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Numerical method to determine mechanical parameters of engineering design in rock masses*

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Abstract: This paper proposes a new continuity model for engineering in rock masses and a new schematic method for reporting the engineering of rock continuity. This method can be used to evaluate the mechanics of every kind of medium; and is a new way to determine the mechanical parameters used in engineering design in rock masses. In the numerical simulation, the experimental parameters of intact rock were combined with the structural properties of field rock. The experimental results for orthogonally-jointed rock are given. The results included the curves of the stress-strain relationship of some rock masses, the curve of the relationship between the dimension Δ and the uniaxial pressure-resistant strength σ_c of these rock masses, and pictures of the destructive procedure of some rock masses in uniaxial or triaxial tests, etc. Application of the method to engineering design in rock masses showed the potential of its application to engineering practice.

Key words: Continuous micro-element, Orthogonally-jointed rock, Engineering in rock masses, Mechanical parameters
Document code: A **CLC number:** TU455; TU452

INTRODUCTION

The historical development of research in rock mechanics has yielded numerous useful and workable theories. The Coulomb Criterion (1772) and Mohr's Hypothesis (1990) both provide easy and effective methods for determining mechanical parameters such as rock strength. R.E. Goodman formulated the equation of mesh and non-mesh joints construction. Other researchers conducted experiments on different types of rock masses with specific, unique properties, to solve increasingly complex, practical engineering problems. It is an accepted fact that researching the mechanical properties of rock masses is much more complicated than researching just the rock mass properties because the former are influenced by various joint and structural planes.

In Russia and Brazil, mechanical tests used expensive large jacks to test samples of cut rock as large as 8×12×7 m^3. Unfortunately, these samples were still too small for those times when practical engineering requires study of rock masses with complex structural planes (Hudson, 1997; Sun, 1980).

CONTINUITY FOR ENGINEERING IN ROCK MASSES

In the natural world, continuity is a relative

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concept as there is no absolute continuity. So the continuity hypothesis of engineering in rock masses can be stated as follows: Suppose that the volume of an entire object is filled with material micro-elements that form the object, and that there are no voids or empty spaces between the micro-elements. Unlike theoretical abstract mathematical points, material micro-element actually have size. The size of engineering rock masses used for research is determined by the size of these micro-elements. Finding the minimum or the critical size guarantees achievement of engineering purposes; continuity in the rock mass can be assumed. The size meeting this condition is also called the imitated continuous micro-element dimension or continuous micro-element dimension for short (He, 1991).

Based on this hypothesis, the continuity concept indicates that only if the rock mass has sufficient micro-elements of a certain size can the rock mass be assumed to be a continuous object. The continuous micro-element dimension in a continuous object should meet the following conditions:

Firstly, the continuous micro-element dimension should be sufficiently smaller than that of the rock mass being researched, so that it approximates a mathematical point. This guarantees that each physical measurement changes continuously from one micro-element to another and avoids making uneven or inconsistent material properties averaged. Secondly, the continuous micro-element should be sufficiently larger than its contained gaps or particles, and should have sufficient gaps and particles to guarantee that average physical measurement in each unit-section will change continuously. This will allow statistical averages of each physical measurement to be equivalent to a physical measurement of the same quantity for a single micro-element. Finally, the smallest critical dimension that meets the above conditions is used as Δ_c, the continuous micro-element dimension (Cheng and He, 1989).

The continuous micro-element size that meets these conditions for a given rock mass can be derived using mathematical or mechanical methods, allowing the rock mass to be considered as a continuous object. On the other hand, it is necessary to limit the number of measurements when making an engineering analysis of the medium's continuity (Tang, 1997).

STEPS TO DETERMINE THE MECHANICAL PARAMETERS OF ROCK MASSES FOR ENGINEERING DESIGN

To determine the continuous micro-element dimension and mechanical parameters of rock masses, this paper proposes method using the difference of the structural planes or the specific properties of the structural body of a specific rock mass to choose representative rock mass and structural planes with different sizes from geological field engineering investigations. After this, a series of laboratory tests and numerical simulations are conducted. The concrete steps are as follows:

1) Based on the field engineering investigation, determine the spatial distribution of the structural planes and assume a construction model for the rock masses. Collect representative samples of competent rock and samples with typical structural weaknesses from the test-area.

2) In the laboratory, carry out a rock mechanics experiment on the competent rock sample to determine the complete stress-strain curve and the values of σ_c, E, μ, C, and Φ of the competent rock. Then, use numerical analysis software to simulate these results.

3) Also in the laboratory, carry out a rock mechanics experiment on a sample with a single structural plane, to determine its mechanical parameters. Again, use numerical analysis software to simulate these results.

4) Construct a rock mass model that corresponds to the results of the lab tests and modeling of the competent samples and the sample with a single structural plane, which corresponds accords with the construction mode of field engineering rock masses.

5) Construct a numerical model of an engineering object having the same properties as the

competent rock sample, but of a different size and conduct numerical tests on this object.

6) Analyze a series of numerical test results to determine the continuous micro-element dimension Δ_c of the engineering object and the corresponding mechanical parameters of the engineering rock mass.

RESULTS ANALYSIS OF A SIMULATION EXPERIMENT

The texture of rock masses varies, and each separate rock mass will have a different value of Δ_c, different corresponding strength parameters, and different mechanical deformation parameters. As an example, a sandstone mass made up of massive sandstone and the associated orthogonally-jointed, weak interlayer, structural planes will be used to show the new experimental procedure.

Original data from the experiment

The cross-sectional dimensions of the respective rock test masses were: 0.02 m × 0.02 m, 0.2 m × 0.2 m, 1.0 m × 1.0 m, 2.4 m × 2.4 m, 3.6 m × 3.6 m, 5.0 m × 5.0 m, 8.0 m × 8.0 m, 10.0 m × 10.0 m, and 15.0 m × 15.0 m, and the height of each test-mass was 1 m. Based on laboratory testing and an interior mechanics experiment, the uniaxial stress-resistant strength of intact sandstone mass was σ_c= 30 Mpa, the modulus of elasticity was E =2.4×10^4 MPa, and Poisson's ratio was μ=0.25. Similarly, for the jointed layer, σ_c is 1 Mpa, E 50 Mpa, and μ 0.25.

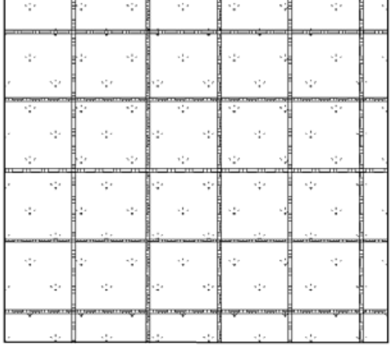


Fig.1 Geological model of rock masses

The geological model of the rock mass, based on the field engineering investigation, is shown in Fig.1, where the maximum size of the rock mass is 1.0 m × 1.0 m and the height of a jointed layer is 10 mm. Fig.2 indicates a way to determine experimental models of rock masses with different sizes. In addition, Fig.2 provides two test models whose sizes are respectively 2.4 m × 2.4 m and 3.6 m × 3.6 m, sizes that can be used for other models.

Analysis of simulation results

(1) The stress-strain relationship curve obtained from laboratory tests was almost the same as the result of numerical simulations for the same conditions. Similarly, the stress-strain relationship curve from laboratory tests of jointed samples is the same as the result of a numerical simulations for the same conditions.

(2) Based on the numerical simulations, the curves of the relationship between dimension Δ of the test samples and uniaxial pressure-resistant strength σ_c, the modulus of elasticity E, residual strength σ_{Rc}, the internal angle of friction Φ, and the cohesive force C were derived individually. Some results are shown in Figs.3 to 4. Due to limited space, the stress-strain curves of each the respective samples are omitted. In addition, Figs.5 and 6 introduce two examples of rock masses with respective sizes of 2.4 m and 10 m to explain the evaluation procedure for C and Φ, based on a triaxial test. The values of Φ are shown by dots A and B in Fig.4. It is necessary to stress that this experiment was divided into two groups, Sequence I and II. The test samples in each sequence were taken from rock masses with the same nature. Although

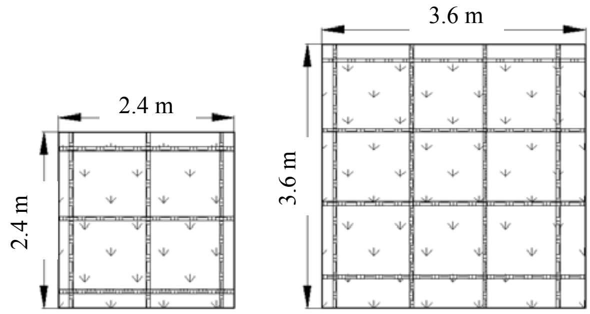


Fig.2 Geological models of test samples

their respective dimensions were the same, because test samples for each sequence were taken in different manners and sequences, the number of joints and the distribution mode for the joints in each test sample in Sequence I were different from those in Sequence II.

It is easy to determine the value of the mechanical parameter Δ_c of a rock mass on the basis of these five curves. As determined by this experiment Δ_c should be 10 m. These diagrams show that when the size of the test samples, Δ<10 m, the five parameters σ_c, E, μ, C, and Φ in Sequence I and II change greatly. When Δ>10 m there is little change. In addition, when Δ<10 m these five parameters change radically with size increases, whether in Sequence I or II. After the size of test samples reached 10 m, they stabilized and changed only a little in some areas. So, Δ_c =10 m is a critical value in this rock mass. Therefore it is clear that Δ_c=10 m is the continuous micro-element dimension of these sandstone masses.

(3) To demonstrate how the numerical simulations were performed, the procedure for two test samples is shown in Figs.7 to 8 where each specific step indicates the loading time based on a certain displacement measurement. Their corresponding stress-strain curves are shown in Fig.9a and Fig.10b. Each curve shows the stress and strain for every step. For example, Steps 1 and 15 in Fig.7 corresponds respectively with dots A and B of Fig.9a.

CONCLUSION

This paper presented a new method for carrying out numerical simulations of mechanics experiments on rock masses, for determining the parameters of selected rock samples on the basis of continuous micro-element dimension of the rock mass, combined with research in engineering geology, laboratory measurements, and numerical simulation. We believe this approach is convenient, highly efficient, and practical. It can replace many kinds of large equipment used in rock mechanics experiments and allow the analysis of larger rock masses for the purposes of engineering design.

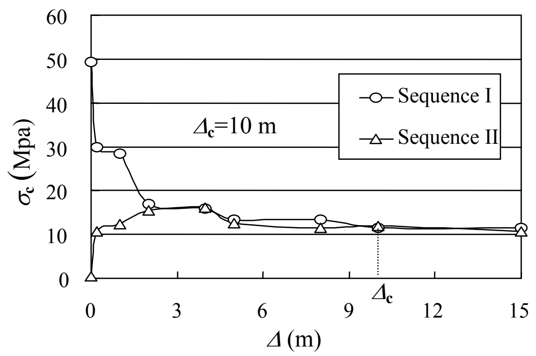


Fig.3 Relationship between σ_c and Δ

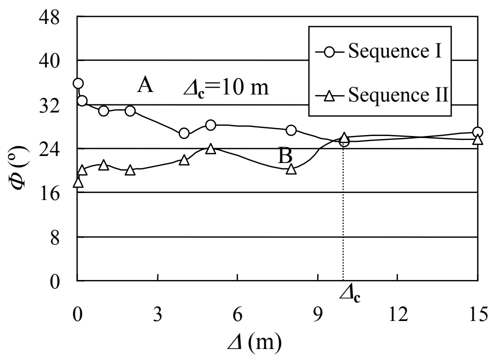


Fig.4 Relationship between Φ and Δ

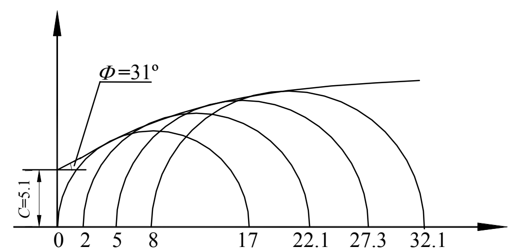


Fig.5 Evaluation of C and Φ for the 2.4 m Samples in Sequence I

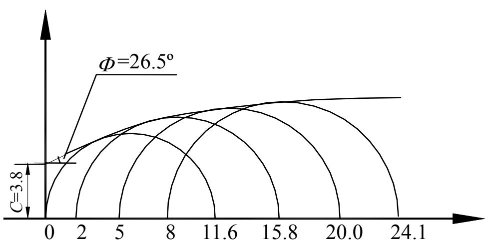
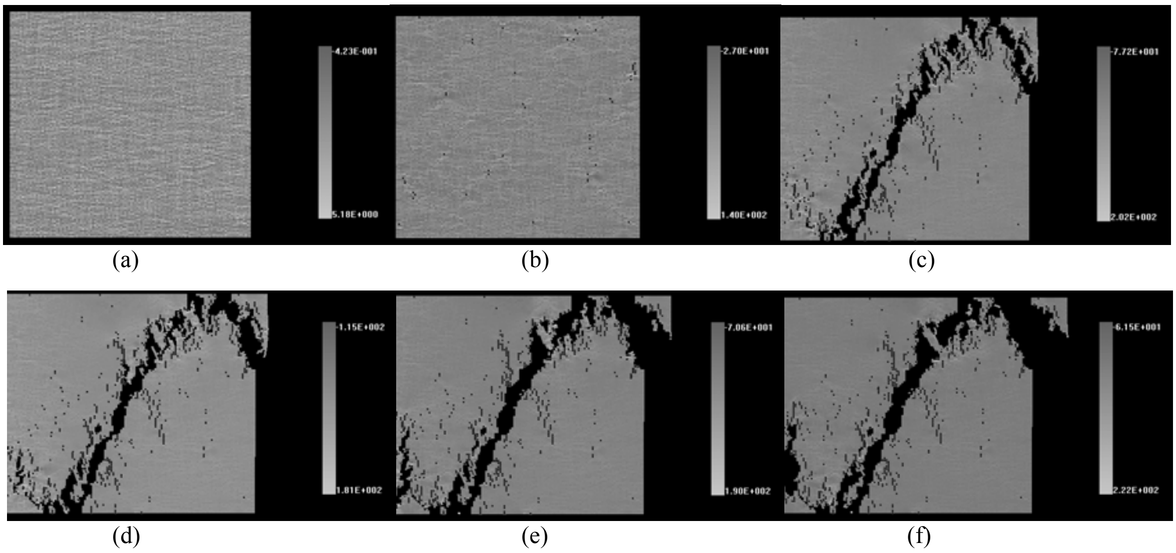


Fig.6 Evaluation of C and Φ for the 10 m Samples in Sequence I



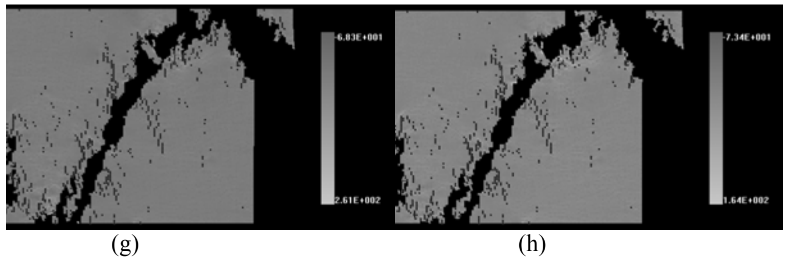
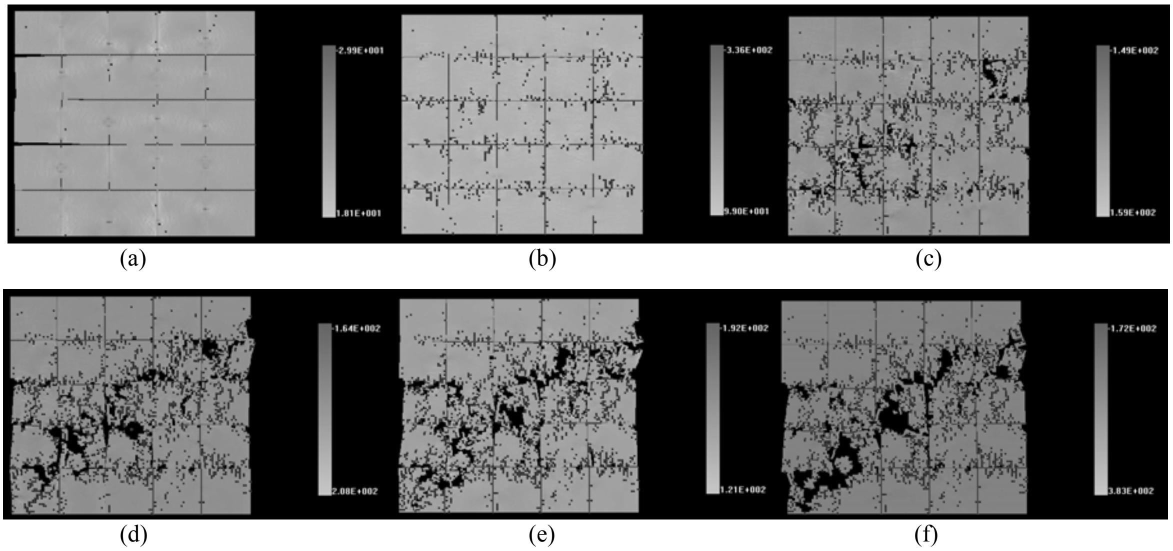


Fig.7 Simulated destruction of a 1000 mm rock sample in a uniaxial test, Sequence I
(a) Step 1, Dot A; (b) Step 15, Dot B; (c) Step 17, Dot C; (d) Step 20, Dot D; (e) Step 25, Dot E; (f) Step 30, Dot F; (g) Step 35, Dot G; (h) Step 40, Dot H



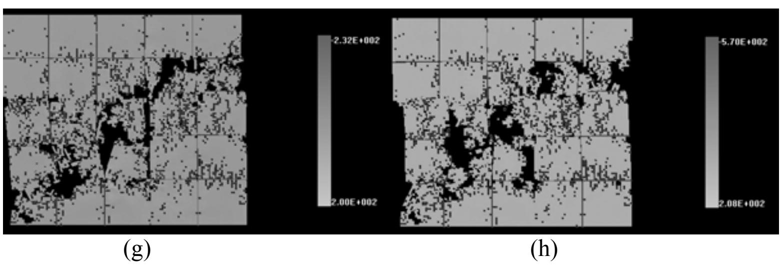
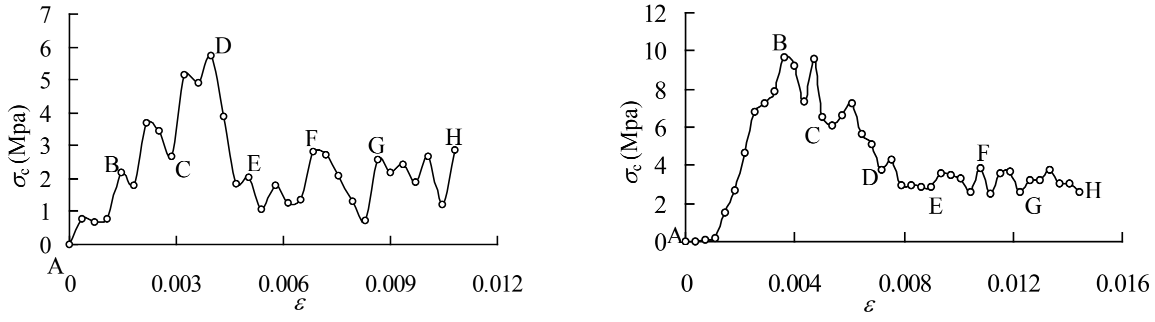


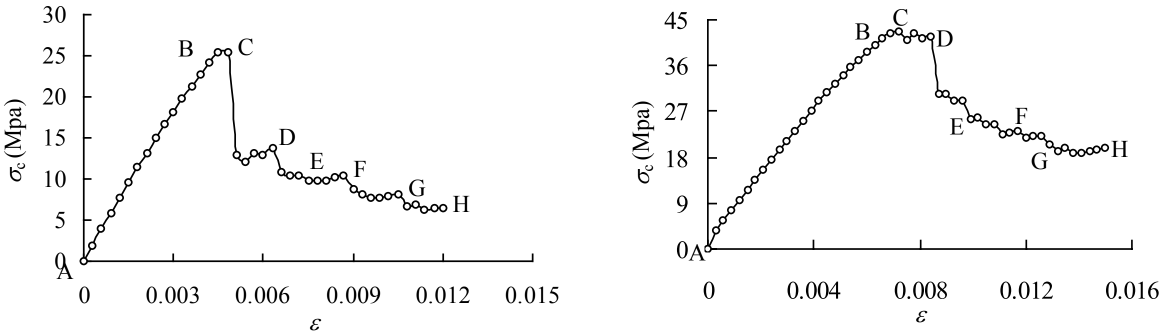
Fig.8 Simulated destruction of a 5000 mm rock sample in a triaxial test, σ_3 =1 MPa, Sequence II
(a) Step 1, Dot A; (b) Step 10, Dot B; (c) Step 15, Dot C; (d) Step 20, Dot D; (e) Step 25, Dot E; (f) Step 30, Dot F; (g) Step 35, Dot G; (h) Step 40, Dot H



(a) (b)

Fig.9 The stress-strain relationship curve for a 1000 mm rock mass

(a) Uniaxial test; (b) Triaxial test, σ_3=5 MPa



(a) (b)

Fig.10 Stress-strain relationship curve for 5000 mm rock masses

(a) Uniaxial test; (b) Triaxial test, σ_3=1MPa

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