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EXPERIMENTAL ANALYSIS OF HEAVY COMPACTION AND SOAKED BEARING RATIO CHARACTERISTICS OF CLAY-SAND-GRAVEL MIXTURES

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Abstract*— The pavement structure distribute the load to the subgrade and depends on aggregate interlocking, moisture content, particle friction and cohesion for stability. The overall strength and performance of a pavement is dependent on load-bearing capacity of the subgrade soil. Subgrade structural capacity can improve the pavement load-bearing capacity and thus, pavement strength and performance. Subgrade strength is evaluated from its California Bearing Ratio value. CBR, Density, moisture content and type of soils are dominant geotechnical factors which affect the CBR value of a flexible pavement. If the subgrade is not compacted to an adequate density it will continue to compress causing pavement deformation. Soils containing gravel sized particles are generally over looked and attract much less attention than clay and sand. The present study focuses on the impact of clay fraction on heavy compaction and soaked bearing ratio behaviour of clay-sand-gravel mixture by a series of laboratory experiments. The modified compaction test and soaked bearing ratio tests were conducted on various content of clay-sand-gravel mixture. The obtained results are graphically presented and statistically analysed. Multiple linear regression analysis was used to find out relationship for California bearing ratio of soaked conditions. Analysis of the experimental data indicated that there exist a good correlation among observed value and predict value of CBR.

***Keywords*— California Bearing Ratio, Optimum moisture content, Regression analysis, Soil sub grade, Statistical Analysis**

I. INTRODUCTION

Sub grade is the bottom most component of flexible pavement which provides support to all layers. The properties of soil sub grade are important in deciding the thickness requirement of flexible pavement. It is made of superior soil and provide adequate strength to the layers above it. The strength of subgrade is accessed from CBR value. The behaviour of soil mass depends on the composite effect of amount and type of soil, size, shape and chemical composition of particle. Moisture and density influence the engineering behaviour of a soil mass. The clayey soil is widely distributed in India. Pavement construction over such soil causes a major problem due to their low bearing capacity. The physical properties especially of clay very much differs with moisture content. The presence of clay within the mix has a serious impact on cohesion and angle of internal friction. To achieve maximum structural support as measured by CBR, subgrade soil must be compacted to an adequate density. To achieve these densities, subgrade must be near or at its optimum moisture content. For moisture content slightly above the optimum value, the clay addition improves the cohesion of the mix.(Muawia, A.2013) The initial moisture content has a remarkable influence on the CBR value, and the CBR value reaches the maximum with the optimum water content. (Liu. Z et.al 2009). The quantity of clay has a significant influence on the on the performance of road pavement. The contact mechanism varies by change in the amount of clay. (Ali Firat et. al 2015) Even a small amount of clay fraction entirely governs the behaviour of whole soil mass. .(Naser.A 2001) The influence of particle size distribution on shear strength of soil has been well established. For a clay-gravel mixture, it is commonly acknowledged that increasing gravel content certainly increases constant volume friction angle. (Yanrong Li et al, 2012). The results of compaction characteristics of fine grained soils indicate that controlling the compacting moisture content is useful to improve bearing capacity of fine grained soil. (Prakash, K. et al 2014) When the percentage of fine particles exceed certain amount, the granular bearing course becomes sensitive which might imperil the pavement structure. (Babic.C et al 2000).

II. EXPERIMENTAL PROGRAM

A. Materials:

Three different type of soil - clay, sand and fine gravel were used to prepare the samples. The clay was obtained from BHAL region in Gujarat, India. It was a disturbed sample with grey colour and in dry state. Clay was prepared to pass through 425 micron, and then it was used in the analysis. The physical properties were evaluated using the standard procedures as specified by Indian Standard (IS-2720 Part 3, 4, 5, 8, 11 and 16).

TABLE I
Physical testing results of clay sample

Sr. No.	Test	Result Obtained
1	Specific gravity	2.71
2	Sand (%)	11
3	Silt + clay(%)	89
4	Liquid limit(%)	54
5	Plastic limit (%)	27
6	Shrinkage limit(%)	11
7	Plasticity Index	27
8	Free swell index (%)	44
9	Optimum Moisture Content (%)	18
10	Maximum dry density (kN/m^3)	17.1
11	Cohesion (kN/m^2)	145
12	Angle of friction (Ø°)	12°
13	CBR (%) -Un soaked condition	3.2
14	CBR (%) -Soaked condition	1.07
15	Median size (d_{50}) mm	0.0014
16	Classification	CH

Locally available sand and gravel from Sabarmati river, Ahmedabad was used in the experiment. Sieve analysis was conducted for the selection of gravel sized fraction to ensure them ranging from 10 mm to 4.75 mm.

TABLE II
Effective size for sand and gravel

Sr. No	Property	IS standard	Sand	Gravel
1	D_{10}	IS 2720 Part 4	0.32 mm	5.0 mm
2	D_{30}		0.40 mm	6.0 mm
3	D_{60}		0.50 mm	7.60 mm
4	C_u		1.56	1.52
5	C_c		1	0.94
6	D_{50}		0.48 mm	7.10 mm
7	Classification		SP	GP

B. Testing Procedure

Clay obtained from the field was dried in the sunlight and grinded to convert into powder form. and was used in the preparation of cohesive soil mixture. Clay in various proportions by weight was mixed with sand and gravel and blended to form a homogeneous mix. Nine different mixtures were prepared by varying clay content from 10% to 50 % at the increment of 5%. Sand and gravel were mixed in equal proportion by weight.

C. Modified Proctor Test:

All desirable properties are highly associated with higher unit weight which is associated with compaction. The load bearing capacity is affected by soil type, degree of compaction and moisture content. Moisture tends to affect subgrade properties like shrinkage and swelling. In order to obtain the maximum dry density and optimum moisture content , to be used for making the specimen for CBR, modified proctor test according to IS: 2720 Part 8 was conducted. The specimen were compacted in five different layers with a hammer of 4.89 kg, each layer by 25 blows. The volume of the mould was 1000cc, knowing the weight and moisture content, dry density of compacted specimen were calculated.

D. California Bearing Ratio test:

California bearing ratio test for clay-sand-gravel mixtures were conducted as per the IS: 2720 (Part-16). CBR tests were conducted under soaked condition and CBR values were evaluated to understand the effect of clay on clay-sand-gravel mixtures. Correct weight of wet soil was determined to obtain the desired density. The compaction of the sample was attained by pressing the spacer disc using a compaction machine. The subgrade does not exactly remain dry throughout the year. Moisture affects the subgrade when it exceeds the omc. It becomes weakest after rainfall. To take into effect of impact of water rainfall, as per the present Indian recommendations, the CBR samples were prepared at OMC, and soaked for four days prior to testing in order to take into account the most severe condition encountered in the subgrade soil. At the end of soaking, moulds were taken out and allowed to drain down words for 15 minutes.

III. **RESULTS AND DISCUSSION**

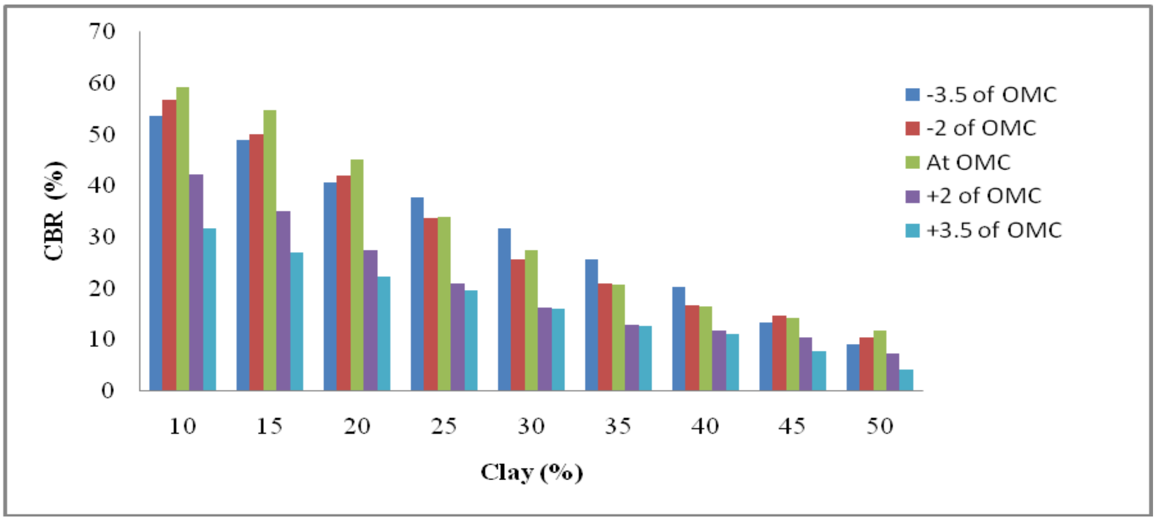

Fig. 1 Soaked CBR vs clay percentage

The CBR results with variation in clay percent are shown in Fig.(1). From the Fig.1 it is observed that soaked California bearing ratio reduces sharply between 20% and 40% of clay fraction for both dry and wet side of OMC. However on dry side of OMC showed larger value of soaked California bearing ratio and have nearly same value. Experiments conducted on OMC showed the largest range of California bearing ratio**.** It is observed that increase in fine fraction decreases the soaked CBR values, the sharp drop in the Bearing Ratio Value (59.12% to 11%) is recorded for the samples prepared at optimum moisture content. When its moisture was increased by 2% and 3.5% over the optimum, the reduction is still higher. It is revealed that beyond 20% clay fraction, the falling effect is severe. However, the BV did not decrease as significantly on dry side of OMC. In few cases, for clay percentage between 25% to 40% , the CBR on dry side is observed marginally higher than at OMC.

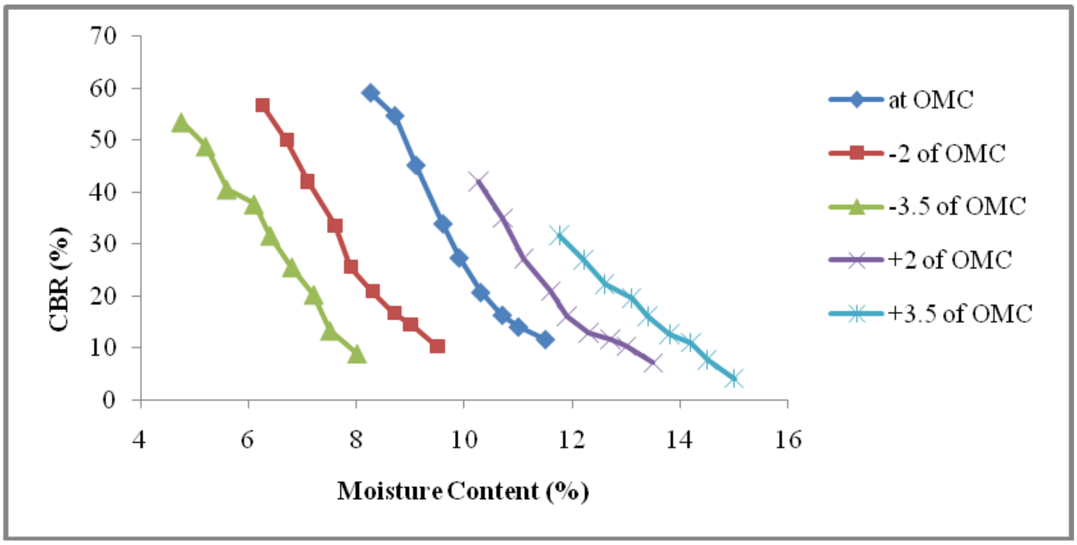

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Fig. 2 Soaked CBR vs moisture content at various clay percentage

It is clear from the Fig.(2) that CBR is maximum for the tests conducted at OMC and its value reduces as moisture content is varied from OMC. It is also evident from the figure that larger is the moisture content in the mixture smaller is the CBR value. For doing the test at saturated condition, the specimen were submerged in water tank for 96 hours after placing a filter paper on the top surface and 2.5 kg of surcharge weight.

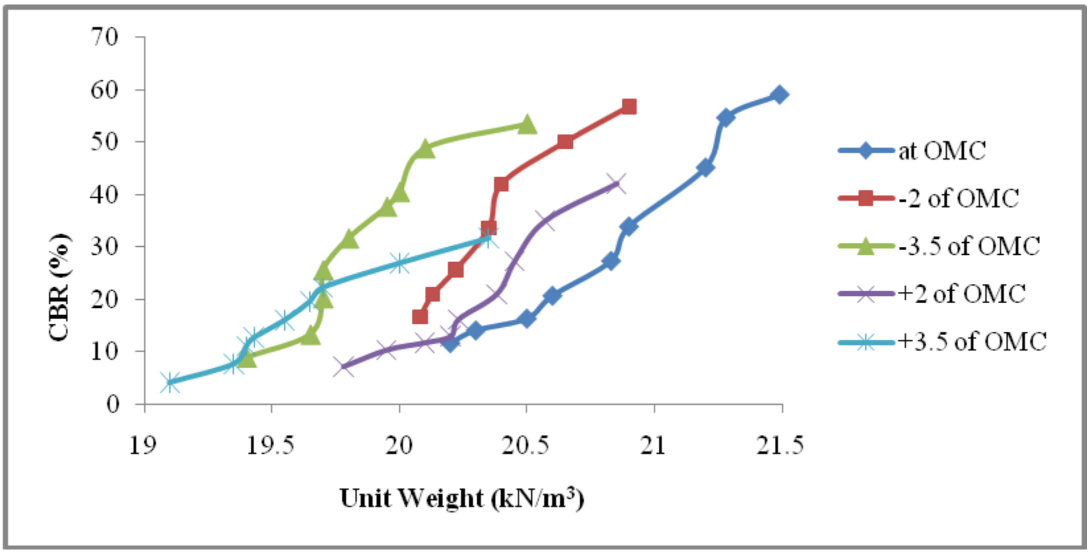

Fig. 3 Soaked CBR vs dry density at various clay percentage

The experiments were conducted under five values of dry density viz; at maximum dry density (MDD), dry density corresponding to 2% and 3.5% below and above OMC. From Fig.(3), it is evident that California bearing ratio decreases as dry density reduces in general. Maximum value of CBR is obtained in the experiments conducted at MDD.

IV **NON DIMENSIONAL RELATIONSHIP**

From the literature review, it is observed that California bearing ratio of clay-sand-gravel mixtures depends on amount of clay, dry density, moisture content, plasticity index, specific gravity of soil mixture, and shear strength parameters. Therefore, the following functional relationship can be written to compute CBR in case of clay-sand-gravel mixtures.

$$CBR = f(P_c, \gamma_d, w, PI, G, C, \phi, d_a) \tag{1}$$

Where P_c in clay percentage, γ_d is dry density, PI is plasticity index of soil mixture, w is moisture content and G is specific gravity, C is the cohesion and ϕ is the angle of friction and d_a is the arithmetic mean size of clay-sand-gravel mixture. Due to presence of gravel in soil mixtures it was very difficult to find out the plastic limit, therefore plasticity index has been dropped from the analysis. Also analysis of results showed that variation in specific gravity is minimal for all mixtures, therefore it is dropped from the further analysis (Danistan and Vipulanandan, 2011). For a soaked condition, it is very difficult to find out undrained shear parameters. Therefore, new functional relationship for CBR is written as

$$CBR = f(P_c, w, \gamma_d, da) \tag{2}$$

Using dimensional analysis, the variables of Eq. (2) can easily be arranged into the following non-dimensional form (Peerless, 1967):

$$CBR = f\left[P_c, w, \frac{\gamma_d d_a}{S}\right] \tag{3}$$

where d_a is the mean particle size of the mixture and S is the surcharge weight, 2.5 kg kept on the mould during soaking period. The functional relationship in the form of Eq. (3) can be used to develop an expression for the computation of California bearing ratio of clay-sand-gravel. Taking logarithm of all data and using multiple linear regression, the following relationship is proposed to compute CBR of clay-gravel mixtures under unsoaked conditions.

$$CBR = \alpha_0 + \alpha_1 P_c + \alpha_2 w + \alpha_3 \frac{\gamma_{d.} d_a}{S} \tag{4}$$

Where α_0, α_1, α_2, α_3, are multiple regression co-efficient and their values are mentioned in table 2.

TABLE III
Regression Statistics

Regression Statistics		ANOVA				
Multiple R	0.9807		d_f	SS	MS	F
R Square	0.9619	Regression	3	3.2259	1.0753	344.6509
Adjusted R Square	0.9591	Residual	41	0.1279	0.0031	
Standard Error	0.0559	Total	44	3.3538		
Observations	45					

F test and t test are performed to study the significance of the model.

F Test: Significance of the multiple regression co-efficient as a whole of the model presented in equation 3 is tested using F test. From the table of the F distribution with $\alpha = 0.5$, F (0.95,3,41) = 2.84. Therefore, F cal = 344.65 is greater than the tabulated F critical = 2.84. Therefore it rejects the null hypothesis that there is no association among the variables. The variables of equation 3 helps to explain the variation in soaked CBR value.

***t* Test:**

TABLE IV
t statistics for Clay-Sand-Gravel mixture

Discription	**Coefficients**	**Standard Error+**	**t Stat**	**P-value**	***t* critical = t (0.975,41)**
Intercept	6.2410	0.2868	21.7587	0.0000	2.021
Clay (%)	0.3553	0.1277	2.7825	0.0081	
Moisture Content (%)	-0.7847	0.0700	-11.2065	0.0000	
Density* = γ_d*d_a/surcharge	3.2109	0.3151	10.1910	0.0000	

$$CBR\ (S) = 6.241 + 0.355P_c - 0.784w + 3.210\ \gamma_d \quad (5)$$

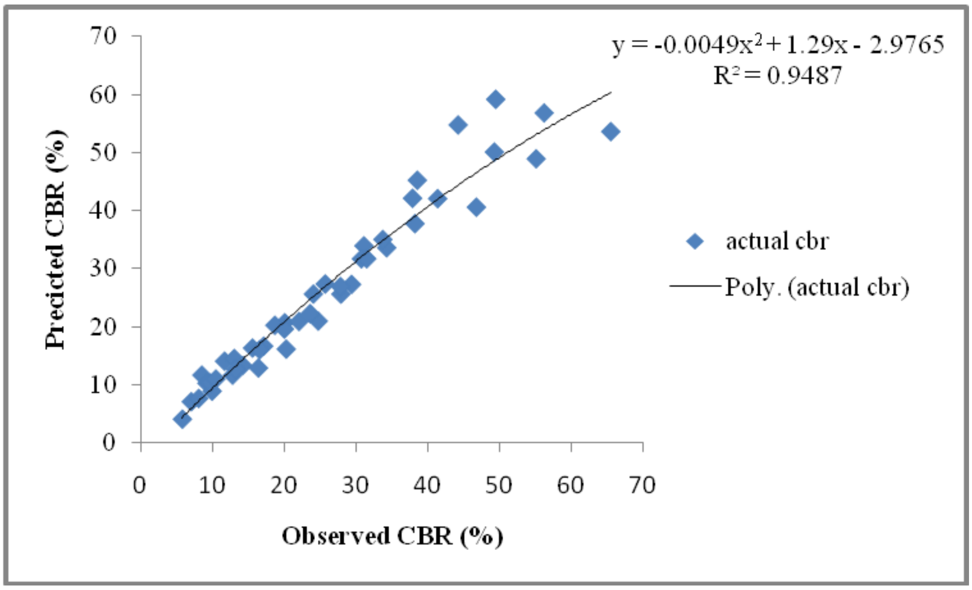

Fig. 4 Predicted versus observed soaked CBR in clay-sand-gravel mixtures

V CONCLUSIONS

Using multiple linear regression analysis, relationships is proposed to estimate CBR of clay-sand-gravel mixtures under soaked conditions. The larger $R^2 = 0.96$, indicates that proposed model is compatible and is sufficient for predicting the response. The P values for each variables of the mixture is less than 0.05, which strongly indicate that changes in predictor's value are related to the changes in response variable. The reduction in CBR is not linearly related. When fine particles are added, the hydrate film becomes thin. In soaked situation, friction eventually decreases and sharp reduction in CBR value is observed. The regression statistics shows that the predicted model fits best in soaked condition.

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