UTILIZING THE UNCERTAINTY MATRIX IN ESTIMATION OF ROCK MASS DEFORMATION MODULUS ON THE BASIS OF EMPRICAL RELATION

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Abstract: Uncertainty in parameters required for analysis and design of structures is an important issue that is usually considered by rock engineers, which is caused by the developed equations and also the nature of rocks. Modulus of deformation is one of the geo-mechanical parameters widely utilized in design and analysis. But estimating this parameter using empirical models is associated with uncertainty and this causes mistakes in engineering decision making process. The purpose of this study is to develop a novel concept entitled uncertainty matrix for practical prediction of deformation modulus with high level of certainty. Therefore, modulus of deformation is obtained based on the uncertainty matrix and statistical methods. Later, using the uncertainty matrix and t distribution, the range for variation of deformation modulus is determined. As a case study and also for defining the elements of uncertainly matrix, models that are just functions of Rock Mass Rating (RMR) were used and data sets of sand-stone slopes in Kahar formation were applied. Results indicate that prediction of deformation modulus for rock mass using the developed method is more reliable in comparison with general methods. In addition, deformation modulus for the studied sand-slope is in the range of 23.67<E<30.00, with 95% certainty.

Keywords: Uncertainty matrix, Deformation modulus, Sandstone Kahar formation, empirical models, Student's T distribution.

INTRUDOCTION

Engineers in the analysis and design of rock structures always deal with a series of uncertainties due to the inherent nature of rocks and empirical models. Deformation modulus is one of the most applicable geomechanical parameters which is widely used in engineering. In fact, deformation modulus relates stresses and relative deformations in a rock mass and consists of elastic and deformable behaviors.

There are two methods for determining the deformation modulus- direct and indirect methods. Direct estimation of deformation modulus is time-consuming and expensive, thus there are many operational problems with this analysis. Therefore, nowadays determination of deformation modulus is done indirectly utilizing the empirical models. Input parameters in empirical models mainly consist of geomechanical parameters and different rock mass classification systems such as Rock Mass Rating classification (RMR), Geological Strength Index (GSI), Q system and Rock Quality Designation (RQD). But estimating the deformation modulus by different models leads to different results, which is due to the nature of models not developed in similar condition.

On the other hand, for determining the input parameters (such as RMR, GSI), geological survey is performed directly on the rock mass and due to the inherent heterogeneity of rocks, obtained values are not reliable.

In this condition, statistical and probabilistic methods may be useful for determining the deformation modulus with a higher level of confidence. Statistical methods were first developed by Weibull, since then several studies have been performed on the probabilistic estimation of rock mass properties.

Kim and Gao proposed a probabilistic method considering the uncertainty in the rock mass properties. Monte Carlo method was used to simulate random variables, and Chi-square was utilized for fitting the experimental results in basalt rock.

Point estimation method for predicting the Hook-Brown criterion parameters was used by Hook. For this purpose, input parameters such as geological strength index, uniaxial compressive strength, and m_i were considered as random variables with normal distribution.

Sari presented a probabilistic practical method for estimating rock mass geomechanic parameters using Monte Carlo simulation. Distribution of required parameters, such as uniaxial compressive strength, spacing, length and aperture of discontinuity (variable parameters of RMR) were determined and distributions of Hook-Brown parameters and geomechanic parameters of rock masses were simulated based on the obtained parameters, and it was concluded that the certainty level of results according to this method is more than that of other decision making methods.

In the present paper, a statistical population is generated by developing an uncertainty matrix and statistical methods. Then the range of real deformation modulus is predicted with high certainty level using the Student's T-distribution.

METHOD

This paper focuses on the estimation of deformation modulus, considering the uncertainty in available models and the properties of rock mass. Thus, a $m \times n$ matrix is defined so that the elements of the first column represent the characteristics of the rock mass that were repeated several times in the geological survey, and the first row of the matrix indicate different models for predicting the deformation modulus. Also, the other elements of the matrix stand for the predicted deformation modulus corresponding to each row and column. Using statistical methods, the obtained $m \times n$ matrix is converted to a $1 \times n$ matrix. Finally, the simplified matrix is converted to an element. Hence, the obtained result is more reliable than conventional methods. Also, using the uncertainty matrix, the range of real deformation modulus is determined using the Student's T-distribution.

In the case study, the application of uncertainty matrix is expressed. In this study, models with the only input parameter of Rock Mass Rating (RMR) were selected for determination of elements of rows in uncertainty matrix and estimation of deformation modulus. Therefore, 16 models were collected among the developed models by researchers.
To form the matrix columns, which are RMR parameters, the available data sets of sandstone slopes in Kahar formation of Chalous road were used. The studied area is located in Alborz mountain range in northern Iran. Ten RMR data were harvested.

DISCUSSION

By forming a 10×16 matrix, 160 elements of the matrix were prepared to predict the deformation modulus. In the other words, if the usual methods were used, each predicted results may have been used in analyzes. But results would not be reliable.
According to the results obtained from the matrix, the characteristic of each input parameter (corresponds to the elements of the first column) is determined using the statistical methods in order to reduce the uncertainty caused by the predicted results from different models. Therefore, the uncertainty matrix is converted into a matrix of 1×10. The statistical characteristic of the matrix is determined to be 1×10, for reducing the uncertainty due to the intrinsic nature of rock and determining a deformation modulus for the rock mass. Table 1 shows the statistical characteristic of deformation modulus of the rock mass and RMR.

Table 1- Characteristics of the sandstone rock of Kahar Formation

Variable	Minimum	Maximum	Domain	Average	Middle	Mode	Standard deviation	number of samples
RMR	64	76	12	69.4	68.5	2	4.53	10
$E_r (GPa)$	19	37.8	18.8	26.87	24.9	2	7.15	10

However, using the uncertainty matrix and the Student's T-distribution, the range of the real deformation modulus is estimated. For this purpose, the results of uncertainty matrix that consists of 160 elements are considered as the statistical population. To investigate whether the data follows normal distribution, the normalization of data had to be done in two steps:
1- Investigating data skewness. If the skewness of samples is in the range of -2 to +2, then the second stage can be examined.
2- Using Shapiro–Wilk Test. In this test, zero assumption that the distribution of normal data distribution is tested at 5% error rate in order to check the normality of the data. The results of normalization tests are shown in Table 2. Therefore, with a high level of certainty, data may be assumed to be normal. Figure 1 shows the significance level of data in the test. Hence using

Student's T-distribution, with a certainty level of 95%, deformation modulus changes is the range of 23.67<E<30.00(GPa).

Table 2- Results of the test of statistical data normalization test

Shapiro–Wilk Test	Kurtosis	Skewness
0.07	0.04	0.65

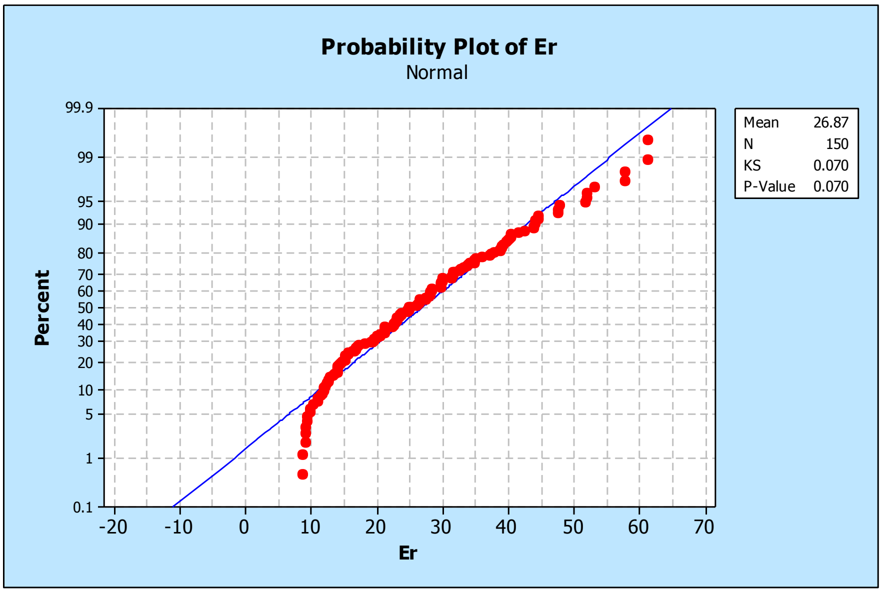

Fig 1- Normality of data based on Shapiro–Wilk test

CONCLUSIONS

Uncertainty in geomechanical parameters is unavoidable, and researchers are always trying to develop methods to create more certain results for analyzes and designs. Deformation module is an important parameter in analysis and design. But the uncertainty of the developed models and the intrinsic nature of rocks cause the predicted results to mislead engineers. In this paper, by developing of uncertainty matrix using statistical methods, deformation modulus with higher certainty was estimated and the range of deformation module was determined. Having a case study, for the construction of the elements of first column in uncertainty matrix, ten data sets of sandstone rocks of Kahar formation was investigated. Also, for determining the elements of the row of matrix, 16 models that are only function of RMR were considered. The results showed that the deformation module derived from an uncertainty matrix consisting of 160 elements is more accurate and reliable in comparison with other empirical models. Also, in order to determine the range in which the actual deformation module is located, matrix elements were considered as statistical population. Considering that this population follows normal distribution, using Student's T-distribution with a confidence level of 95%, the deformation modulus is located in the range of 23.67<E<30.00(GPa).

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