Effect of Cohesion on
California Bearing Ratio

Ph.D. Synopsis

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By

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1 Abstract

Subgrade is a layer of natural soil, prepared to receive various layers of the pavement. Thickness of the pavement depends upon the properties of subgrade. Clay-sand-gravel and clay-gravel mixtures are commonly used as a barrier material in various engineering applications, such as construction of highways.

California Bearing Ratio value and undrained shear strength are the key technical characteristics in a flexible pavement design. Soil having gravel sized particles attract much less attention than clay and sands, though they are most commonly encountered materials in geotechnical engineering practices. Literature review indicates that although fine grained soil is given due attention in the computation of CBR, clay- sand- gravel and clay-gravel mixtures have not been comprehensively attended. It is also noticed that no definite relationship exists which relates behaviour of clay-sand-gravel and clay-gravel mixture in estimating CBR of subgrade.

The present investigation is taken up to fill the above mentioned gaps in knowledge.

In this research, the compaction characteristics, California Bearing Ratio and tri-axial shear parameters of clay-sand-gravel and clay-gravel mixtures are investigated. The samples were soaked in water for four days to simulate highly unfavourable condition. Experiments were conducted on nine different mixtures of clay-sand-gravel and clay-gravel. Specimens were prepared under heavy compaction characteristics by varying clay content from 10% to 50 % (by weight) at the increment of 5% to measure unsoaked and soaked CBR values and undrained shear strength. Based on the test result data, relationships are developed using regression analysis and Artificial Neural Network modelling to estimate subgrade soil strength in terms of CBR values for unsoaked and soaked conditions and undrained tri-axial shear strength parameter. This study describes the influence of clay content on compaction characteristics, CBR values and undrained shear strength parameter of clay-sand-gravel and clay- gravel mixture.

2 Brief description on the state of the art of the research topic

The behaviour of a soil depends on the composite effect of several interacting factors, namely, amount and type of soil, shape and size, gradation, unit weight and moisture. Clay minerals produce very important soil types, which are known to have high plasticity, cohesion and swelling potential, but low hydraulic conductivity and friction angle. They are also known for their dominating influence on the behaviour of entire soil mass even if they exist only as a small fraction. The clay properties are only mobilized by the presence of water. The physico-chemical interactions between clay minerals and water resulting from surface hydration and diffused double layer, affect many properties of clayey soil. The amount of clay fraction in a soil is crucial in determining its properties required for all geotechnical applications. India is covered by black cotton clayey soils in about 20 percent of its area. Engineers face difficulties with economically sourcing sand and gravel for subgrade application. Any reliable research finding that recommends an optimum clay content to be used with sand-gravel can be of significant importance. Such findings for clay-sand-gravel and clay- gravel soil are rarely available in the literature

3 Definition of the problem

With the adoption of IRC-37-2012, there is a need to characterize subgrade soil in terms of bearing ratio. The quantity and type of fines have a major influence on the performance of an unbound aggregate road-base. The inter-particle forces are relatively important for fine grained soils. The amount of clay fraction in a soil is therefore very crucial in determining its properties required in geotechnical applications.

The effect of moisture on California Bearing Ratio (CBR) value is significant because it changes the soil fabrics. The other properties like unit weight, particle size, friction angle can have significant effect of subgrade strength. Literature review indicates that no comprehensive study has been carried out on the influence of cohesion on CBR value of soil mixtures consisting of clay-gravel and clay-sand-gravel. It has been observed that fine grained soil is given due attention in the investigation but clay- sand- gravel mixture has not been attended. Subgrade and subbase course mostly consist of such kind of materials (especially in the roads built in hilly terrain) and contribute directly to the structural performance of pavement. It is noticed that no definite relationship exists to estimate CBR of subgrade consisting of clay-sand-gravel and clay-gravel mixture. The present investigation is taken up to fill the above mentioned gap in the knowledge and a new methodology is suggested.

4 Objective and scope of work

The specific objectives of present investigation are listed below.

- To evaluate effect of cohesion on California bearing ratio and undrained shear parameters of clay-sand-gravel and clay-gravel mixtures.
- To identify various parameters influencing California bearing ratio and their sensitivity.

- To develop relationships using multiple linear regression analysis and artificial neural network for the estimation of California bearing ratio of clay-sand-gravel and clay-gravel mixtures.

The scope of the present study is as under.

- To identify source of clay, sand, gravel and procurement of materials
- To determine all index properties of procured materials for the characterization.
- To investigate type of mineral present in clay using X ray diffraction method.
- To evaluate compaction characteristics viz; optimum moisture content and maximum dry density for nine different proportions of clay-sand-gravel mixtures and clay-gravel mixtures using modified Proctor test.
- Evaluation of California bearing ratio nine soil mixtures for un-soaked and soaked conditions and undrained shear parameters by tri-axial testing.
- Development of correlation among the variables through dimensional analysis using multiple linear regression and artificial neural network.

5 Original contributions by the thesis

1. In this thesis, California bearing ratio of clay-gravel and clay-sand-gravel mixtures under unsoaked and soaked conditions is determined experimentally. Undrained shear parameters of these mixtures are also evaluated. Samples are prepared for nine different combinations of clay percentage (10% to 50% at an increment of 5 % by weight) and moisture content.

2. Combined effect of moisture content, dry density and clay fraction on California bearing ratio is studied for clay-gravel and clay-sand- gravel mixtures. Influence of cohesion on CBR of these mixtures is analyzed.

3. Functional relationships have been identified to estimate CBR of clay-gravel and clay-sand-gravel mixtures under soaked and unsoaked conditions.

4. Using multiple linear regression analysis, relationships are proposed to estimate CBR of clay-gravel and clay-sand-gravel mixtures under soaked and unsoaked conditions.

5. The statistical analysis is carried out to judge the behavior of the pertinent variables on CBR. Significance of the developed models is studied through F test and *t* test.

6. Artificial neural network (ANN) analysis using R programming is also performed to adjudge the behavior of the pertinent variables on CBR. Sensitivity analysis is done to check the effect of input variables on unsoaked and soaked CBR values.

7. Sensitivity bar plots are developed by Garson's method, Olden's method and Lek's profile method in the case of clay-gravel and clay-sand-gravel mixtures under soaked and unsoaked conditions.

8. Both the ANN and MLRA models very well predict the CBR of clay-gravel and clay-sand-gravel mixtures under soaked and unsoaked conditions.

6 Methodology of Research, Results / Comparisons

6.1 Material Characterization

In the present investigation, clay was collected by excavating at a depth of 1.5 to 2.0 feet from natural ground level from Bhal region of Gujarat, India. The properties of the clay were determined as per Indian Standard Code (IS-2720 Part 3, 4,5,8,11,16 and 40). The median size of clay was 0.0014 mm (see Fig.1). The engineering properties of clay material were: specific gravity = 2.71, liquid limit (LL) = 54%, plastic limit (PL) = 27% and plasticity index (PI) = 27%, optimum moisture content (OMC) = 18%, maximum dry density = 17.1 kN/m^3, cohesion at OMC = 142 kN/m^2, angle of friction at OMC = 12°. The free swell index was 44%. Based on the liquid limit and plasticity index, soil was classified as CH type. Clay was identified as kaolinite clay using XRD test.

Gravel and sand collected from Sabarmati river basin were used in the present investigation. Gravel finer than 10 mm and retained on 4.75 mm sieve was used. The median size of gravel was 7.1 mm (see Fig.1). It is fine gravel with a sub-angular type shape. The coefficient of uniformity and coefficient of curvature of fine gravel was 0.94 and 1.52 respectively. The median size of gravel was 7.1 mm (see Fig.1). Sand finer than 2.36 mm and retained on 75 micron sieve was used. The median size of sand was 0.47 mm (see Fig.1). The coefficient of uniformity and coefficient of curvature of sand was 0.96 and 1.62 respectively. For both the materials, value of coefficient of curvature C_c is less than 2, which indicates that they are uniformly graded materials.

Firstly, the clay obtained from the field was dried in the sunlight. It was then ground to convert into powder form. This powder clay was used in the preparation of cohesive soil mixtures. Clay in various proportions by weight was mixed with gravel. Nine different mixtures were prepared by varying clay content from 10% to 50 % at the increment of 5% by weight. Sand and gravel were mixed in equal proportions by weight.

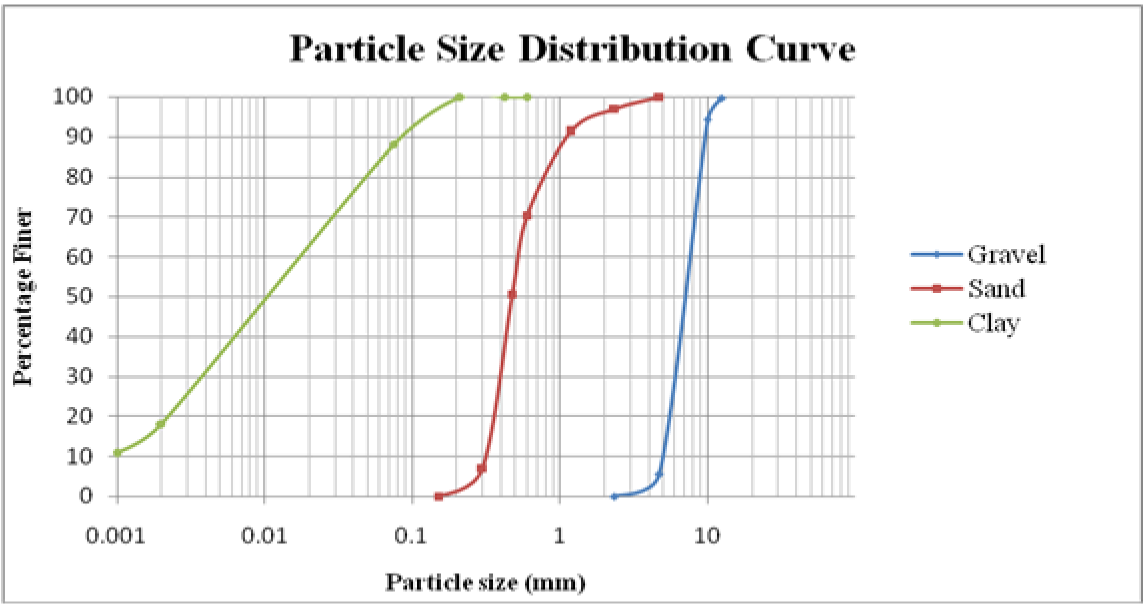

Fig.1 Particle size distribution for clay, sand and gravel

6.2 Measurements of dry unit weight and optimum moisture content

Maximum dry density and optimum moisture content of clay- gravel and clay-sand-gravel mixtures were found out following the procedure of modified Proctor test as per the IS: 2720 (Part-8).

6.3 California bearing ratio test

Accurately weighed clay powder, sand and gravel were mixed thoroughly. Already calculated amount of water was then added into this mixture. It was again mixed uniformly. The prepared mixture was left covered with a polythene sheet for 3 to 4 hours. It was done to achieve uniform distribution of moisture throughout the mixture. The mixture was again mixed thoroughly prior to placing it into the test specimen. Specimens were prepared under five moisture content to simulate various field conditions viz; (1) at optimum moisture content, (2) below 2 and 3.5 of OMC and (3) above 2 and 3.5 of OMC. Thus prepared soil specimen was placed in CBR apparatus and experiment was conducted.

California Bearing ratio test was conducted on remoulded specimen as per the IS: 2720 (Part-16). The CBR mould of 150 mm diameter and height 175 mm having volume 2250 ml was used in the testing. The correct weight of the soil mixture was determined and filled in the mould by static compaction method. The spacer disc was placed at the bottom of the mould over the base plate. The wet soil was placed in the mould and filter paper placed on the top of soil. Another spacer disc was placed at the top of the filter paper. The compaction was achieved by pressing in the spacer disc using a compaction machine. Thus prepared mould was tested for unsoaked and soaked conditions. The specimens were kept in water for 96 hours to achieve complete soaking. In all, 180 experiments are conducted to measure CBR of clay-gravel and clay-sand gravel mixtures in soaked and unsoaked conditions.

6.4 Measurement of undrained shear parameters

Unconsolidated undrained tri-axial tests were performed as per the IS: 2720 (Part-11) to determine undrained shear parameters. The samples, 50 mm in diameter and 100 mm in height were prepared to fit in triaxial test cell. The specimens were prepared using a steel split compaction mould. Specimens were prepared under five moisture content: (1) at optimum moisture content, (2) below 2 and 3.5 of OMC and (3) above 2 and 3.5 of OMC. A hand held compactor was used for compacting the specimen. The unconsolidated undrained tests were conducted with a strain rate of 1.2 mm/ min. The samples were given confining pressure of 0.5 kg/cm^2, 1.0 kg/cm^2 and 1.5 kg/cm^2. The samples were subjected to all round stress and additional vertical stress till failure. The tests were repeated with identical samples using different values of confining pressure. During the shearing process, the soil samples experience axial strain, the area of sample increases as the length decreases. The calculation of deviator stress was done on the basis of corrected area. Figure 2 shows sample of clay gravel mixture during tri-axial shear testing.

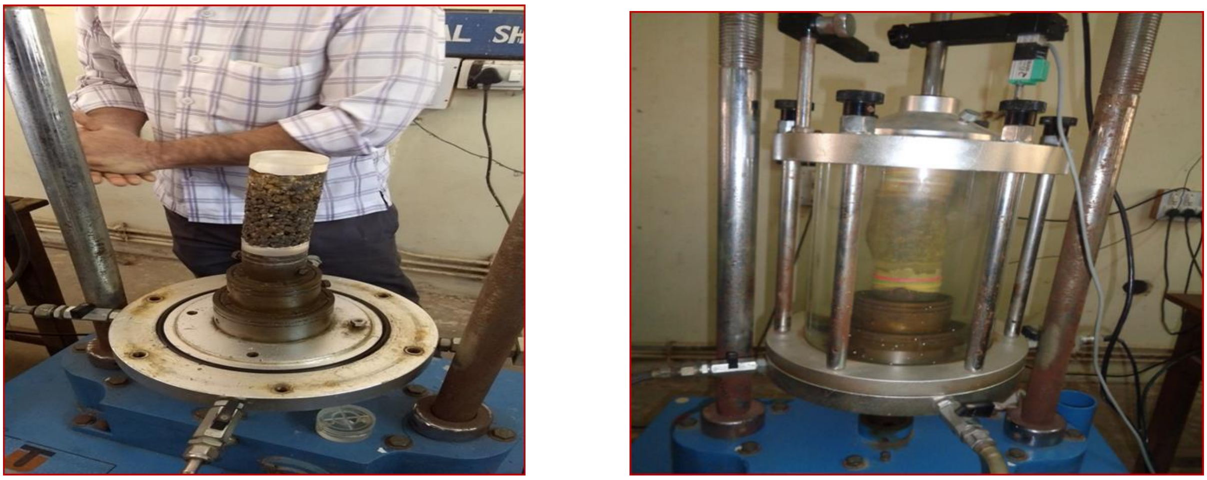

Fig. 2 Sample-30% clay+ 70% gravel (before testing)   Sample-30% clay+ 70% gravel (during testing)

6.5 Visual analysis

Visual inspection of clay-gravel soil mixture samples (containing various percentage of clay) at the end of measurement of shear parameters in tri-axial apparatus was carried out. The behaviour of soil at different percentage of clay in clay-gravel mixtures during tri-axial shear testing is described herein. At lower percentage of clay (20%) in the sample, failure is observed by particle dislodging. With the increase in clay content in the soil sample failure of sample took place with the development of a crack at the inter-transition zone (Photo-1). With further increase in clay percentage in soil sample bonding between clay and gravel enhances and improvement in clay-gravel soil matrix takes place. However, strong cracks are observed at the top and bottom of sample at the failure. With the maximum clay content present in the soil mixture, strong crack has not been seen in the sample and failure took place by bulging along with minor cracks (photo-2). Only two photographs are shown here due to space limitation.

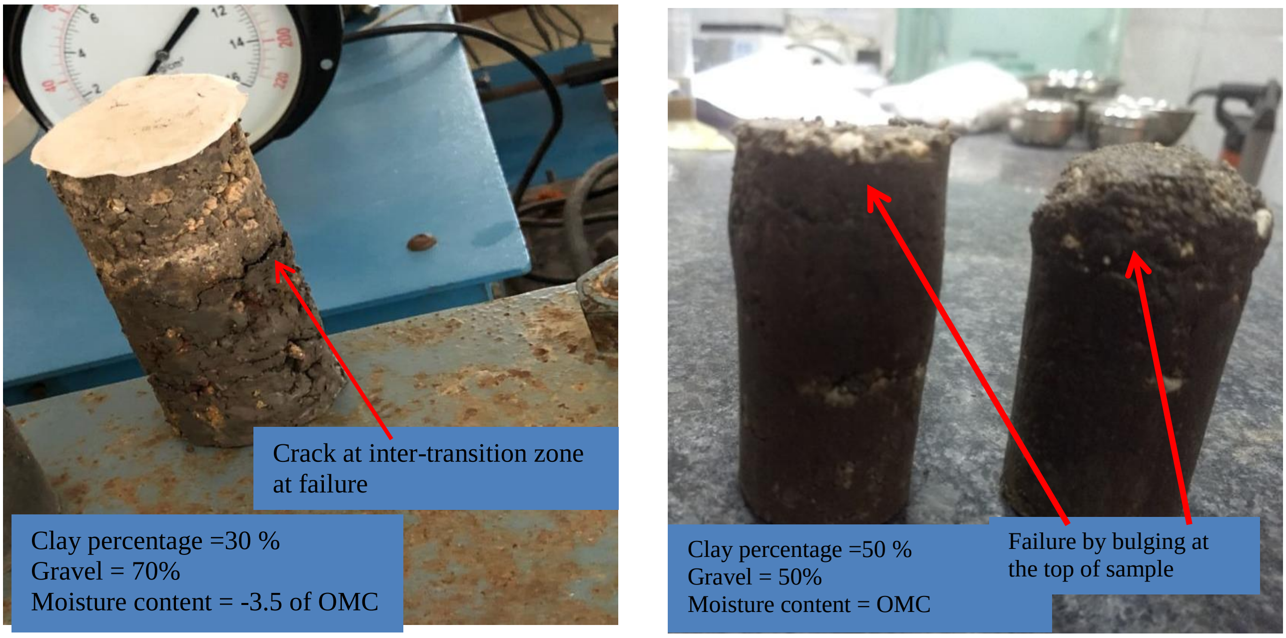

Photo 1 and 2 Clay-gravel sample at the end of measurement of shear parameters

7 Analysis of data

In order to investigate the influence of clay percentage, moisture content and dry density on California bearing ratio of clay-gravel mixtures under unsoaked condition, Figs. 3 to 6 were prepared. The experiments were conducted on five values of moisture content to simulate various field conditions. One experiment was conducted at optimum moisture content (OMC), two each experiments were conducted on wet side of OMC and dry side of OMC. It is evident from Fig.3 that the CBR value decreases with the increase in clay content in the clay-gravel mixtures. Also the maximum value of CBR is obtained for the experiments conducted at the optimum moisture content. It is also confirmed here that the CBR value of soil sample containing higher percentage of fine particles reduces drastically but the reduction is not exactly linear. The reduction is significant at smaller increment in clay percentage.

Figures 4 and 5 show the variation of CBR with moisture content and dry density respectively. The detailed study of Figs. 4 to 5 revealed that experiments conducted with dry side of OMC showed larger value of California bearing ratio. However experiments conducted at OMC showed the largest value of California bearing ratio. The similar results were also observed by Liu et al; (2009) in the investigation of CBR in the case of silt road bed. It is also evident that California bearing ratio decreases as water in the sample reached to wet side of OMC. Therefore it is advised to compact subgrade in road pavement construction on dry side of OMC to achieve higher strength (Arora, 2000).

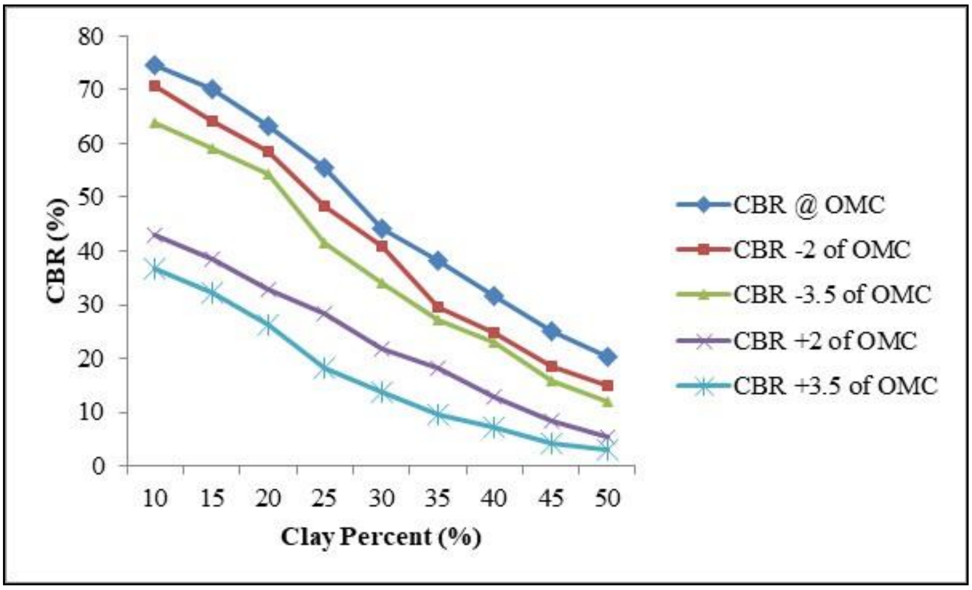

Fig.3 Variation in CBR with clay percent

CBR also decreases with an increase in clay percentage in clay-gravel mixtures. Hasan and Mehdi (2015) stated that the dry and saturated CBR decreases with decreasing percentage of angular sand and gravel, and increasing the percentage of fines. The parallel lines shown in the Figs. 4 and 5 are drawn by eye judgment and they merely illustrate that data can be partitioned on the basis of clay percentages. However a few data may encroach into neighboring zone where clay percentage is higher. In Figs. 4 and 5 P_c is clay percentage present in the clay-gravel mixtures.

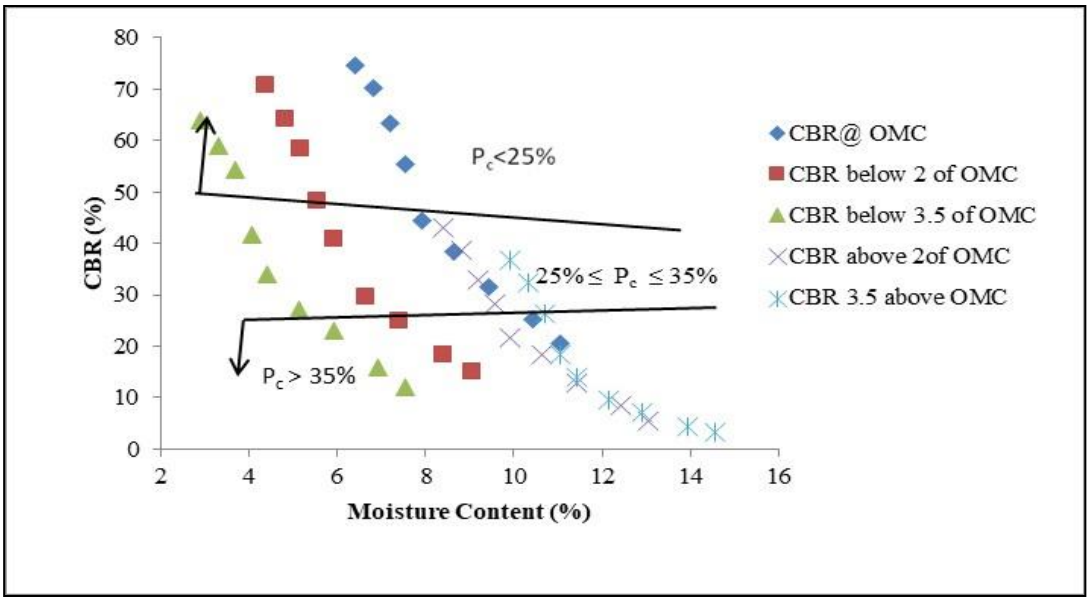

Fig.4 Variation of unsoaked CBR with moisture content at various clay percentages

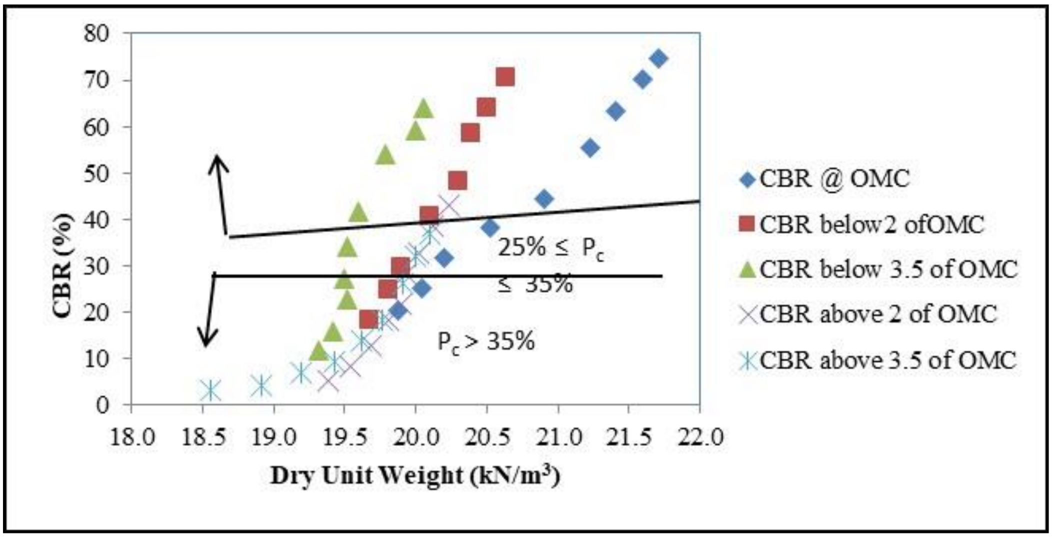

Fig.5 Variation of unsoaked CBR with dry density at various clay percentages

In order to examine the effect of shear parameters on the California bearing ratio, Figs. 6 and 7 were prepared. Figures 6 and 7 characterize the variation of CBR with cohesion and angle of internal friction. On careful investigation of these figures, it is revealed that in general CBR increases with the increase in angle of internal friction of clay-gravel mixtures. The effect of change of moisture content of mixture on angle of friction is not quite noticeable. However the samples tested at OMC and below OMC gave higher value of angle of internal friction. Also CBR decreases with the increase in cohesion of clay-gravel mixtures. The mixtures having moisture content more than optimum moisture content showed a slight different behavior than the rest of the samples (Fig.7). This distinct behavior may be attributable to particle orientation due to presence of larger moisture (above OMC) in the mixtures.

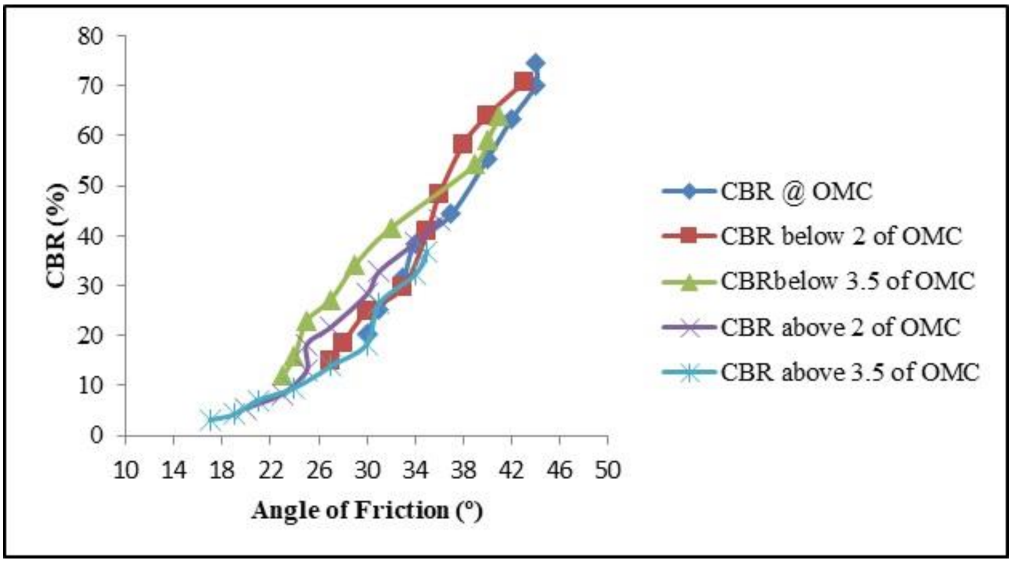

Fig.6 Variation in CBR with angle of friction

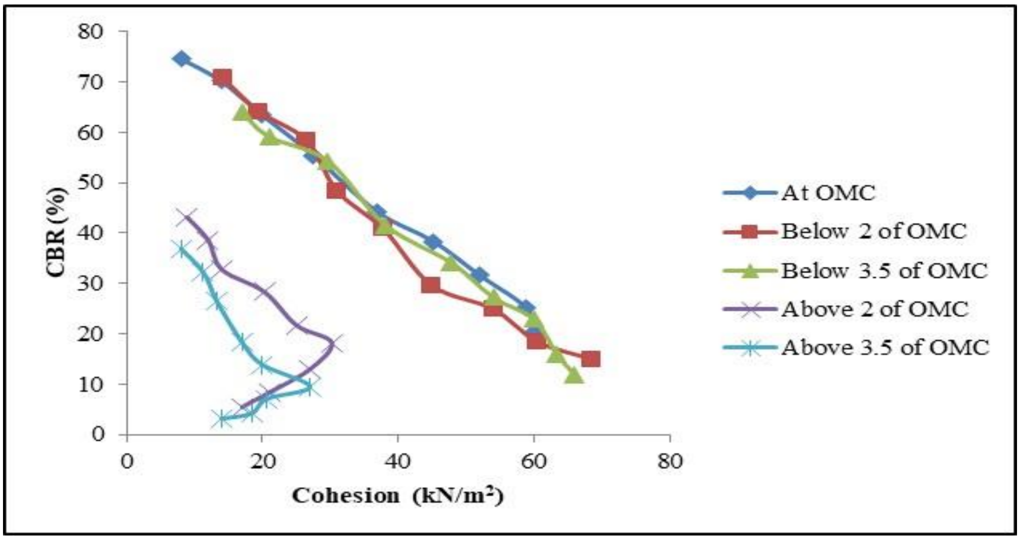

Fig.7 Variation in CBR with cohesion

Similar figures have been prepared in the case of clay-sand-gravel mixtures also under unsoaked conditions. Also analysis have been carried out to identify influence of clay percentage, moisture content and dry density on California bearing ratio of clay-gravel and clay-sand-gravel mixtures under soaked conditions. These figures are not presented here due to space limitation.

7.1 Dimensional Consideration and Development of Relationship

The main objective of the present investigation is to assess the influence of cohesion on California bearing ratio of clay-gravel and clay-sand-gravel mixtures. The functional relationship is worked out for the determination of California bearing ratio of clay-gravel and clay-sand-gravel mixtures under various antecedent conditions. A mathematical model has been proposed to compute the CBR of clay-gravel and clay-sand-gravel mixtures under soaked and unsoaked conditions. The literature studied revealed that California bearing ratio of cohesionless soil has been studied extensively. However little or no information is available regarding the computation of CBR of cohesive soil consisting of clay-gravel and clay-sand-gravel mixtures. The highway and railway embankment in the hilly region mainly consist of such cohesive soils. The computation of CBR is mainly carried out through laboratory experimentation. The functional relationships for the computation of California bearing ratio are also formulated herein.

7.1.1 Dimensional consideration (Unsoaked condition)

A large number of variables influence the variation of California bearing ratio of cohesive soil mixtures. It is therefore difficult to investigate such variation through analytical methods. The same is therefore studied herein using the dimensional analysis. An inspection of various theoretical and semi-theoretical approaches on the prediction of California bearing ratio in the case of cohesionless soil revealed that CBR is function of size of soil particle only. However, in the case of cohesive soils, because of physico-chemical properties, other factors such as clay percentage, moisture content, dry density, shear strength etc. become important in the computation of California bearing ratio of cohesive soil mixtures. The California bearing ratio in such soils is mainly affected by the following variables.

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

Here P_c in clay percentage, γ_d is dry unit weight, 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 soil mixture. The d_a is calculated by multiplying the fractional weightage of proportion (by weight) of clay, sand and gravel to their median size respectively present in the clay-sand-gravel or clay-gravel mixtures (Lodhi et al. 2015). Due to presence of gravel in soil mixtures used in present study, it was difficult to calculate plasticity index (Kothyari and Jain, 2008). Therefore plasticity index has been eliminated from further analysis. Also analysis of results showed that variation in specific gravity is minimal for all mixtures, therefore it is also dropped from the further analysis (Danistan and Vipulanandan, 2011). Hence a new functional relationship for CBR is written as

$$CBR = f(P_c, \gamma_d, w, C, \phi, d_a) \tag{2}$$

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

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

The functional relationship of Eq. (3) can be used to develop an expression to compute California bearing ratio of cohesive soil consisting of clay-gravel and clay-sand-gravel mixture under unsoaked conditions.

7.1.2 Dimensional consideration (Soaked condition)

The following functional relationship can be written to compute CBR in case of clay-sand-gravel and clay-gravel mixtures under soaked conditions.

$$CBR = f(P_c, \gamma_d, w, PI, G, C, \phi, S, d_a) \tag{4}$$

Here S is the surcharge pressure applied on the mould during soaking period wherein surcharge weight was kept 2.5 kg. It is difficult to compute the shear strength parameters under soaked conditions of specimen in tri-axial apparatus therefore C and ϕ have been dropped from further analysis. PI and G have also been dropped as the justification given in section 7.1.1.Therefore, new functional relationship for CBR is written as

$$CBR = f(P_c, w, \gamma_d, S, d_a) \tag{5}$$

Using dimensional analysis, the variables of Eq. (5) can easily be arranged into the following non-dimensional form (Peerless, 1967):

$$CBR = f\left[P_c, w, \frac{\gamma_d d_a}{S}\right] \tag{6}$$

The functional relationship in the form of Eq. (6) can be used to develop an expression for the computation of California bearing ratio of clay-gravel and clay-sand-gravel mixtures under soaked conditions.

Transforming all data into logarithm and using multiple linear regression with all pertinent parameters, the following relationships are proposed to compute CBR of clay-gravel and clay-sand-gravel mixtures under unsoaked conditions and soaked conditions.

Clay-gravel mixture (unsoaked condition)

$$CBR = 2.35 - 0.40P_c - 0.21w + 0.23\frac{C}{\gamma_d.d_a} + 2.64\phi \tag{7}$$

Clay-sand-gravel mixture (unsoaked condition)

$$CBR = 2.28 - 0.43P_c - 0.26w + 0.23\frac{C}{\gamma_d.d_a} + 1.25\phi \tag{8}$$

Clay-gravel mixture (soaked condition)

$$CBR = 5.51 - 0.43P_c - 0.78w + 3.55\frac{\gamma_d.d_a}{S} \tag{9}$$

Clay-sand-gravel mixture (soaked condition)

$$CBR = 5.18 - 0.40P_c + 0.64w + 2.92\frac{\gamma_d.d_a}{S} \tag{10}$$

7.2 Significance of the model

The significance of all proposed models has been studied through following statistical tests (Ambrish, G. 2010). Due to space limitation only, the significance of model (Eq. 7) is discussed herein.

F Test

Significance of the multiple regression co-efficient as a whole of the model presented in Eq. (7) is checked using F test. From the table of the F distribution with α = 0.05, df_1=4, df_2=40, it is found that F (0.95, 4, 40) = 2.61, and $F_{cal,}$ = 284.35 which is is greater than the tabulated $F_{critical}$ = 2.61. Therefore it can be concluded that all the variables of regression model (Eq. 7) have a strong correlation with CBR.

t Test

The multiple regression coefficients of Eq. (7) have been studied through the *t* statistics. Table 1 presents the summary of *t* statistics of the coefficients. Parameters dry density, cohesion and angle of friction showed t values (Table 1) higher than *t* critical value *t* (0.975, 40) = 2.021, which rejects null hypothesis. There is strong evidence that the explanatory independent variable of regression model of Eq. (7) helps to explain the variation in CBR. P values in the table (1) for each variable is well below the significance level α =0.05. This indicates that there is a strong correlation between each independent and dependent variable. Therefore proposed model is statistically significant.

Table 1 Value of t statistics for different parameters of model (Equation 7)

	Coefficients	*Standard Error*	*t Stat*	*P-value*	$t_{critical}$ = t(0.975,40)
Intercept	2.3558	0.1108	21.2552	0.0000	2.021
Clay (%)	-0.4092	0.2014	-2.0323	0.0488	
Moisture Content (%)	-0.2179	0.1063	-2.0506	0.0469	
Friction	2.6440	0.1911	13.8356	0.0000	
Dimensionless Cohesion $\frac{C}{\gamma_d d_a}$	0.2310	0.1027	2.2496	0.0300	

In order to check the adequacy of the proposed relationship, the experimentally computed values of California bearing ratio are plotted against their values predicted by the proposed relationship (Eq. 7) and shown in Fig. 8. It can be seen from this figure that, the proposed relationship predicts the CBR of clay-gravel mixtures with a maximum error of ±10% for all the data under unsoaked conditions. It is necessary to mention here that no experimental data on computation of CBR of clay-gravel mixtures is available in the literature. Therefore, the data obtained in the present study only are shown in Fig. (8). The calculated value of multiple co-efficient of determination (R^2), multiple co-efficient of determination (R^2_{adj}), and standard error (I_s) of the model are $R^2 = 0.960$, $R^2_{adj} = 0.969$ and $E_s = 0.0654$ respectively.

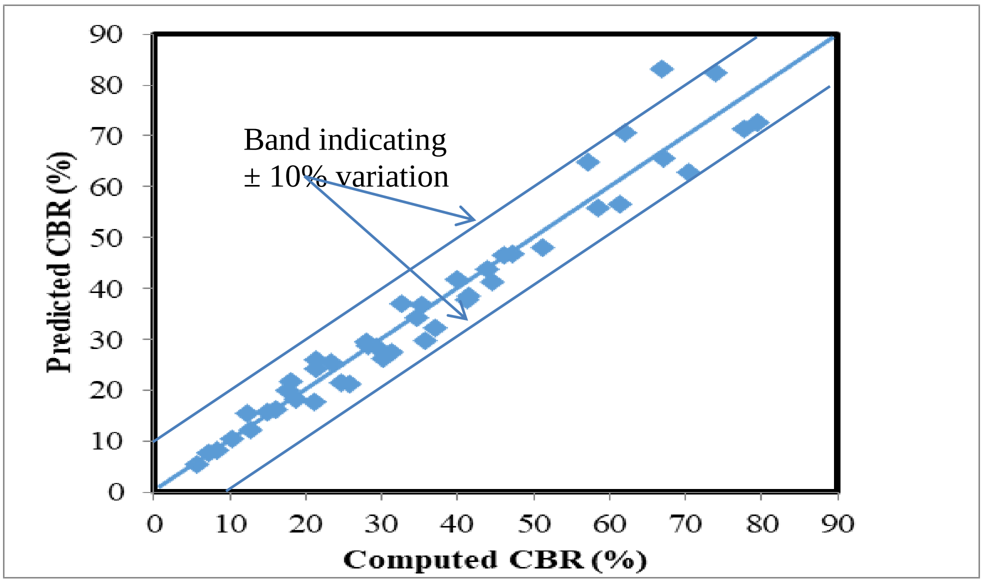

Fig.8 Predicted versus computed unsoaked CBR of clay-gravel mixtures

Similarly the adequacy of Eq. (8), Eq. (9) and Eq. (10) have also been checked and prediction by model was found satisfactory. Figures are not shown here due to space limitations.

7.3 Artificial Neural Network Modelling

Artificial neural networks (ANNs) have predictive quality and explanatory capacity. It is a powerful tool for modelling relationships between variables. 'Neural-Net-Tools' package was used to generate the models to gain insight into relationships among variables. The available data set was segregated in to two parts, 60% data was employed to develop neural network architecture, called training set and 40% data was used to check the performance of the developed model. Three different models are generated to study the sensitivity of input variables. Figure 9 shows the architecture of neural network for the computation of CBR of clay-gravel mixtures under unsoaked conditions.

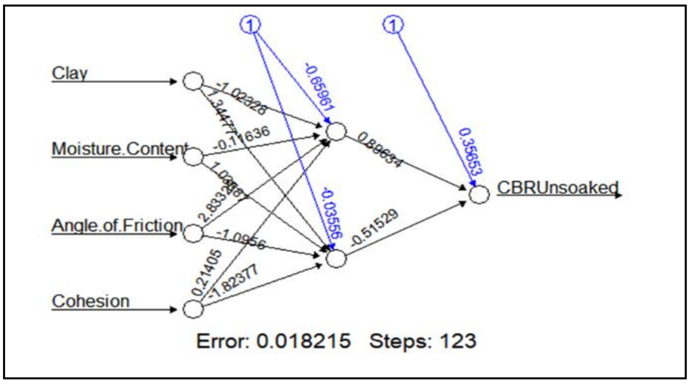

Fig. 9 Neural Network architecture for prediction of CBR

The method proposed by Garson is based on connection weights. It considers only absolute values of connection weights. In this model, all the variables are assigned importance value from 0 to 1. According to Garson's method, most important parameter is friction followed by clay, cohesion and moisture content (Fig.10). Olden's method accounts for variable's relative importance based on magnitude and signs of connection weights. This model indicates angle of friction and cohesion increase the CBR response, have positive relationship with CBR, whereas moisture content and clay decrease the CBR response (Fig.11).

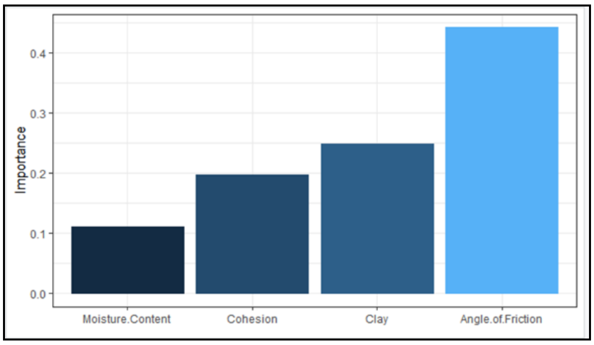

Fig.10 Relative importance of variables from Garson Method method

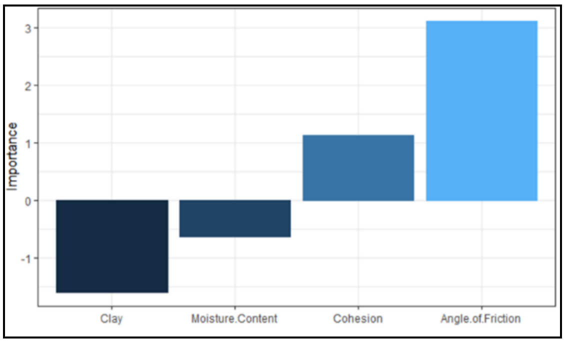

Fig. 11 Relative importance of variables from Olden

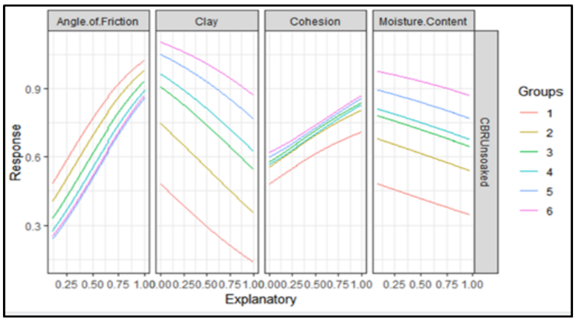

Fig.12 Lek's profile response of input variables

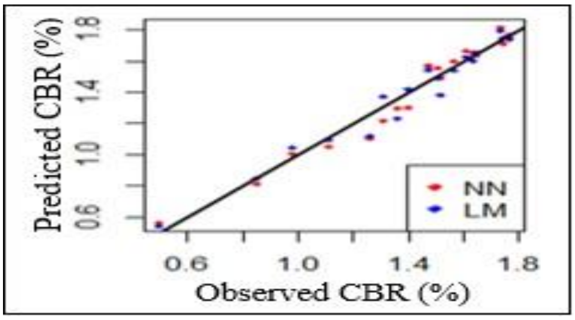

Fig. 13 Predicted versus observed CBR

Lek's profile method not only classifies the input variables by relative importance but also describes how these inputs contribute to the output which is visualized in Fig. (12). In this method, effect of each independent variable of interest is evaluated by holding all other variables at constant value. Four response curves are generated. By analyzing the graph from Lek's profile model for CBR response, it is observed that friction and cohesion has a positive relationship, whereas moisture content and clay has negative relationship. Clay percentage contributes minimally across its range to CBR which also confirms the results from Olden's model.

The value of CBR of clay-gravel mixtures was predicted using 'Neural-Net-Tools' package tool using 40% of the dataset kept reserved for validation. Figure (13) shows a comparison of observed CBR (Experimentally computed for the clay-gravel mixtures) with those predicted by model. It also depicts the comparison of observed CBR and predicted CBR using regression linear model (Eq. 7). A close investigation of figure revealed that both models are able to predict the CBR value of clay-gravel mixtures with reasonable degree of accuracy. The RMSE values of both the model are 0.0677 and 0.0657 respectively.

Similar analysis for clay-gravel mixtures under soaked condition, clay-sand-gravel mixtures for unsoaked and soaked conditions have been are carried out. They are not shown here due to space limitation,

8 Achievements with respect to objectives

Variables influencing California bearing ratio of clay-gravel and clay-sand-gravel mixtures under soaked and unsoaked conditions have been identified. Functional relationships have been identified to estimate CBR of clay-gravel and clay-sand-gravel mixtures for unsoaked and soaked conditions. Using multiple linear regression analysis (MLRA), relationships are proposed to estimate CBR of clay-gravel and clay-sand-gravel mixtures under unsoaked as well as soaked conditions. The statistical analysis is carried out to judge the behaviour of the pertinent variables on CBR. The proposed relationships very well predict the CBR of both clay-gravel and clay-sand-gravel mixtures. Artificial neural network (ANN) analysis using R programming was also performed to judge the behavior of the pertinent variables on CBR. It is revealed that both the ANN and MLRA models are accurate in predicting the CBR of both types of mixtures. It is further revealed that MLRA and ANN models are reliable and quick tool for accurate estimation of CBR of cohesive soil mixtures using their basic soil properties. Therefore, it can be utilized as an inexpensive substitute of the laboratory testing of CBR. The presented experimental works as well as statistical results are useful in assessing and predicting the performance of subgrade layer in the pavement construction.

9 Conclusions

Several laboratory experiments were conducted to study the variation of California bearing ratio (CBR) of cohesive mixtures consisting of clay-gravel and clay-sand-gravel mixtures. Nine different clay-gravel and clay-sand-gravel mixtures were prepared by varying clay content from 10% to 50 % (by weight) at the increment of 5%. In all, 180 experiments are conducted to measure CBR of clay-gravel and clay-sand gravel mixtures under both soaked and unsoaked conditions. The experiments were conducted on five values of moisture content to simulate various field conditions. One experiment was conducted at optimum moisture content (OMC), two each experiments were conducted on wet side of OMC and dry side of OMC. The influence of clay percentage, dry density, shear strength parameters and moisture content on CBR was examined. CBR value decreases with the increase in moisture content in the mixtures and increases with an increase in dry density of mixture under unsoaked conditions. CBR value decreases with an increase in clay fraction in unsoaked conditions. The reduction is significant at about 20% to 35% increment in clay percentage. The shear parameters are controlled by clay fraction when it is more than 20%. CBR increases with the increase of angle of internal friction and decreases with the increase of cohesion in clay-gravel mixtures.

Functional relationships have been identified to estimate CBR of clay-gravel and clay-sand-gravel mixtures under soaked and unsoaked conditions. Using multiple linear regression analysis, four relationships are proposed to estimate CBR of clay-gravel and clay-sand-gravel mixtures under soaked and unsoaked conditions. The statistical analysis is carried out to judge the behaviour of the pertinent variables on CBR. The proposed relationships very well predict the CBR of both mixtures. Artificial neural network (ANN) analysis using R programming was also performed to adjudge the behavior of the pertinent variables on CBR. It is revealed that both the ANN and MLRA models are accurate in predicting the CBR of both mixtures. It is further revealed that MLRA and ANN models are reliable and quick tool for accurate estimation of CBR of cohesive soil mixtures using their basic soil properties. Therefore it can be utilized as an inexpensive substitute of the laboratory testing of CBR. The presented experimental works as well as statistical results are useful in assessing and predicting the performance of subgrade layer in the pavement construction.

10 Publications

1. K.L.Timani and R.K.Jain, “Experimental Analysis of Heavy Compaction and Soaked Bearing Ratio Characteristics of Clay- Sand- Gravel Mixtures”, International Journal of Technical Innovation in Modern Engineering and Science, (IJTIMES), UGC approved Journal No. 47955, Volume 5, Issue 2, February-2019, ISSN (online): 2455-2585.

2. K.L.Timani and Dr. R.K.Jain, “Prediction of clay-sand-gravel mixtures from compaction and shear parameters by soft computing technique". Indian conference on Geotechnical and Geo-Environmental engineering (ICGGE-2019), MNNIT, Prayagraj, March - 2019 (Paper ID-131)

Paper under review:

1. K.L.Timani and Dr. R.K.Jain, “ Statistical Assessment of Compaction Characteristics, California Bearing Ratio and Shear behaviour of Clay-Sand Gravel Mixture for Pavements" Journal of Civil Engineering, i Manager Publications UGC approved Journal No. 43156, ISSN : 23472235

Paper Submitted:

2. K.L.Timani and Dr. R.K.Jain “Effect of cohesion on California Bearing Ratio of Clay-Gravel mixtures” KSCE journal of Civil Engineering, KSCE-D-19-01204.

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