Settlement Prediction of Shallow Foundations on Granular Soils using Multi Expression Programming (MEP)

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1. Introduction

Due to the heterogeneous nature of the non-cohesive soils and the complicated parameters affecting the settlement, it is usually very difficult to predict the foundation settlement accurately. Researchers have examined this problem for many years and some have proposed equations to predict the settlement of shallow foundations. Due to the insufficient accuracy of these expressions for predicting the settlement, the researchers have tried new methods such as the finite element method, finite difference method, soft computing, and so on. In this study, a new model is proposed using artificial intelligence for the prediction of the foundation settlement. Such methods are expected to yield more accurate and if possible, more simple formulas. The purpose of this study is to predict the settlement of the shallow foundations on non-cohesive soils by using the algorithm of multi expression programming (MEP). First, the settlement prediction model is developed, then the suggested formulas are compared with the expressions presented earlier using the soft computing approaches.

2. Multi Expression Programming

Soft computing could be considered as a set of techniques that simulate the behavior of living organisms such as plants, animals, and humans, namely, a soft, flexible, adaptable, and smart behavior.

MEP is a kind of genetic programming (GP) that is developed by Oltean and Dumitrescu. It is also a technique for developing computer programs by an evolutionary approach. The GP has been successfully used to solve some civil engineering problems.

Compared to other evolutionary techniques, MEP has some important advantages:

- It encodes the multiple solutions in one chromosome. It means that the search space is explored more properly. The evaluation of such a chromosome (in most cases) is done with the same complexity as a single solution in each chromosome.
- It evaluates the computer programs command to command and saves the partial results for every training data and also its processing speed is very high.

MEP algorithm starts with random population of individuals. The following steps are repeated until a certain number of generations are reached:

- Two parents are chosen by the standard method.
- Parents are combined to reproduce two new offspring.
- The offspring are mutated and the worst individual in the current population is replaced with the best.

3. Database

The effective parameters for predicting the settlement of the shallow foundation on the granular soil are: foundation breadth (B), foundation length (L), foundation bearing capacity (q), SPT test number (N), and foundation burial depth (Df). The number, quality, and the way of introducing data are also important factors for improving the modeling quality. Thirty eight data are related to the small-scale tests and 151 data are from the large-scale experiments. In order to create and analyze the model, the problem inputs are classified into two sets of training (80%) and testing (20%) data. The current database includes a wide range of granular soils. These data classes must be close to each other in terms of maximum, minimum, mean, and standard deviation indicators so that they could be adapted to each other properly.

4. Modeling by MEP

In order to make the models for the prediction of shallow foundations' settlement, the training data were given to the MEP algorithm. The data include independent input parameters and the dependent output parameter. In order to find a suitable accurate prediction equation, the MEP algorithm was operated with different settings and by considering different forms of input parameters. Accordingly, different models were made and the most proper one was chosen.

$$S = \frac{1}{Ln(N)} \times \frac{L \times D_f \times Ln(q)}{(L \times Ln(N)) + 1} + (Ln(q - N)) \times \frac{2 \times (Ln(q) + B)}{\frac{2}{L} + Ln(N) + D_f} \quad (1)$$

Like other expressions developed by soft computing methods, the proposed model is valid only in the range of the used data. The high correlation coefficient (CC=93.46) and determination coefficient (R^2=87.25) and low errors (of MAE and RMSE) show the great ability of the new MEP model for accurate prediction of the shallow foundations' settlement.

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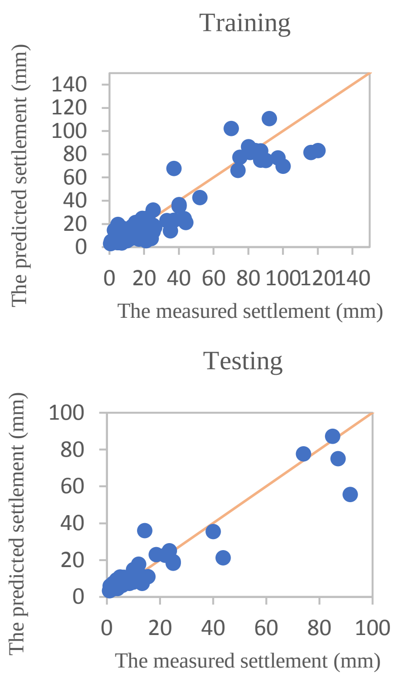

Figure 1. The measured vs. predicted values by the MEP model (A) Training data (B) Testing data

5. Conclusion

This paper investigated the development of a new model for the prediction of the shallow foundations' settlement on the granular soil. This model is built based on the multi expression programming (MEP) approach using the genetic programming methodology. In order to build this model, 189 laboratory data were gathered from former studies. First, the data were classified into training and testing data, then, they were introduced to the MEP algorithm. The new model was compared with the most accurate existing models in the technical literature.

- The proposed MEP model can correctly predict the settlement of the shallow foundation on the non-cohesive soils. Due to its accuracy and simplicity, this model can be used in practical projects successfully.
- The comparison between the MEP model and the most accurate models including GEP, GP, ANN, and EPR in the technical literature indicated that the proposed model of this study shows a better performance than the most of the formerly developed models.
- In this study, the statistical indices of CC and R^2 are 93.45% and 87.25% respectively, and the statistical indices of RMSE and MAE are 9.13 and 5.77 respectively. These indices show the superiority of this model over the previous ones.
- In this research, the ability of the MEP approach for finding a solution for the nonlinear problem of the shallow foundations' settlement on granular soils is shown clearly. Further, the prediction ability can be developed by the suggested technique through retraining the model with new data. More information about the parameters reflecting the field conditions of the ground and load can help the researchers to propose more reliable models for the accurate prediction of the settlement of shallow foundations on granular soils.

Table 1. Descriptive statistics of the variables used to build the model

Reference	Method	Statistical Indices			
		CC (%)	R^2 (%)	RMSE	MAE
Shahin (2002)	ANN	92.62	85.82	9.89	7.12
Rezania and Javadi (2007)	GP	67.66	82.59	11.07	6.77
Shahnazari (2014)	EPR	93.06	87.09	9.53	6.88
Shahnazari (2014)	GEP	89.41	79.93	11.89	7.73
Shahnazari (2014)	GP	93.69	87.78	9.27	6.03
This research	MEP	93.46	87.25	9.13	5.77