of the foundation (D), length of the foundation (L), unit weight of soil (γ) and angle of internal friction (φ). The ultimate bearing capacity of the foundation (q_u) is the single output variable.
The current study uses data sets from Gandhi (2003), which have been obtained from small-scale foundations loading tests on cohesionless soil.
Generally in pattern recognition procedures (e.g., neural networks or support vector machines) it is common that model construction is based on adaptive learning over a number of cases and the performance of the constructed model is then evaluated using an independent testing data set. Therefore, in this study, from the 50 foundation experiments, 40 were used to train the model and the remaining 10 tests were used to test the model capability for data generalization randomly.

3.2 Criteria of evaluation

The performance of the model developed in this study has been assessed using various standard statistical performance evaluation criteria. The considered statistical measures have been correlation coefficient (R), root mean square error (RMSE), and mean absolute error (MAE).

3.2. Development of the model. For building the model, based on training data set, M5P model tree implemented in WEKA software was used. The model tree generated by the M5P algorithm is shown in Fig. 2.

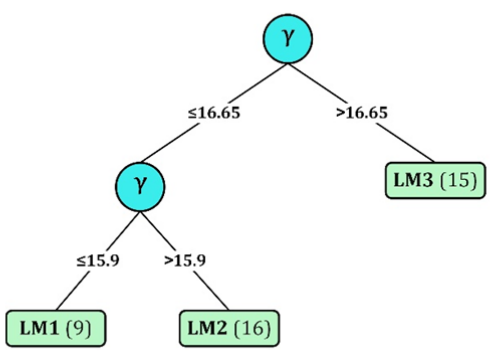

Fig. 2: Model tree generated by the M5P algorithm

The following equations were obtained through using M5P:

LRM 1:

$$q_u = (502.6418 \times D) + 48.4988$$
$$\text{for } \gamma \leq 15.9 \qquad (1)$$

LRM 2:

$$q_u = (432.7071 \times B) + (598.9093 \times D) + (142.6164 \times \gamma) - 2264.3851$$
$$\text{for } 15.9 < \gamma \leq 16.65 \qquad (2)$$

LRM 3:

$$q_u = (987.238 \times B) + (1033.3307 \times D) + (136.0887 \times \gamma) - 2228.3015$$
$$\text{for } \gamma > 16.65 \qquad (3)$$

4. Result

A comparative study has been carried out between the developed model (M5P) and traditional methods of Meyerhof, Vesic and Hansen for the prediction of the ultimate bearing capacity(q_u) of shallow foundation on cohesionless soil. The comparison was done for all of the dataset. Table 1 shows the values of performance indices for the traditional methods and developed model in this paper. The error indicators reveal that the results of the M5P model have much higher values of R and lower errors (RMSE and MAE) in comparison with the theoretical equations. Also, the equation proposed by Hansen shows the best performance among the theoretical formulas.

Table 1. Comparison of M5P model tree with theoretical methods

Model	R	RMSE (kPa)	MAE (kPa)
M5P (Training set)	0.9965	8.0295	5.4087
M5P (Testing set)	0.9925	11.2144	9.4381
M5P (All data set)	0.9961	8.05	6.43
Meyerhof (All dataset)	0.9247	95.49	61.49
Vesic (All dataset)	0.9272	60.68	39.78
Hansen (All dataset)	0.9325	44.48	35.09

4. Conclusions

In this study, M5P model tree was used to predict the ultimate bearing capacity of shallow foundations on granular soil. The model was first developed and tested using an experimental tests dataset. Then, the performance of the proposed model (M5P) was compared with those of the theoretical methods of Meyerhof, Vesic and Hansen. The statistical parameters showed that the M5P model tree is more accurate and has better performance than the theoretical equations. In addition to the higher accuracy, the other advantage of the model trees compared to other soft computing approaches such as ANN and SVM is the ability to generate simple and meaningful formulas. The generated model tree and its three rules are easy to understand, and it gives some scientific insight regarding the importance of different parameters to the user. Furthermore, it was noted that ANNs require some processes of trial and error to find the optimal values of internal parameters. However, the model tree does not require optimization of the network geometry or finding internal parameters. Therefore it takes less computational time, needs much less effort, and can be much faster to run.

Prediction of Shallow Foundations Bearing Capacity on Cohesionless soils using M5P Model Tree

Vahid Reza Kohestani[1] Mahmoud Hassanlourad[2]*
Mohammad Reza Bazargan-lari[3]

1. Introduction

Predicting the ultimate bearing capacity of shallow foundations is an important issue in geotechnical engineering. Terzaghi was the first researcher to propose a comprehensive theory for estimating the ultimate bearing capacity of shallow foundations. After Terzaghi, many researchers including Meyerhof, Hansen and Vesic have offered theories for predicting the ultimate bearing capacity. Most methods require assumptions that are inconsistent with experimental data. A basic method of determining the ultimate bearing capacity of a foundation is in situ testing. However, this method is both costly and time consuming.

Soft computing approaches (i.e., artificial neural networks and support vector machines) are alternatives for estimating the ultimate bearing capacity of shallow foundations based on historical data sets. The previous studies indicated that these methods are more accurate when compared with analytical formulas. However, these methods are not very transparent and also the modeling process is complicated. Decision tree algorithms are quite transparent and also do not need optimization of the model and its internal parameters. For example, in the neural networks approach, the network parameters such as the number of hidden layers and neurons need to be found by trial and error. And these processes are time consuming.

This paper describes the application of the M5P model tree (as another soft computing method) to predict the ultimate bearing capacity of shallow foundations. The main advantage of model trees is that they are easier to use and more importantly they represent understandable mathematical rules. To the best of our knowledge, no study related to determining the ultimate bearing capacity of shallow foundations by using the M5P model tree has been reported in the published literature. However, the M5P model tree could be a useful method for developing an alternative ultimate bearing capacity computation method instead of the usual methods. It has been found that M5P outperforms when fewer data events are available for model development. In other words, M5P has the potential to be a useful and practical tool for cases where less measured data is available.

[1] M. Sc, Central Tehran Branch, Islamic Azad University.
[2]* Corresponding Author, Assistant Professor, Department of Civil Engineering, Imam Khomeini International University.
Email: hassanlou@eng.ikiu.ac.ir
[3] Assistant Professor, East Tehran Branch, Islamic Azad University.

2. M5P model tree

Decision trees are commonly applied in machine learning and data mining as a comprehensible form of knowledge representation. In general, a decision tree is a tree in which each branch node represents a choice between a number of alternatives and each leaf node represents a classification or decision. Regression trees and model trees are special types of decision trees developed for regression issues. However, the main difference between model trees and regression trees is that the leaves of the regression trees have a constant value, while model trees which can predict numeric values for a given data sample hold multivariate linear models in their leaves. The M5P algorithm is the most commonly used classifier of the decision trees family.

M5P model tree algorithm first builds a regression tree by splitting the instance space recursively. Fig. 1 illustrates a tree structure of the training procedure corresponding to a given 2-D input parameter domain of x_1 and x_2.

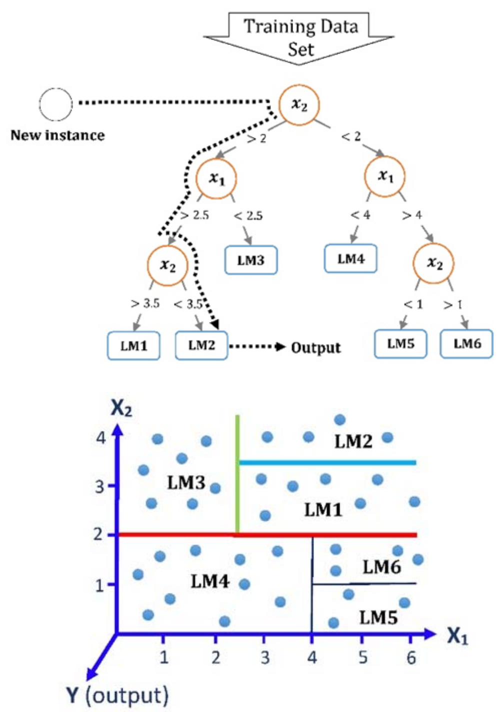

Fig. 1. Example of M5P model tree (LRM 1-6 are Linear Regression Models)

3. Development of the model

3.1 The data used for model development. In this paper, the input variables used in the development of the models are width of the foundation (B), depth