaining the required values of soaked CBR the remaining relationships are computed. The chi-square calculated value is less than chi-square tabled value at 99.5% Confidence interval which suggests that the above hypothesis is acceptable. Further as the OMC value increases the soaked CBR also decreases.

4.6 Relationship between soaked CBR and Cohesion (C)

Table.4.6Table showing chi-squared results for Cohesion of soil.

CBR (O_j)	Cohesion (C)	Expected Values (Ej)	χ^2 Calculated	χ^2 Tabled	R^2
1.382	0.430	1.564			
2.112	0.500	1.955			
2.227	0.610	2.625			
3.225	0.650	2.884			
3.225	0.650	2.884			
3.302	0.650	2.884			
3.379	0.700	3.219			
3.494	0.750	3.565	0.523	4.07	0.948
3.532	0.770	3.707			
3.763	0.830	4.143			
4.646	0.850	4.291			
4.953	1.000	5.459			
5.106	1.050	5.869			
7.141	1.150	6.715			
8.101	1.250	7.598			

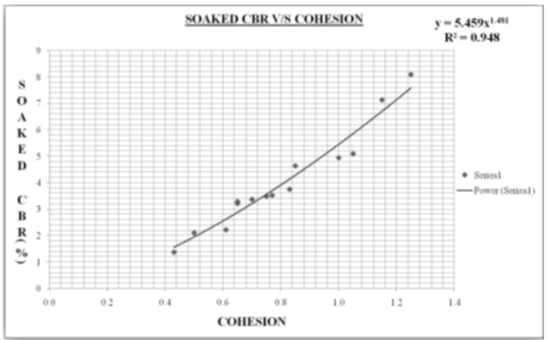

Figure.4.6. Graph plotted for Cohesion versus CBR

The triaxial shear test was done as per IS 2720:1981 and the cohesion is calculated. A graph is plotted between soaked CBR and cohesion and presented in above figure. It satisfies power series and the relation is having a correlation coefficient of 0.948 which is very close to 1.0.

$$\textbf{CBR} = 5.459C^{1.481}$$

After obtaining the required values of soaked CBR the remaining relationships are computed. The chi-square calculated value is less than chi-square tabled value at 99.5% confidence interval which suggests that the above hypothesis is acceptable. Further as the cohesion value increases the soaked CBR also increases.

4.7 Relationship between Soaked CBR and Angle of Internal Friction (ϕ)

Table.4.7Table showing chi-squared results for Angle of internal friction (ϕ) of soil.

CBR Soaked (O_j)	(ϕ)	Expected Values (Ej)	χ^2 Calculated	χ^2 Tabled	R^2
1.382	33	2.565			
2.112	33	2.565			
2.227	33	2.565			
3.225	33	2.565			
3.225	32	2.733			
3.302	32	2.733			
3.379	31	2.918			
3.494	31	2.918	1.422	4.07	0.91
3.532	28	3.598			
3.763	28	3.598			
4.646	26	4.190			
4.953	25	4.542			
5.106	23	5.393			
7.141	20	7.190			
8.101	18	8.931			

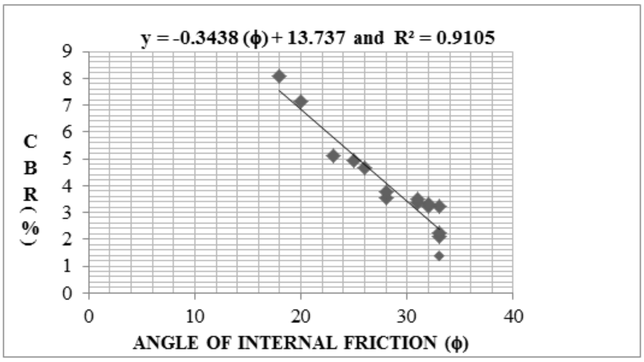

Figure.4.7. Graph plotted for (ϕ) versus CBR

The triaxial shear test was done as per IS 2720:1981 and the angle of internal friction is calculated. A graph is plotted between soaked CBR and angle of internal friction and presented in above figure. It satisfies linear series and the relation is having a correlation coefficient of 0.8822 which is very close to 1.0

CBR= -0.343(□)$^{+13.73}$

After obtaining the required values of CBR the remaining relationships are computed. The chi-square calculated value is less than chi-square tabled value at 99.5% confidence interval which suggests that the above hypothesis is acceptable. Further as the angle of internal friction value increases the soaked CBR decreases.

4.8 Relationship between Soaked CBR and Liquid limit of soil.

Table.4.8Table showing chi-squared results for Liquid Limit of soil.

CBR (O_j)	Liquid Limit (%)	Expected Values (Ej)	χ^2 Calculated	χ^2 Tabled	R^2
1.382	37.000	1.651	0.758	4.07	0.925
2.112	34.000	2.361			
2.227	33.000	2.678			
3.225	33.000	2.678			
3.225	33.000	2.678			
3.302	31.000	3.488			
3.379	31.000	3.488			
3.494	31.000	3.488			
3.532	29.500	4.302			
3.763	29.000	4.624			
4.646	29.000	4.624			
4.953	29.000	4.624			
5.106	28.000	5.363			
7.141	26.000	7.335			
8.101	25.000	8.658			

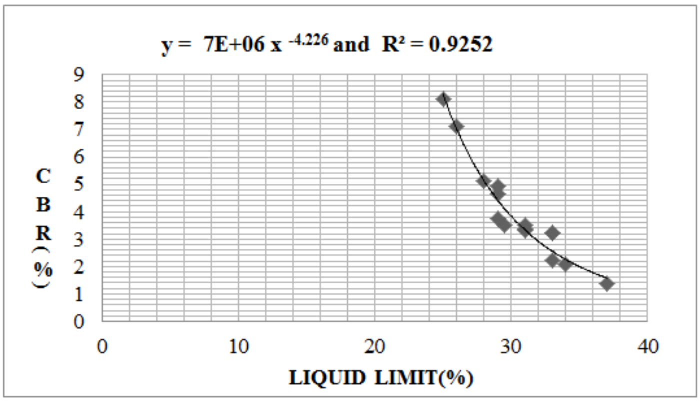

Figure.4.8. Graph plotted for liquid limit versus CBR

The liquid limit test was done as per IS: 2720-(PART V) -1985 and the liquid limit is calculated. A graph is plotted between soaked CBR and liquid limit and presented in above figure. It satisfies power series and the relation is having a correlation coefficient of 0.9252 which is very close to 1.0.

CBR = 7E+06 $(\mathbf{L.L})^{-4.226}$

After obtaining the required values of CBR the remaining relationships are computed. The chi-square calculated value is less than chi-square tabled value at 99.5% confidence interval which suggests that the above hypothesis is acceptable. Further as the limit increases the soaked CBR decreases.

V. Calculation Of Pavement Thickness And Percentage Of Reduction As Per Irc: 37-2001

Table.5.1Table showing calculated thickness and percentage of reduction.

Soaked CBR Observed (%)	Thickness (mm)	percentage of Reduction	Soaked CBR Expected (%)	Thickness (mm)	Percentage of Reduction
1.382	875	1.143	1.891	875	0.000
2.112	865	1.156	1.923	875	0.800
2.227	855	9.708	2.079	868	1.382
3.225	772	0.000	2.201	856	8.411
3.225	772	0.648	3.030	784	5.867
3.302	767	0.522	3.782	738	1.084
3.379	763	0.917	3.930	730	0.000
3.494	756	0.397	3.930	730	0.274
3.532	753	1.726	3.960	728	0.962
3.763	740	5.405	4.098	721	4.854
4.646	700	1.857	4.987	686	1.166
4.953	687	1.019	5.158	678	2.065
5.106	680	11.618	5.433	664	2.108
7.141	601	4.992	5.721	650	6.308
8.101	571	-	6.892	609	-

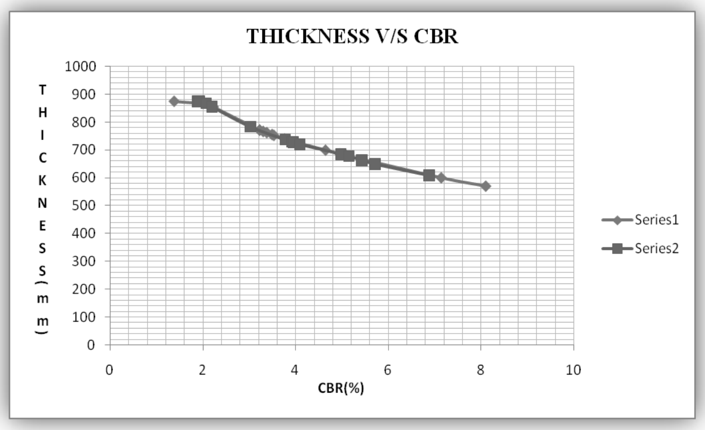

Figure.5.1 showing relation between thicknesses versus CBR.

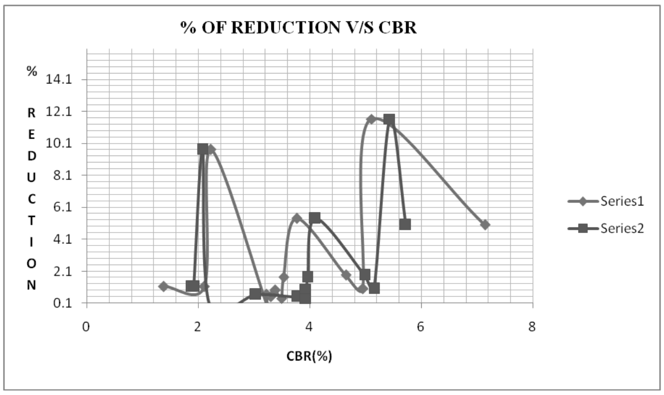

Figure.5.2 showing the relation between percentage of Reduction in thickness and CBR

VI. Conclusions

6.1 As the value of specific gravity increases corresponding soaked CBR value also increases.
6.2 As the value of field density increases corresponding soaked CBR value also increases.
6.3 As the value of dry density increases corresponding to soaked CBR value also increases.
6.4 As the value of optimum moisture content (OMC) decreases corresponding soaked CBR value increases.
6.5 As the value of liquid limit decreases corresponding soaked CBR value increases.
6.6 As the value of cohesion increases corresponding soaked CBR value also increases.
6.7 As the value of angle of internal friction (ϕ) decreases corresponding soaked CBR value also increases.
6.8 Field density, dry density, bulk density and cohesion of soil are directly proportional to CBR. This is because as the density of soil increases the soil particles become more compact to carry more loads or stresses. Therefore as CBR increases strength of subgrade increases
6.9 We have established the two curves, one is observed % of reduction versus CBR and other is expected % of reduction versus CBR. These two curves are varying in the same manner, from this we can infer that the % of reduction is varying in same manner for both observed and expected CBR.

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[6]. Is 2720 Part –8 "Method Of Test For Soil-Determination Of Water Content, Dry Density Relation Using A Heavy Compaction".