

The application of artificial neural network in geotechnical engineering

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Abstract. The artificial neural network (ANN) is a machine learning technique, which can simulate the physiological structure and mechanism of human brain. The study aims to review the principles of ANN algorithm and their application in geotechnical engineering. Firstly, the basic principles of ANN algorithm are introduced. Secondly, the application of ANN algorithm is presented. The review suggests that ANN can classify soil accurately, and it is able to group rock mass, predict the stability of slopes exactly, which could be used for risk assessment. The predicted settlement that is generated by ANN is near real value.

1. Introduction

Geotechnical engineering is the basis for the various engineering project construction. Nowadays, owing to the climate change, extreme weather often happens worldwide, such as rainstorm, hail, which causes the damage of foundation of engineering projects and makes these engineering problems become more pronounced. More importantly, with the development of technology, the stresses that the engineering facilities tolerate are getting larger and the frequency of the stresses become more frequent. For example, the transportation infrastructures have to sustain bigger and more frequent pressures because vehicles become heavier and faster. It would cause more and increasingly severe geotechnical accidents than before.

Since rock and soil's mechanical properties have significant non-linearity and plasticity^[1], traditional methods in geotechnical engineering cannot predict the non-linear and plastic properties of rock and soil accurately. Therefore, the industry pressingly requires an effective method to analyse the mechanical properties of rock and soil. Machine learning techniques are able to deal with non-linear and plastic issues of rock and soil effectively and avoid the weaknesses that may be caused by using traditional methods. Machine learning is a technique that can make computers have ability to learn by themselves and help human to get identify and understand trends and laws in vast data sets and use the trends and laws to establish models to predict the characteristics of unknown things. Algorithms are the core of the machine learning technique, and the kinds of algorithms are many. Every algorithm has its own advantageous and disadvantageous fields when it is utilised to deal with problems. ANN algorithm is a popular machine learning algorithm that is widely applied in geotechnical engineering. ANN is a



simulation of physiological structure and mechanism of human brain, which is a machine learning technique that is different from signal reasoning and logical thinking approaches. The ANN is good at dealing with the problems of incomplete associative memory and defective characteristics pattern recognition and automatic learning. The ANN has three main advantages: firstly, the calculation speed of it is high. Secondly, the fault-tolerant ability of it is strong. Thirdly, it is adept in addressing the problems with complicated solving rules.

There are two objectives of this study. 1. The introduction of the basic principles of ANN algorithm. 2. The overview of the existing research findings about the application of ANN algorithm in geotechnical engineering.

2. The category of ANN

The ANN has three basic structures: feed-forward model, feed-back model and self-organising competition model, and Back-Propagation (BP) Networks, Hopfield Networks and Self-Organizing Map Networks (SOM) are the most representative networks for corresponding basic structures^[2].

3. Back-Propagation Networks

3.1 The principles of the Back-Propagation Networks

The BP network is the core of the feed-forward model, which is a multi-layer ANN based on Backpropagation Algorithm^[3]. The training method of the BP networks is under supervised that means training data do not have label information. The training process of the BP network as follows: firstly the training sample data are input into the network, then the data would transfer forward from the neural in the input layer by layer until the data reach the neural in the output layer and the outcome in the output layer is obtained. When the gap between the input value and output value is bigger than expected value, the deviation would be transferred reversely to the neural in the hidden layer. After that the weight of each neural would be adjusted based on the deviation under the steepest descent method that means calculating the minimum value (maximum value) of the loss function along gradient descent (ascent) direction, and the deviation would be transited to the input layer. In the next stage, the value would proceed forward propagation again, after repeated iteration, the error constantly diminishes^[4]. The training process is over until the gap between the input value and output value is smaller than the expected value. The expected BP network is Figure 1.

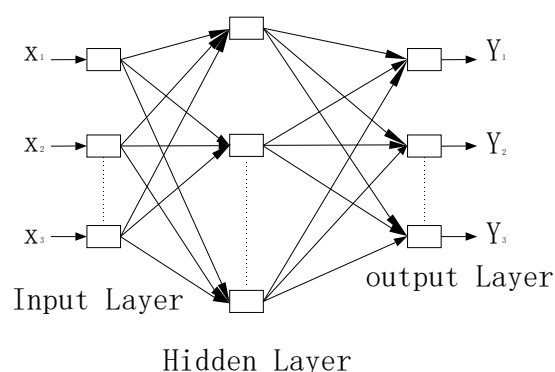


Figure 1. The schematic of the BP network

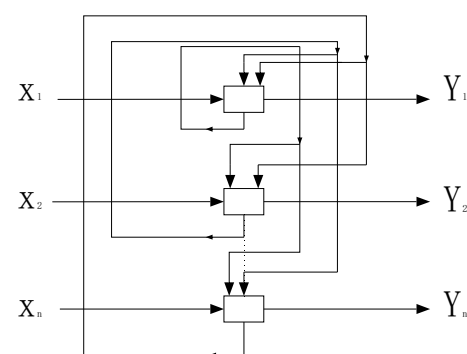


Figure 2. The schematic of the Hopfield network

3.2 The application of the BP network in geotechnical engineering

The BP network is widely applied in geotechnical engineering to address the issues of classification, pattern recognition and functional approximation and interpolation.

The BP network can efficiently divide soil and predict the properties of soil. A BP network back-analysis model was established by Wang to predict the settlement of soil embankment. The results

signify that through combining the momentum approach and the self-adaptive learning-rate, the proposed BP network model is superior than the traditional network in avoiding local minimum and diminishing training time and the prediction accuracy of the new model is higher than that of the traditional ones^[5]. In the term of soil classification, A model to classify soil texture was established by Zhai based on the artificial neural networks algorithm. He came up with that the ANN technique has relatively inferior performance when the sample of data are not large enough. However, when the training data are sufficient, the artificial neural networks techniques is able to deal with the classification of soil texture effectively^[6].

Due to the presence of fracture and joints inside rock, the properties of cement have more significant nonlinear and plastic characteristics than soil, and it is convenient for researchers to take the BP network to solve this kind of problems. As an example, Deng attempted to use the BP network to back analyse displacement of rock slopes and the results were contrasted with the outcomes obtained by using traditional approach, which demonstrates that introducing the BP network can increase the calculation speed and the reliability of results^[7]. Yilmaz further constructed a multiple regression model based on the BP network to forecast the elasticity modulus and unconfined compressive strength of rock. The results reveal that the multiple regression model has high predicted accuracy^[8].

According to the above-analysis, the BP network is able to cluster and foretell the nature of soil and rock validly. Thus some researchers utilise the BP network in the area of earthquake prevention. Panakkat investigated the magnitude of seismic event by using BP network based models. The outcomes manifest that the proposed model performs well in predicting the scale of earthquake, and the model also can be used to forecast the short-term earthquake hazard^[9].

4. Hopfield Networks

4.1 The principles of the Hopfield Networks

The Hopfield network is a symmetrically single layer full-feedback network, which can be divided by Discrete Hopfield Neural Network (DHNN) and Continuous Hopfield Neural Network (CHNN) based on various activation functions^[10]. Now a majority of applications of the Hopfield network adopt the DHNN. Hence this paper mainly discusses the principles and the application of the DHNN in geotechnical engineering. The activation function of the DHNN is the ramp function. The weight matrix of the DHNN is determined by weight design of Lyapunov function. The weight design of the Hopfield network is achieved by the cyclic operating the network to finally converge to a balancing point that is memorised by the network, namely the stable point of Lyapunov function. Since the minimal value of a function is the stable point, the key of the Hopfield design is to choose weight matrix W and the deviator vector b to get the minimal value of Lyapunov function. Hence the issue of solving the balancing point of the Hopfield function is transformed to the matter of solving the minimal value of quadratic function^[11]. The DHNN has three major advantages: firstly it has good astringency. Secondly, balancing points of it are finite. Thirdly, it has favourable stability^[12]. As shown in Figure 2.

4.2 The application of the Hopfield network in geotechnical engineering

The Hopfield network is extensively utilised in geotechnical engineering to solve the matter of combinatorial optimization, classification, pattern recognition and associative memory^[13].

The Hopfield network is an efficient tool to predict nonlinear and plastic deformation of rock and assess the stability of rock structure. Cai attempted to establish a rock engineering system based on the Hopfield network. The Hopfield promoted the dynamic procedures and produced the energy of the system. The study showed that the Hopfield network is a useful tool to implement and computer the rock engineering system^[14]. The determination of status arguments of rock are also crucial to the geotechnical engineering. Dagdelenler discussed the effectiveness of applying the Hopfield network to the weathering degree of granitic rocks. He came up with that the suggested model can forecast the weathering degree of granitic rocks efficiently based on part database of all weathering classes because the normalising process was not used in the model^[15].

The prediction of the deformation of rock by using the Hopfield network can be employed to forecast subsidence. Turk utilised the Hopfield network to construct a model to forecast surface subsidence owing to underground mining. The research demonstrates that the suggested model is able to produce satisfied outcomes, and the predicted results do not depend on the approach of the subsidence presentation because small difference between expected value and measured value is observed by various presentation means^[16]. Apart from that Santos and Celestino, in 2008, investigated the multiple layer Hopfield network to predict tunnel settlement demonstrating that the multiple layer Hopfield network preforms best to forecast the phenomenon, and the excavation rates before and after the instrumented part have large influence on settlement^[17].

5.SOM network

5.1 The principles of the SOM network

The SOM network is a competitively learning ANN network without supervision, which can map input data in high dimension space to low dimension space without changing the topological structure of input data in high dimension space^[18]. SOM network is composed of input layer and competitive layer, and the neural in input layer and competitive layers fully interconnects, as shown in Figure 3. The training method of the SOM network is that firstly the sample data are input into the network, then the neural in competitive layer would calculate the gap between the sample data and its own weight vector, and the neural that has the smallest gap would become the best matching unit. After that the weight vectors of the best matching unit and the neural that is near it would be adjusted to make the gap between the sample data and the weight vectors become the smallest. The process constantly iterates until the model converges^[19].

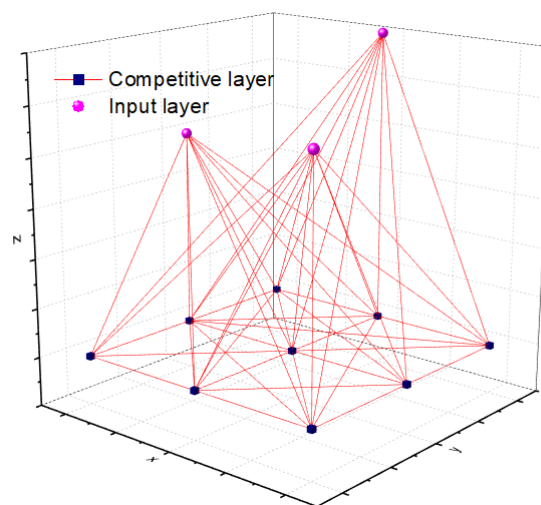


Figure 3. The schematic of the SOM network

5.2 The application of the SOM network

The SOM network is widely used in geotechnical engineering to deal with the problems of classification, aggregation, visualization and picture processing^[20].

The SOM network is capable of dividing and forecasting the nature of soil and rock. Mokarram attempted to explore the validity of the SOM in clustering soil for soil fertility evaluation. He proposed that the SOM is an excellent instrument in visualising data, and it is capable of classifying soil based on its fertility assessment exactly^[21]. In the respect of rock, Chuahan introduced the SOM technique to establish 2D segmented pictures of rock score. The outcomes showed that the SOM technique is helpful in constructing the 2D segmented images of rock score and helping the analysis of the microstructure of

rock score ^[22].

The ability of the SOM network to cluster and foretell the properties of soil and rock is able to utilised to forecast the stability of landslides. Huang conducted deeper research on the effectiveness of applying the SOM network based on ELM model on the prediction of landslides. The study showed that the SOM network based on ELM model is more accurate than the single ELM model and SOM-SVM models on the forecast of landslides susceptibility. The proposed SOM-ELM network manifests that the high susceptibility landslides areas that are located at the regions of low elevation and clay stones ^[23].

6. Conclusion

The review listed the application and principles of ANN algorithms in geotechnical engineering are introduced in detail. The vital findings are surmised as follows:

1. ANN algorithm can be used to classify soil. Overall, the ANN approach can group soil more correctly than other algorithms.
2. Rock cluster is also significant to the construction of engineering, which is able to achieved by using ANN. In general, the accuracy degree of classification by adopting ANN is high.
3. ANN is able to be adopt to establish models to forecast the deformation of rock and soil validly. on the whole, ANN algorithm is able to predict the properties of rock correctly.
4. The landslide map is able to be established based on ANN algorithm. In general, ANN algorithm has high accuracy in forecasting the stableness of slopes.
5. The model of the deformation of building materials under earthquake loading can be constructed validly by adopting ANN algorithm.
6. ANN algorithm is used to establish models to predict the subgrade sedimentation. Overall, the prediction produced by using ANN is close to real subsidence.

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