Prediction of Bearing Capacity and Settlement from SPT Values Using Genetic Algorithm

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ABSTRACT: Many empirical and semi empirical methods are existing to predict bearing capacity and settlement, but majority of them are inconsistent and not user friendly. In this work, a genetic algorithm approach is used for predicting bearing capacity and settlement of shallow foundations on C soil, φ soil and C- φ soil, separately, based on those input parameters which can be easily find out from simple experiments. The development and verification of the genetic models were done using a large database containing about 832 datasets from 167 soil investigation reports. The equation developed for bearing capacity and settlement thus obtained can be used in prediction of new cases that were not used for the development of the genetic model. The results of the model obtained were compared with various conventional equations available for calculating bearing capacity and settlement and was found to be superior. The correlation of predicted data with actual field measurements was determined and it was found out that the genetic algorithm approach have high degree of accuracy. Parametric study was also done to evaluate the effect of varying each of the input parameters on the corresponding output.

KEYWORDS: Bearing capacity, Settlement, SPT, Genetic Algorithm

1 INTRODUCTION

Two important soil parameters which determine the type of foundation are settlement and bearing capacity. Usually existing methods to measure them, including plate load tests, can only give a rough idea due to a number of limiting conditions. So we need an integral method of prediction. Genetic algorithms are a part of evolutionary computing, which is a rapidly growing area of artificial intelligence. In this study an approach is made to create an integral method to form a genetic algorithm which is trained to predict bearing capacity and settlement of a soil in a particular condition with given values of some practical input parameters that can be easily find from construction sites, which are SPT value, water content, depth of water table and bulk density of soil, cohesion and angle of internal friction.

2 METHODOLOGY

GA is mainly an optimization technique and to use this algorithm for prediction we need to collect a number of actual values of input and the resulting output parameters and that is the first step. For Bearing capacity GA model, the input parameters are Standard Penetration Test (SPT) values, depth of water table, bulk density of soil, cohesion, angle of friction and moisture Content. For Settlement GA model, the input parameters are SPT values, bulk density, cohesion, angle of friction and bearing capacity. The data were collected from bore log details and other related reports regarding each site in different parts of Kerala, India, from Geotechnical Laboratory of NIT Calicut, Kerala. Separate dataset were created for C-Soil, φ – Soil and C- φ soil for easiness of comparison of results from GA models with conventional methods. The output parameters in the dataset, both bearing capacity and settlement will be treated as actual values of output parameters with which the results of GA models compared.

Next step is dividing dataset of each soil into subsets such as training and validation set. In this paper 80% adopted as training and 20% as testing or validation data and is shown in Table 1. Division of data was done using a statistically consistent approach so that both sets possess similar statistical properties including mean, standard deviation, maximum and minimum.

<table>
<thead>
<tr>
<th>Item</th>
<th>Training Data</th>
<th>Testing Data</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>C soil</td>
<td>273</td>
<td>68</td>
<td>341</td>
</tr>
<tr>
<td>φ – Soil</td>
<td>110</td>
<td>28</td>
<td>138</td>
</tr>
<tr>
<td>C- φ soil</td>
<td>282</td>
<td>71</td>
<td>353</td>
</tr>
<tr>
<td>Total Data</td>
<td></td>
<td></td>
<td>832</td>
</tr>
</tbody>
</table>

Table 1 Division of database
Then GA models were developed using dataset with the help of Scilab 5.5.2 software until the Objective function = \((\Sigma\text{predicted value-experimental value)}^2)/N\), is minimized, where N is the number of data available in training set. In order to arrive at the best solution, the program was run several times by changing parameters like number of generations, crossover and mutation probabilities and the expression of bearing capacity and settlement corresponding to the best solution was selected for each model. Table 2 shows the features of developed models.

Table 2 Features of Developed Genetic Algorithm models

<table>
<thead>
<tr>
<th>Model</th>
<th>Crossover Pro.</th>
<th>Mutation Pro.</th>
<th>Population size</th>
<th>No. of generations</th>
<th>Variable array size</th>
<th>Operating array size</th>
</tr>
</thead>
<tbody>
<tr>
<td>BC C-Soil</td>
<td>0.8</td>
<td>0.05</td>
<td>300</td>
<td>5000</td>
<td>9</td>
<td>10</td>
</tr>
<tr>
<td>BC (\varphi) – Soil</td>
<td>0.8</td>
<td>0.05</td>
<td>300</td>
<td>5000</td>
<td>9</td>
<td>10</td>
</tr>
<tr>
<td>BC C- (\varphi) soil</td>
<td>0.8</td>
<td>0.05</td>
<td>200</td>
<td>5000</td>
<td>11</td>
<td>12</td>
</tr>
<tr>
<td>Settlemet C-Soil</td>
<td>0.8</td>
<td>0.1</td>
<td>300</td>
<td>5000</td>
<td>7</td>
<td>8</td>
</tr>
<tr>
<td>Settlemet (\varphi) Soil</td>
<td>0.8</td>
<td>0.09</td>
<td>200</td>
<td>5000</td>
<td>7</td>
<td>8</td>
</tr>
<tr>
<td>Settlemet C- (\varphi) soil</td>
<td>0.8</td>
<td>0.09</td>
<td>300</td>
<td>5000</td>
<td>9</td>
<td>10</td>
</tr>
</tbody>
</table>

3 RESULTS AND DISCUSSIONS

The relationships obtained for each of the models to predict bearing capacity and settlement are shown below.

For C-Soil

\[ BC = 106.394N^{0.0937} + \frac{82.532W^{0.0056} + 427.785M^{2.6276}}{7.0589Y^{2.3011} + 418.323C^{-1.7114}} \]  

\[ s = 224.4172N^{-3.6921} + 197.1212Y^{-2.5558} + 195.0985C^{-5.3672} + 18.0130BC^{-7.9628} \]  

(2)

For \(\varphi\) – Soil

\[ BC = 0.0649N^{0.1067} \times 14.1645W^{0.1162} \times (472.4094M^{-0.5723} - 3.6548Y^{-1.4720} + 8.9611C^{0.5214}) \]  

\[ s = 82.2013N^{-2.6483} + 436.4909Y^{-3.0253} + 5.7952C^{-6.5541} + 277.663BC^{-2.3415} \]  

(3)

For C- \(\varphi\) soil

\[ BC = (26.1341N^{0.3488} \times 11.6380W^{1.0454} \times 19.4894M^{-6.1385} \times 323.0065Y^{0.5279} x 2.0989C^{-1.1524} + 141.3081\varphi^{0.6697}) \]  

\[ s = 711.3924N^{-3.7469} + 52.6576Y^{-2.2392} + 59.0848C^{-7.9594}(452.5694\varphi^{-1.2921} + 626.8442BC^{-2.6938}) \]  

(5)

Where W – Depth of water table (m)

M – Water content (%)

N – SPT value

\(\gamma\) – Bulk density of soil (kN/m³)

C – Cohesion of soil (kN/m²)

\(\Phi\) – Angle of internal friction (Degree)

BC – Bearing capacity (kN/m²)

S – Settlement (m)

The correlation of results from 6 GA models for bearing capacity and settlement for C-Soil, \(\varphi\) – Soil, and C- \(\varphi\) soil, with the actual values were checked in terms of RMSE, Correlation Coefficient, MAE values and found to be superior.

The performance of the models for training dataset was found out by plotting predicted values against actual values and found that for all models majority of data fall near 1:1 normal line. As an example performance of bearing capacity and settlement models of C-soil are shown in Figure 1 and Figure 2 respectively.

Then the 6 GA models were tested with the testing or validation dataset to show that GA model can predict over a wide range of, even, unseen cases with accuracy, and the correlation of obtained results from GA models with actual values were checked in terms of RMSE, Correlation Coefficient, MAE values and found to be superior. As an example performance of bearing capacity and settlement models of C-soil with testing or validation dataset are shown in Figure 3 and Figure 4 respectively.

Next step is comparison of results obtained from these 6 GA models with conventional methods, separately for C soil, \(\varphi\) soil and C- \(\varphi\) soil and the error were calculated for each data, as the difference between actual value and the value given by each of the method – (including GA model). The same was plotted in a graphical form. For each model, the conventional methods used were selected based on nature of database available. From the obtained graphs, it can be seen that all GA models gives the lesser error than any other conventional method. As an example,
comparison results of bearing capacity and settlement models for C-soil are shown in Figure 5 and Figure 6 respectively.

Fig. 1 Bearing capacity model of C soil with training data

Fig. 2 Settlement model of C soil with training data

Fig. 3 Bearing capacity model of C soil with testing data

Fig. 4 Settlement model of C soil with testing data

Fig. 5 Comparison of Bearing capacity model of C soil

Fig. 6 Comparison of Settlement model of C soil

Parametric study was done to evaluate the predictive capability of obtained formulas as well as the effect of varying each of the input parameters on the corresponding output. This was done by fixing all input parameters to their mean value, except one and varying it between its range of minimum and maximum values and then noting down effect of the variation on the output.

For bearing capacity models, it is observed that the bearing capacity values increases as the values of SPT, water table depth, bulk density, cohesion and angle of
internal friction values are increased. But in case of water content, bearing capacity values reduces as the value of water content increases.

For settlement models, it is observed that the settlement values decreases as the values of SPT, bulk density, cohesion, angle of internal friction and bearing capacity values are increased.

4 CONCLUSIONS

The prediction and calculation of bearing capacity and settlement is a wide area of research and each method or empirical formula has its own limitations that it can be used under certain conditions. In this paper Genetic Algorithm technique was used to develop expressions for bearing capacity and settlement of C-Soil, φ – Soil, and C- φ soil with the help of 832 datasets dealing with almost all soil types of Kerala, India. And thus 6 GA models and corresponding equations were developed for bearing capacity and settlement of C-Soil, φ – Soil, and C- φ soil. The developed equations were checked for their performance using training dataset and were found that the models developed were able to predict the output (either bearing capacity or settlement) near to the actual value. The ability and accuracy of the models while dealing with unseen data was also checked using testing or validation dataset. The models were then compared in performance with some conventional methods of computing bearing capacity and settlement, separately for C-Soil, φ – Soil and C- φ soil and models were found to be superior. The sensitivity analysis was also carried out to check the predictive capability of the models and to study the influence of each of the input parameters on the output, and is also checked and satisfied. These expressions developed in this study are hence suitable for predicting bearing capacity and settlement for either C-Soil, φ – Soil or C- φ soil, and will be mostly suitable for soils in Kerala, India.

The suitability of the said method for other states in India as well as outside India was not checked in this study. The developed equations are based on the soil database solely from Kerala, and that can be said as one of the limitation of the present study. And current study results may requires more refinement before they are used for any comparison purpose or for practical problems.

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