Method for objectively determining design strength with artificial neural network

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ABSTRACT

The unconfined compression strength has been applied popularly as the shear strength in situ, in Japan. It is very difficult to determine the design strength used for designing the earth structure, because the unconfined compression strengths have large variances at even same depth. In this paper, the determination method of the design strength based on the artificial intelligence was proposed. Firstly, the unconfined compression strength at any locations was estimated through an artificial neural network. Secondary, through the discussion of the design strength determined by skillful and experienced engineer, the engineering judgments of the design strength were considered. It was suggested that the design strength is determined so that the safety factor is not less than 1.0. Finally, the design strength was determined by application of spatial estimation of unconfined compression strength. The proposed method is available to automatically determine the design strength, because the design strength based on the proposed method follows approximately that based on the skillful and experienced engineer.

Keywords: Design strength; Artificial intelligence; Unconfined compression strength

1 INTRODUCTION

Recently, the land developments around coastal area in Southeast and Middle Eastern Asia have been performed increasingly with industrial and commercial development. The stability of ground is main geotechnical issue at the construction of earth structure there, because the soft soils are widely spread there in most cases. The unconfined compression test have been frequently applied to investigate the shear strength at in situ in Japan. However, the shear strengths gotten by the unconfined compression test have large variances. Therefore, it is very difficult to determine the design strength used for designing the earth structure, so that the skillful and experienced engineer usually should determine the design strength.

By the way, the usage of artificial intelligence have been spread explosively in the social various fields including geotechnical engineering. The authors have been developed the methods for interpolating the soil properties spatially with an artificial neural network, which is one of the information processing systems. Moreover, the authors have discussed stochastically the effect of the errors of soil properties estimated with the artificial neural network on the estimation of consolidation settlements (Oda et al, 2009, 2011, 2012, 2013, 2015).

In this paper, determination method of the design strength based on the distribution of unconfined compression strengths was proposed. The technique of artificial intelligence is applied to the proposed determination method. Firstly, an artificial neural network was applied to spatially estimate the unconfined compression strength of the Holocene clay in Kobe Airport. Secondary, the engineering points of determination of the design strength were discussed based on the example of design of reclamation revetment in the Kobe Airport. Finally, the design strength was determined by application of spatial estimation of unconfined compression strength from the viewpoint of revealed engineering points. The proposed method is available to automatically determine the design strength, because the design strength based on the proposed method follows approximately that based on the skillful and experienced engineer.

2 ARTIFICIAL NEURAL NETWORK

An artificial neural network is an information processing system, in which the nerve cells (neurons) of the human brain are reproduced mathematically. Figure 1 shows architecture of the artificial neural network used in this study. This type of artificial neural network is called a back propagation neural network, which is the most popular neural network in use. The back propagation neural network consists of an input layer, one or more hidden layers, and an output layer. Each layer is connected by neurons. In this study, the north latitude, east longitude, and altitude at a target position were correlated to items of the input layer. Estimated shear strength was correlated to items of the output layer.

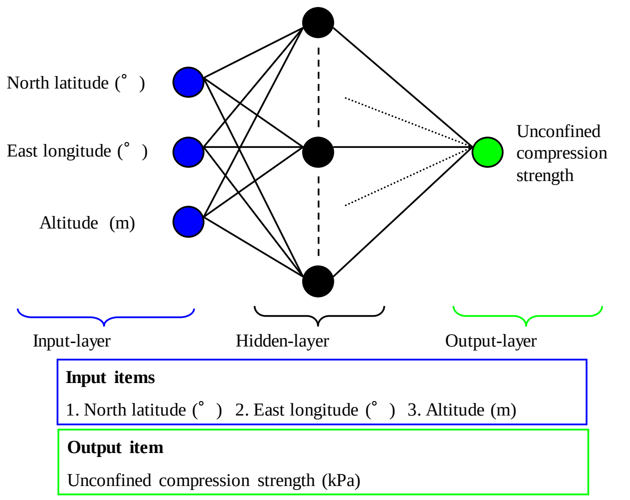

Fig. 1. Architecture of artificial neural network

3 SPATIAL ESTIMATION OF UNCONFINED COMPRESSION STRENGTH

3.1 Subject area

The Kobe Airport, which is one of the large man-made islands in Osaka Bay was chosen as the research target. The stability of reclamation revetment became one of the most important engineering issues at construction of the Kobe Airport, because there is a soft and thick Holocene clay (Ma13) layer at construction site of the Kobe Airport. Figure 2 shows the locations of soil investigations along with the construction section for reclamation revetment. A large number of unconfined compression tests were carried out to investigate the shear strength of the Ma13 by using the samples which were taken by boring investigations at each construction section for reclamation revetment.

Fig. 2. Locations of soil investigations along with construction section for reclamation revetment

3.2 Analytical procedure

The process of determining the optimal architecture of an artificial neural network is called "training." A large number of pairs of input and output items were required in the training process. An artificial neural network was trained as follows. First, the initial network had randomly assigned weights. When input data were given to the input layer of this network, they were propagated through the hidden layer to the output layer; after this, output data could be obtained. However, there were differences be-tween the estimated output values and target values. The network and weights were updated automatically to minimize the differences. Training was repeated until the repetition reaches a preliminarily given number. The optimal architecture was determined in this manner.

3.3 Spatial estimation

Fifty-three boring investigations were applied to determine the optimum architecture of the artificial neural network for spatial estimation of unconfined compression strength. In the analysis, the logarithms of the unconfined compression strength were applied because its variations have remarkable differences between at the shallower and the deeper. Figure 3 shows the three-dimensional distribution of the unconfined compression strength estimated with the artificial neural network. There is hardly different in the lateral distribution of the unconfined compression strengths. Furthermore, the unconfined compression strength increases with depth, because the Holocene clay layer is in the condition of the almost normally consolidated. The artificial neural network can reproduce reasonably its three-dimensional distribution as shown in Figure 3.

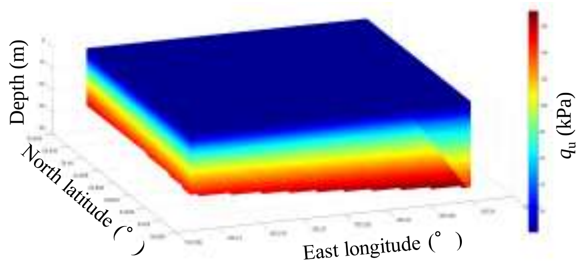

Fig. 3. Distribution of unconfined compression strength

Figure 4 shows the relationship between probability density and relative errors of estimated unconfined compression strength. The relative errors, *re*, is defined as following equation.

$$re = \frac{\log\left(q_u{}^p\right) - \log\left(q_u{}^o\right)}{\log\left(q_u{}^o\right)} \qquad (1)$$

where q_u is a unconfined compression strength. Superscripts p and o denote the estimated and target values, respectively. Also, the distribution of probability density was calculated from the frequency distribution of the relative errors. The distribution of probability density has a sharp and symmetric mountain shape. The average and the standard deviation of the distribution are almost equal to 0.0 and 0.1, respectively.

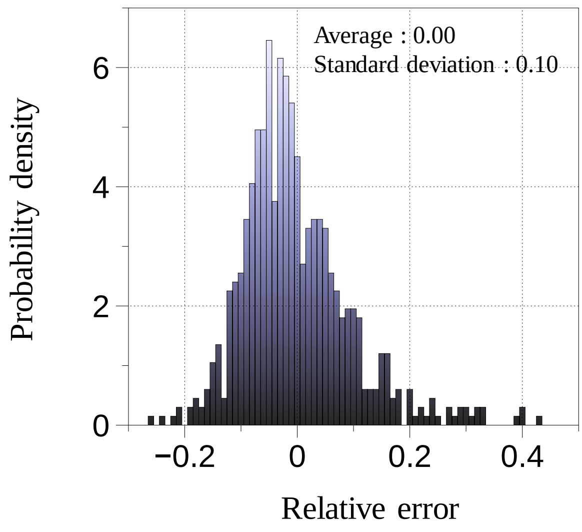

Fig. 4. Relationship between probability density and relative errors

4 DETERMINATION OF DESIGN STRENGTH

Figure 5 shows the comparison of design strength with unconfined compression strengths in the 1st construction section. There is the large variation of unconfined compression strengths at the same depth. The two separated solid lines as the design strength were determined by the skillful and experienced engineer based on the distribution of unconfined compression strengths at preliminary design for reclamation revetment. As you know, it is difficult for the ordinary engineers to express the variations of design strength with depth by two lines.

By the way, the safety factor, F_s, must be applied to consider the uncertainness based on various factors at design of earth structure. The author defines the limited design strength, $q_{u,l}$ as following equation.

$$q_{u,l} = \frac{q_u}{F_s} \qquad (2)$$

The limited design strength can be considered as the design strength at the safety factor equal to 1.0. The two dotted lines represent the limited design strength in Figure 5. In addition, 1.3 was applied as the safety factor in Figure 5. There are 90% of dots of the unconfined compression strength in the gray zone at which the unconfined compression strength is greater than the limited design strength. Table 1 shows the percentage of unconfined compression strengths included in the gray zone. The percentage is greater than about 90% in each construction section. The limited design strength is determined as the boundary of the area in which 90% of dots of unconfined compression strength are included. If the higher design strength than the limited design strength is applied to the design of earth structure, it is suggested that the safety factor does not become smaller than 1.0 in probability of 90%. Moreover, the engineer who determined the design strength has the unconscious judgments based on his experiences for the design. Usually, these judgments are called an engineering judgment. This engineering judgment above-mentioned is a criterion not to cause failure of the earth structure.

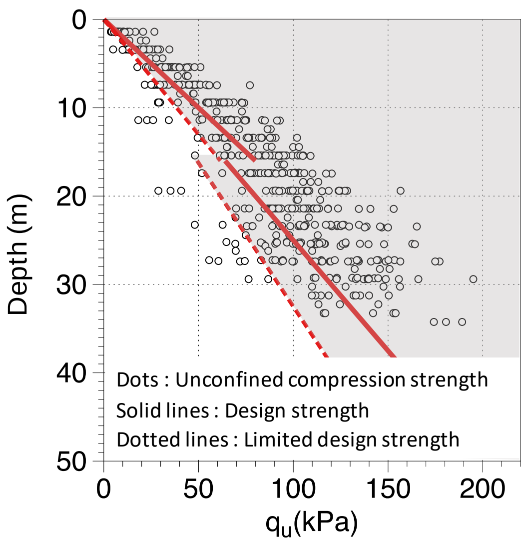

Fig. 5. Comparison of design strength with unconfined compression strengths in 1st construction section

Table 1. Percentage of unconfined compression strengths

Section No.	1	2	3	4	5	6
Percentage (%)	92.7	97.6	93.7	89.7	89.0	90.6

Figure 6 shows variation of estimated limited design strength with depth. Variations of estimated strength with depth could be given by the artificial neural network as shown in Figure 3. Moreover, the error of the estimated strength could be considered by using relationship between probability density and relative error. In this paper, the normal distribution was applied instead of the relationship between probability and relative error shown in Figure 4, in order to simplify the calculation. That is, the maximum strength could be given by adding the error corresponded to three times of standard deviation. On the other hand, the minimum strength could be given by deducting the error corresponded to three times of standard deviation. The extent from the maximum strength to the minimum strength could be regarded as that of the unconfined compression strength. The gray zone occupies the 90% of extent from the maximum strength to the minimum strength. Therefore, the lower boundary of the gray zone could be derived as the limited design strength. Finally, the proposed strength can calculated by using equation 2.

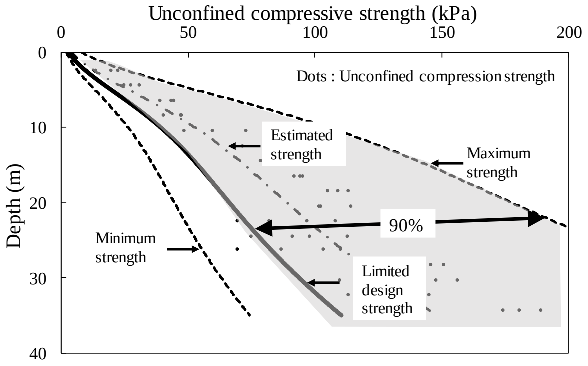

Fig. 6. Variation of estimated limited design strength with depth

Figure 7 shows the variation of proposed strength with depth. In the part which is shallower than depth of 10m, the relationship between proposed strength and depth perfectly matches the relationship between design strength and depth. On the other hand, in the part which is deeper than depth of 25m, the relationship between proposed strength and depth almost matches the relationship between design strength and depth. From 10m to 25m, the relationship between proposed strength and depth smoothly shifts from the upper relationship to lower relationship for design strength. That is, the proposed method in which the technique of artificial intelligence is applied can give automatically the appropriate design strength at any depth without judgement by a well-skillful and experienced engineer.

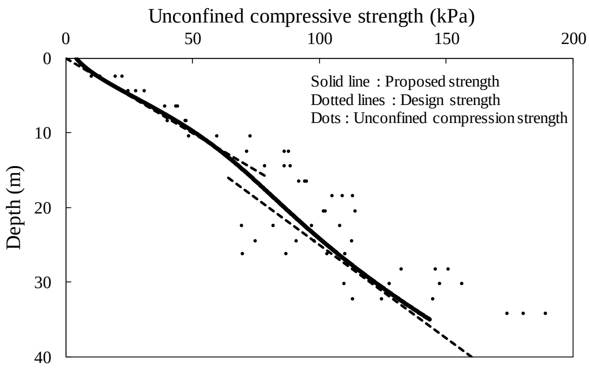

Fig. 7. Variation of proposed strength with depth

5 CONCLUSION

In this paper, an artificial neural network was applied to spatially estimate the unconfined compression strength of the Holocene clay in Kobe Airport. The engineering points for determination of the design strength were discussed. Finally, the design strength was determined by application of spatial estimation of unconfined compression strength from the viewpoint of revealed engineering points. The main conclusions are summarized as follows:

1. The artificial neural network can reproduce reasonably its three-dimensional distribution.
2. Almost 90% of unconfined compression strengths is greater than the limited design strength which is derived from the design strength determined by skillful and experienced engineer.
3. The design strength that was given by applying a neural network follows approximately that based on the skillful and experienced engineer.
4. The proposed method is available because the design strength can be determined automatically.

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