True tri-axial test using Distinct Element Method

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Abstract

Many kinds of rock test for engineering properties have been carried out to obtain rock kinetic properties. However it is difficult to visualize inside rock specimen during laboratory tests. This study's objective is to reconstruct true tri-axial tests using Distinct Element Method (DEM).

At first, tri-axial compression test is carried out to know correlations between analytical properties and rock properties obtained through compression test like cohesion and internal friction angle. Next, true tri-axial test is simulated using properties above.

The result of the simulation, it was clarified that the simulation result can reconstruct a laboratory test qualitatively.

1. INTRODUCTION

Recently, distinct element method has been applied to analysis of rock and soil structure. However it is uncertain that mechanical behavior an aggregate of distinct element affects. In other hand, true tri-axial test is carried out to know mechanical behavior of rocks.

In this paper, we carried out true tri-axial test using DEM to know mechanical behavior of a distinct element specimen.

2. DISTINCT ELEMENT METHOD

2.1 About Distinct Element Method

Distinct Element Method (DEM) is suited for analyzing discontinuous target like rock and soil. In Distinct Element Method, an analyzing target is considered as a particle aggregate, and virtual springs are set between each particle. Fig.1 shows virtual normal and shear springs between two particles. The contact forces acting on two particles are generated from relative displacement between each particle. The acceleration and

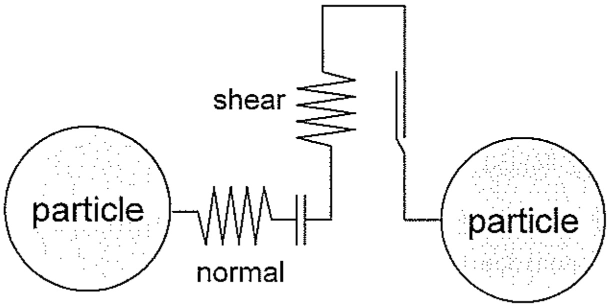


Fig.1 Virtual springs between particles.

velocity are calculated by solving law of motion applied to each particle.

2.2 Bonding force

In this paper, a tensile force is considered at each contact point between next particle. This tensile force is defined as a bonding radius. Fig.2 is an explanation of a bonding force. If a pair of particles overlap each other as shown in Fig.2(a), act repulsion each particle depend on overlap. There is no overlap and overlap is less the bonding radius as shown in Fig.2(b), the tensile force acts on each particle. If a distance of a pair of particles is more than the bonding radius as shown in Fig.2(c), no tensile force acts between a pair of particles. Here, a distance of a pair of particles is defined below.

$$gap = dis - \left(r_i + r_j\right) \tag{1}$$

where *gap* is the distance of the pair of particles, r_i and r_j are the radius of particles, *dis* is the distance of the particle centers. Therefore, condition of contact force is described as below:

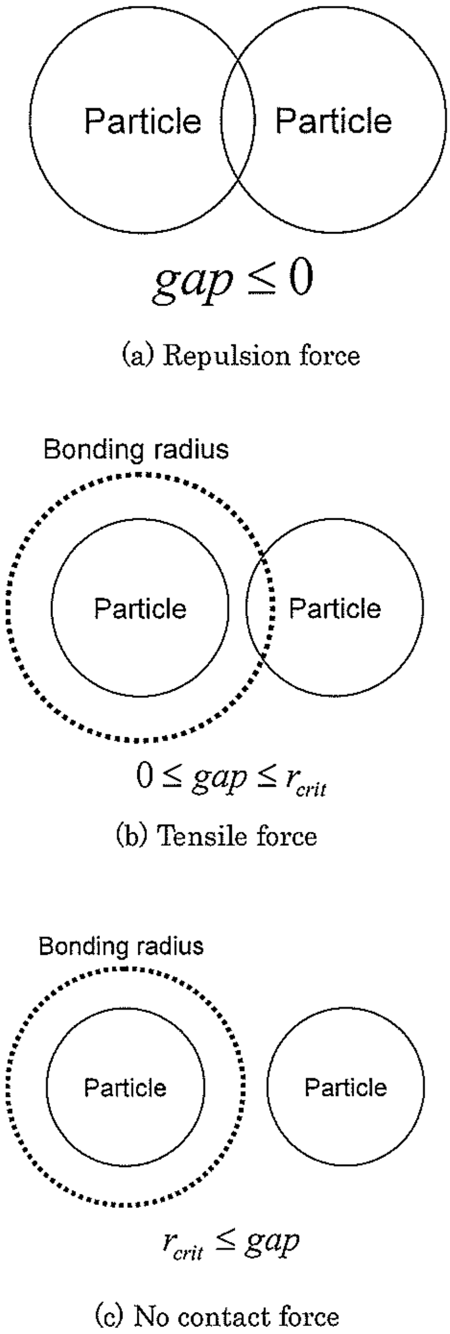


Fig.2 Explanation of bonding.

$$
\begin{cases} gap \le 0 & \text{(repulsion)} \\ 0 \le gap \le r_{crit} & \text{(tensile force)} \\ r_{crit} \le gap & \text{(no contact force)} \end{cases} \quad (2)
$$

where r_{crit} is the bonding radius.

3. SIMULATION RESULT

Fig.3 shows a specimen composed of particles after failure. The contact of white particles is ruptured. One fracture cross section is formed across the specimen. In this figure, minor, intermediate and major principal stresses are loaded to the specimen along x, y and z direction, respectively. The fracture cross section is formed parallel to intermediate stress. This phenomenon is consistent with pattern of laboratory tests.

Fig.4 shows stress-strain curves in a laboratory test. Horizontal axis is an axial strain and vertical axis is the differential stress. The bottom line of Fig.4 is a stress-strain curve under a condition which the minor stress is 20MPa and the intermediate stress is 20MPa. Input parameters are fitted to this stress strain curve. The middle and the top line in Fig.4 stress-strain curves are under conditions which the intermediate stress raises 60MPa and 100MPa, respectively. As is clear from Fig.4, the differential stress curve increases with increment of the intermediate stress. Fig.5 is a stress-strain curve of simulation result.

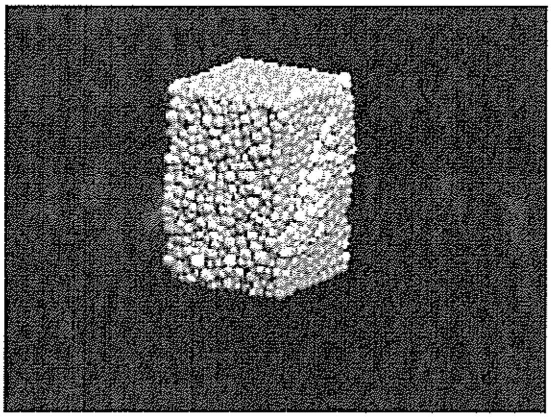


Fig.3 The specimen after failure.

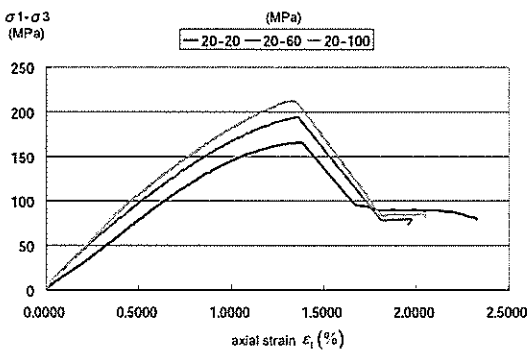


Fig.4 Stress-strain curve (laboratory test).

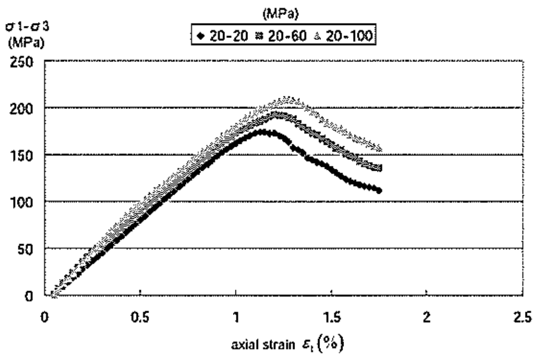


Fig.5 Stress-strain curve (simulation).

Table.1 Input parameters.

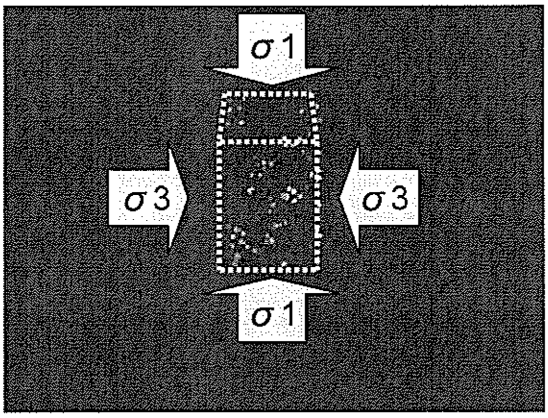
normal contact stiffness	$9.0\times10^{7}\,(N/m)$
shear contact stiffness	$5.0\times10^{6}\,(N/m)$
number of particle	$3658\,(grains)$
porosity	$14.7\,(\%)$
density	$2700\,(kg/m^{3})$
adhesion	$0.015\times(r_i+r_j)$
friction coefficient	0.7

Table.1 shows the input parameters fitted to laboratory test under condition which minor and intermediate stresses are 20MPa. In Fig.5, the stress-strain curve increases with increment of the intermediate stress. This trend is consistent with the stress-strain curves from laboratory tests.

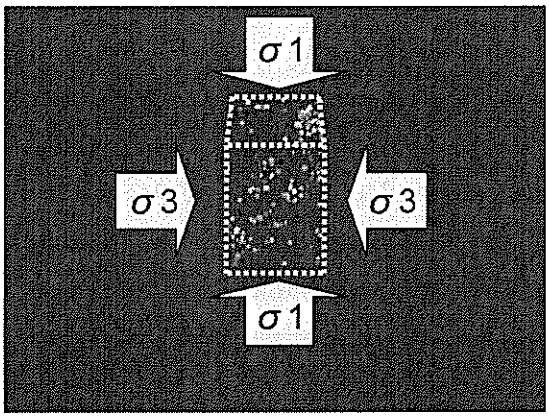
Herewith the simulation result fits to laboratory test result qualitatively.

4. *VISUALIZATION INTERIOR OF A SPECIMEN*

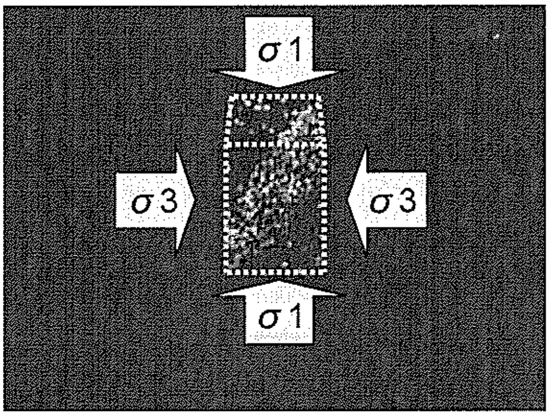
It is difficult to visualize interior of a specimen while laboratory test is carrying out. But numerical simulation enables to visualize interior of a specimen easily. Fig.6 shows interior of the specimen after failure from the intermediate stress direction. Colored disks with violet are marking points where the contact between particles is broken in the specimen. In early stage of failure, the broken points are distributed overall the specimen as shown in Fig.6(a). Next stage, the broken points start to localize in one place. And latest stage, broken points consist of one fracture cross section clearly.



(a) early stage of failure



(b) broken points start to localize



(c) clear fracture cross section

Fig.6 Interior of the specimen.

5. CONCLUSION

In this paper, true tri-axial test using DEM is conducted to reconstruct a laboratory test. The conclusions shown as follows are led.

- Stress-strain curves of simulation analysis are consistent with stress-strain curves of a laboratory test.
- There was a fracture cross section parallel to intermediate stress direction in the specimen after failure. This trend is consistent with laboratory tests.
- This simulation analysis enables to visualize interior of the specimen while a test is carrying out.

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