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Prediction of Engineering Properties of Kerala Soil

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Abstract. Engineering properties are determined from various tests performed on undisturbed samples collected from the site. These test results depend upon the method of testing, loading conditions, strain rate, loading rate, etc. Some of the tests require a considerable amount of time. So for initial requirements like preparation of a budget, estimates, preliminary designs, etc., alternative methods have to be chosen. Many theoretical and prediction methods are already available in the literature, however, not much studies have been done for soils available in Kerala. Two major types of soils seen in Kerala are lateritic soil near the Western Ghats and soft soils in lowlands like Kuttanad and backwater environment. The objective of this paper is to develop predictive equation for determining the engineering properties from the available index properties for soil collected from Kerala. The main engineering properties considered are shear strength and coefficient of consolidation. For this study, the soil data was collected from various geotechnical consulting firms who have undertaken various infrastructural projects in Kerala. Artificial Neural network (ANN) tool of MATLAB and Regression analysis was used for predicting the properties. In ANN, Levenberg-Marquardt algorithm was used for training the network. From the results, it was concluded that, for Kerala soils, the developed predictive equation is more accurate than equations already available in literature. Also, the Neural Network tool can model the relation much reliable than conventional regression analysis.

Keywords: soil behavior, ANN, lateritic soil, Kuttanad soil.

1 Introduction

Soils are produced as a consequence of denudation of rocks. It will have the same mineralogical composition as that of the parent rock. Some of the main engineering properties of the soils include compressibility, permeability, and shear strength. They are determined either in situ or in the laboratory from the undisturbed samples collected from the site. The test results depend upon the method of testing, loading condition, strain rate, load rate, etc. These properties are of great importance because they are used as design parameters to determine bearing capacity, slope stabilization, etc. To prepare the budget and for preliminary designs, only a rough estimate of the properties are needed. But the tests to determine the properties are time-wasting and costly. There comes the importance of index properties which can be easily determined.

The main index properties of the soil are water content, specific gravity, unit weight of soil, particle size distribution, consistency limits, etc. They are obtained from laboratory tests and are used for the classification of soil. Some of the index properties can be correlated with the engineering properties but it varies for different types of soil. Also the correlation may not be perfect. So in the case of small projects where quick determination and a rough estimate of engineering properties are required, a correlation with a factor of safety may be used. But for large projects engineering properties need to be determined. Several predictive and theoretical studies regarding the correlation of index properties with engineering properties are already available in the literature. However, not much study has been done for soils available in Kerala.

Kerala state is located in the Southwestern coast of India. Mainly two types of soils are seen here, Lateritic soil and Soft soil. About 40% of the Western Ghats are located in Kerala. They are the mid and high lands of Kerala and the lateritic soils are seen here. These soils are also known as acid ferruginous soils of Kerala. Studies have been conducted to determine the mineralogy because of its importance in industry and agriculture [3]. The soft soils are seen in the Kuttanad region and Cochin marine region. These are the lowlands of Kerala and Kuttanad is the place with the lowest altitude in India.

In this project, attempts have been carried out to collect data from literature and geotechnical consulting firms on undisturbed samples that they have used for various infrastructural projects in Kerala. The engineering properties considered are Shear strength parameters (c and φ) and coefficient of consolidation. The relation of these properties with index properties were determined by Regression analysis and Artificial Neural Network (ANN). ANN is a statistical technique used to determine the complex relationship of these properties. The main advantage of ANN is that it can be trained, hence the compound relation can be determined.

2 Scope and Objective

The main scope of this study is to develop predictive equations for engineering properties of soils. Both Regression analysis and Artificial Neural Network were used in order to compare the relation of engineering properties, with index properties and other properties of soil. Since many literatures are available for predicting the properties of soils in different places, the applicability of these equations was checked in soils collected from Kerala.

Data for this study, was collected from various geotechnical consulting firms in Kerala and were subjected to statistical analysis to check the sufficiency. All the data were combined and mean, standard deviation, and variance were obtained. The data set was thus prepared and, Regression analysis and Neural Network analysis were performed. The coefficient of determination (R^2) value was determined in each case. Predictive equations for shear strength parameters and coefficient of consolidation were suggested. The RMSE values of the developed predictive equation and available equations were compared and studied.

3 Methodology

Simple regression analysis and multiple regression analysis of the engineering properties with different index properties were performed. Those index property with a high value of correlation coefficient were selected and predictive models were developed. A comparative study was also performed using Artificial Neural Network (ANN).

3.1 Index properties

The index properties like bulk density, Natural moisture content, percent fines, Liquid limit, Plastic limit, plasticity index, and other properties like SPT number were considered in this study. Data were collected from the undisturbed samples, used for various infrastructural projects in Kerala, by various geotechnical consulting firms. The tests they performed include grain size distribution, atterberg limits, tests for determination of shear strength like triaxial tests, direct shear tests, and tests to determine the coefficient of consolidation like oedometer tests. These data were used for the preparation of the data set for this study. Two different datasets, each including 95 samples and 45 samples were prepared for shear strength parameters and coefficient of consolidation respectively. Some properties like shrinkage limit, specific gravity, etc. were not determined for every test. Due to their unavailability, these properties were not considered for the regression analysis. The main aim of this study is to determine the best from the available properties, having more correlation to the target engineering properties.

3.2 Engineering properties

In this study, the engineering properties such as shear strength parameters (cohesion (c) and angle of internal friction (φ)) and the coefficient of consolidation (c_v) are considered. Shear strength parameters are of great importance in designing the structures and determining the slope stability. In order to estimate the settlement, c_v is also important. But the oedometer test is time-consuming and costly. Here arises the need of a correlative equation for these properties.

For the correlation of shear strength parameters c and φ, the properties considered are Bulk density, Natural moisture content, SPT value, Liquid Limit, Plastic Limit, and Plasticity Index. For the correlation of coefficient of consolidation; Bulk density, Moisture content, percent clay and silt, Liquid Limit, Plastic Limit, and Plasticity Index were the properties considered. The relation of the parameters to the engineering property is determined by performing regression analysis. The Root Mean Square Error (RMSE), coefficient of determination (R^2) and Mean Square Error (MSE) were obtained. The lowest value of R^2 implies that the parameters are not related to the engineering properties. Parameters with the highest value of R^2 and lowest value of RMSE were selected. Multiple Regression Analysis was performed on these selected parameters and correlative equations were formulated. The equation was in the form.

$$Y = b + mx1 + mx2 + mx3 \quad (1)$$

Where b is the constant, m is the slope of the regression, x1, x2, and x3 are the independent variables. The selected parameters were taken as the input parameters for the Artificial Neural Network (ANN) modelling.

3.3 Comparison of other predictive techniques

In the present study, the previously predicted equations from various papers were compared. In the case of shear strength, not much literature are available for correlating the shear strength parameters with various properties. Mahmod Mostafa [6] correlated shear strength parameters with the corrected SPT value. This correlation was applied to the data available. It was found that this equation is not suitable for Kerala soil. In the case of the Coefficient of Consolidation (c_v), less number of correlations are available. Asma [4] correlated c_v with the Liquid Limit.

Table 1. RMSE values of available equations

Parameter	Equation	Author	RMSE
Cohesion (c)	C= 0.014N”+0.18	Mahmod Mostafa Abdou Abdel Naiem	0.2
Angle of Internal friction (φ)	Φ = 0.209N”+19.68	Mahmod Mostafa Abdou Abdel Naiem	3.28
Coefficient of Consolidation (c_v)	$c_v = 4258LL^{(-1.75)}$	Asma	3.99

3.4 Artificial Neural Network Model (ANN)

Artificial Neural Network is an analytical technique which is non-linear and is used to solve complex problems. The main feature of ANN is that it consists of neurons that represent the human nervous system. One of the advantages of ANN is that the network can be trained. Its neurons are arranged in layers consisting of the input layer, the hidden layer, and the output layer. The input layer is the most transparent and it consists of the dependent parameters. All the parameters to be included in the network is given as the input layer. The property to be determined by the network is the output. In the case of hidden layers and the number of neurons in each layer, an optimum number should be provided. They are determined from the trial and error process. The available data set is divided into two parts to provide as feed to the network. Two parts namely, the training set which consists of 90% of the data and is used to build the network and validation set consist of 10% of data and are used for the evaluation of the network.

4 Results and Discussion

4.1 Linear Regression analysis of properties

The linear regression analysis of individual properties with the respective parameters were done to determine the relation. The regression app of MATLAB was used to perform the analysis. From the analysis, it was observed that Natural moisture content and SPT value have an R^2 value greater than 0.5 which shows its moderate relation with cohesion. Whereas other parameters like bulk density, liquid limit, plastic limit have an R^2 value greater than 0.3 that shows its mild relation, and plasticity index has an R^2 value less than 0.3 showing no relation.

The R^2 value for parameters that correlates the angle of internal friction (φ) was obtained. SPT value has an R^2 value greater than 0.7 which shows its strong relation with φ. While properties like bulk density, liquid limit, plastic limit, and plasticity index have a value less than 0.3 which has no relation with φ. Natural moisture content has an R^2 value of 0.38 which shows its mild relation.

In the case of parameters correlating coefficient of consolidation (c_v), the R^2 value of Liquid Limit is 0.82 which shows its strong relationship with c_v. The values of bulk density, percent fines, and plasticity index are 0.61, 0.59, and 0.5 respectively showing its moderate relation with c_v. the properties like natural moisture content and plastic limit have values 0.49 and 0.43 respectively which shows its mild relationship.

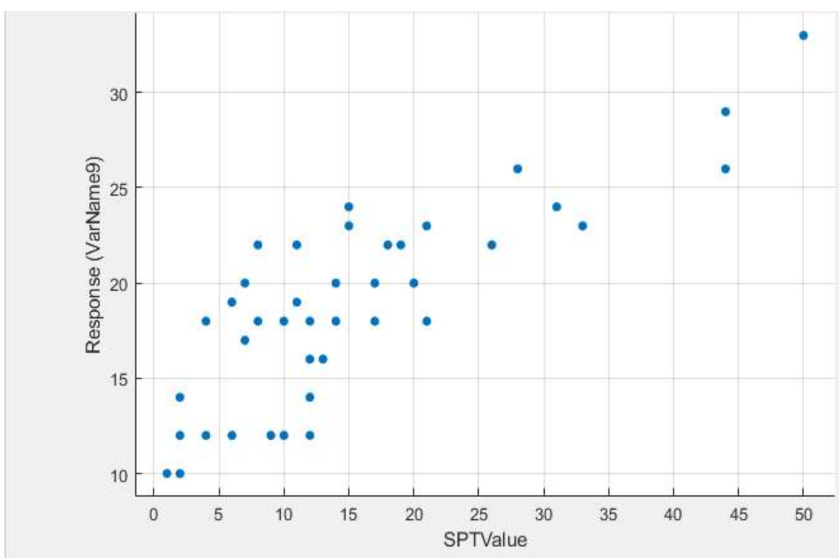


Fig 1. Regression analyis of SPT value with angle of internal friction (φ)

4.2 Development of Predictive equations

To develop the predictive equation for cohesion, the parameters which have a moderate and strong relation with cohesion are considered. The parameters are moisture content and SPT value. Multiple regression analysis of these parameters with cohesion is performed and predictive equations are obtained. For formulating the parameter angle of internal friction, SPT value and moisture content with strong and mild correlation were used.

Table 2. Developed predictive equations

Parameter	Equation	R^2	RMSE
Cohesion (c)	$c=0.139 - 0.0004w_n + 0.0012N$ w_n=Natural water content N=SPT value	0.75	0.014
Angle of internal friction (φ)	$\varphi= 16.73 - 0.08w_n + 0.34N$ w_n=Natural water content N=SPT value	0.8	2.63
Coefficient of consolidation (c_v)	$c_v= 0.044 - 0.006\rho + 0.0001f_n - 0.0002LL$ ρ= Bulk density(g/cc) f_n=percent fines LL=liquid limit	0.88	1.75

4.3 Development of ANN model

The model was developed using an Artificial Neural Network. Three models were created each for cohesion, angle of internal friction, and coefficient of consolidation. A total of 6 iterations were used for training the network for cohesion. Fig 2 shows the performance plot and the best validation performance was at $4.325e^{-4}$ in the zeroth iteration. The R^2 value obtained is 0.90765.

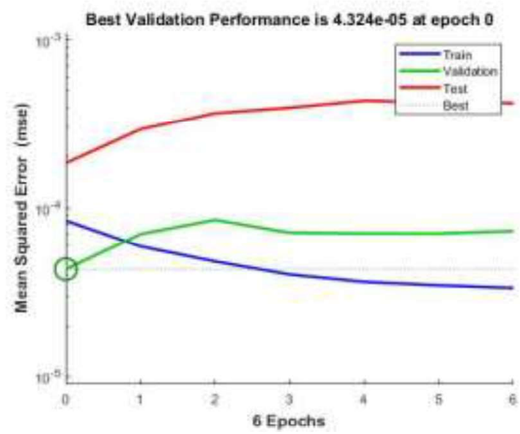
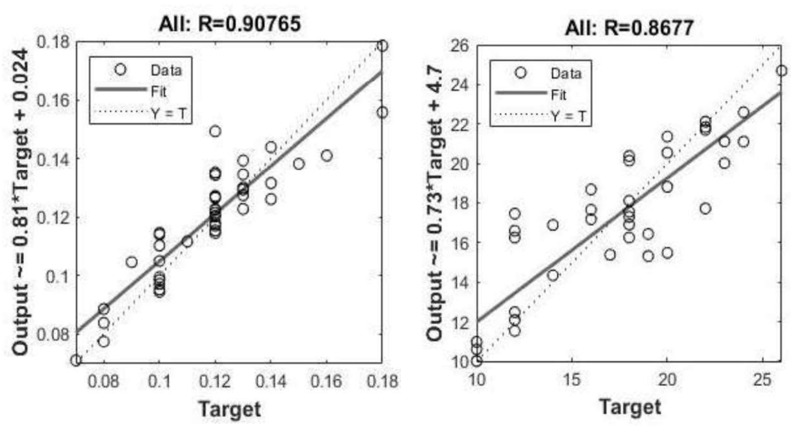
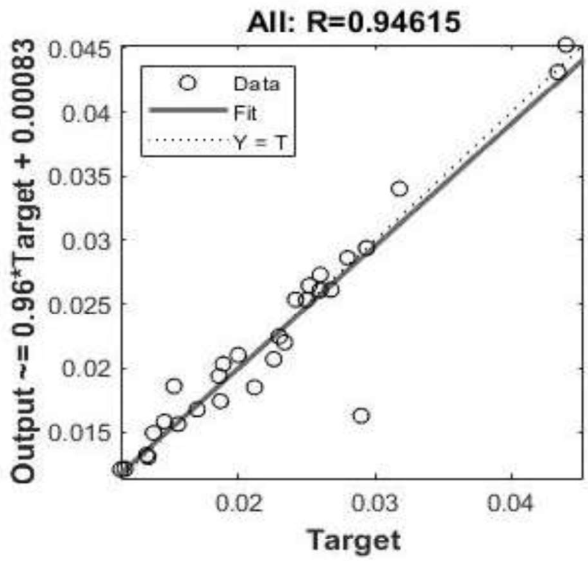


Fig 2. Mean squared error plot for cohesion

6 iterations were used for training the network for modelling angle of internal friction. The best validation performance was at 6.8943 in the zeroth iteration. The R^2 value obtained is 0.8677. A total of 8 epochs were used for training the network for the coefficient of consolidation. The best validation performance was at $6.101e^{-7}$ in the second iteration. The R^2 value obtained is 0.94615.



a. cohesion b. angle of internal friction



c. coefficient of consolidation

Fig 3. Regression plot using ANN

5 Conclusions

In this study, various equations earlier predicted by other authors were compared and concluded. For shear strength, the equation proposed by Mostafa Abdou Abdel Naiem Mahmod for c and φ had an RMSE value of 0.2 and 3.28 respectively. The new correlation formulated in this study has an RMSE value of 0.014 and 2.63 respectively. Also, for cohesion and angle of internal friction parameters like natural water content and SPT value has more relation than others. Hence these parameters are used for the formulation of correlation.

In the case of the coefficient of consolidation, the equation suggested by Asma has an RMSE value of 3.99 whereas the new correlation has an RMSE value of 1.75. For the coefficient of consolidation, the properties like bulk density, percent fines, and the liquid limit have more correlation and hence used for prediction of correlation.

The R^2 value of the predicted equation for cohesion, angle of internal friction, and coefficient of consolidation are 0.75, 0.8, and 0.88 respectively. Whereas the R^2 value of ANN models for cohesion, angle of internal friction, and coefficient of consolidation are 0.90, 0.86, and 0.94 respectively. It can be concluded that prediction using the ANN model is effective than the conventional regression analysis.

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