# 2D simulation analysis of failure of rock slope with bedding planes by DEM

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As is known, there are many fractures and discontinuities in rock slope, and these might be often occurred the slope failure. In this paper, we try to clarify the mechanism of slope failure in modeling of rock slope with discontinuities using two dimensional DEM(distinct element method). However, it is difficult for DEM to express both of the continuum and discontinuities. So, we introduce the concept of bonding force, and it is made to be an applicable analysis method for the continuum. In the rock slope model in this simulation, the slope shape and the location of discontinuities can be arbitrarily set. The simulated rock slope has bedding planes, and we are reflected these in the model. Using this model, we try to simulate a failure rock slope, and to visible progress of fractures. As the results of this analysis, it is recognized that the discontinuities are formed surface and internally the rock slope. Moreover, the factors of failure can be visualized.

## 1. INTRODUCTION

Finite element method and boundary element method are numerical method for continuum. These methods are widely used for rock mass and ground. But, it is difficult for these methods to handle large-scale deformation and destruction. On the other hand, DEM(distinct element method) devised by P.Cundall is useful for discontinuity body analysis. Especially this method got a lot of attention as a solution for a large deformation problem involved with destruction. Researches on DEM have been carried out by many researchers such as P.Cundall, M.Hakuno and M.Hisatake.

However, the force between elements in this method was limited to the repulsive force, and it was difficult to apply the method to continuum such as rock mass and concrete. Then, Hakuno proposes EDEM(extended distinct element method) which can consider filling materials between elements. In this method, an element spring and a pore spring exist. And, this method can express dilatancy effect observed in the aggregate of granular matter such as ground and concrete. In addition, the approach of DEM was developed by Hisatake and others into CEM(contact element method). This method assumed the application to viscous ground. Like this, DEM was more refined, and it was possible to analyze enormous number of element by the development of the recent computer technology.

In this study, we try to clarify the mechanism of slope failure in modeling of rock slope with discontinuities using DEM. However, it is difficult for DEM to express both continuum and discontinuities. So, we introduce the concept of the bonding force into DEM, and it is made to be an applicable analysis method for the continuum. By carrying out the simulation using this method, it has become possible to examine the progress of the fractures in the rock slope.

## 2. ANALYSIS METHOD

### (1) DEM

DEM is an analysis method devised by P.Cundall, and the analysis object is mainly discontinuous body of rock mass and ground. This method analyzes the dynamic behavior of rock mass considering the simulation object as an aggregate of the minute particles. Interparticle force is generated by setting a virtual spring, making it possible to calculate acceleration, velocity and displacement with the use of the force and to track the behavior of particles. The microscopic relationship between the particles is shown in Figure1. In this analysis method, interparticle force is calculated by multiplying the contact distance ( $\Delta n$ ) by spring stiffness.

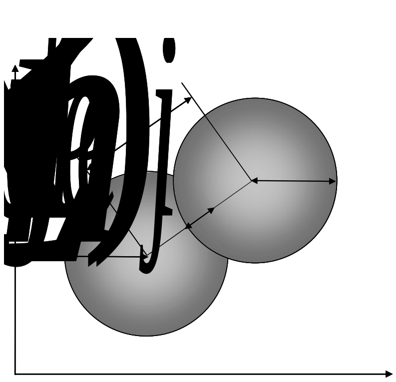


Figure1. The relationship between the particles

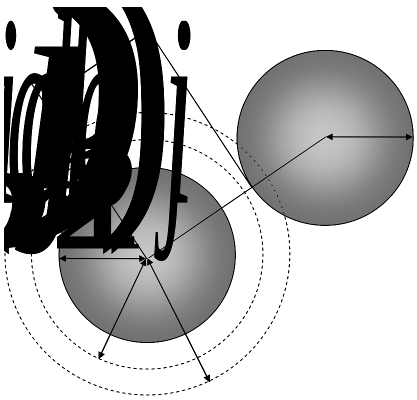


Figure2. The region where the bonding force acts

**(2) Bonding force**

Interparticle force is not only the repulsive force, when the model of granular material is applied to the solid like rock mass. Then, the tensile force is expressed by introducing the bonding force in this study.

Figure2 shows two kind of bonding radii of rb1 and rb2. rb1 shows the distance in which the bonding force comes to the yield, and rb2 shows the distance in which the binding force breaks. In short, the bonding force increases from contact point r to rb1, and it decreases from rb1 to rb2. In addition, the bonding force is broken at rb2. At this time, the value of the tensile force is zero (see Figure3). The repulsive force and the bonding force can be formulated as follows.

$$F_{ij} = \begin{cases} K \cdot \Delta n & (D < r(i)) \\ K \cdot (D - r(i)) & (r(i) < D \leq r_{b1}) \\ K \cdot (r_{b2} - D) & (r_{b1} < D \leq r_{b2}) \\ 0 & (D > r_{b2}) \end{cases} \tag{1}$$

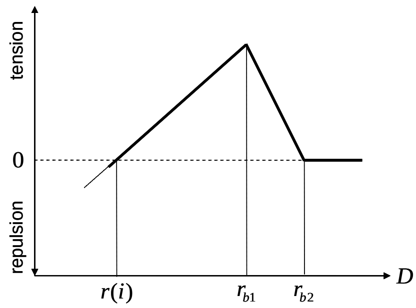



Figure3. The force between the particles

Figure4. The circumstances of failure

## 3. OUT LINE OF ROCK SLOPE FAILUE

An analysis object in this study is a rock slope failure arose in Nara Prefecture, which broke down on the 31st January, 2007. The circumstances after it failed are shown in Figure4. This slope is mainly composed of sandstones and mudstones. The slope has bedding planes with the gradient of about 20~40 degrees . The failure scale was about 35 m in height and 30 m in width, and the volume of failed rock mass was about 1,100 $m^3$.

## 4. A SIMULATION MODEL AND ANALITICAL CONDITIONS

**(1) A simulation model**

A simulation model is composed of random-sized particles. The number of the particles is about 8,000. The packing which packed the random-sized

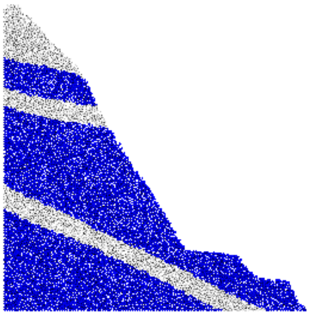


Figure5. A simulation model

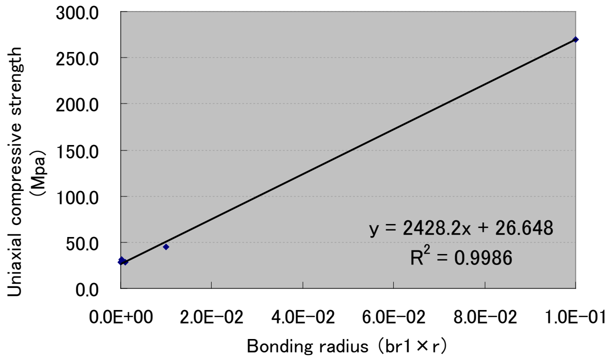



Figure6. The relation between bonding radius and uniaxial compressive strength

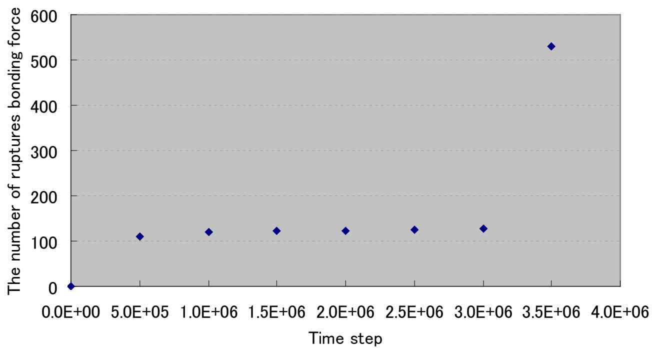



Figure7. The number of ruptures interparticle bonding force

particles was carried out under the gravity. The aggregate of particles was cut off in a slope shape, after all movements of particles stopped. Furthermore, the geological structures of the slope were set in this simulation model (see Figure6). In Figure6, white particles show the sandstones, blue particles show the mudstones.

**(2) Analytical conditions**

The sandstones and the mudstones have different tensile strength. Then, we represented it by setting different bonding radius to each layer.

To decide the bonding radius, we tried the simulation analysis of uniaxial compression test. As

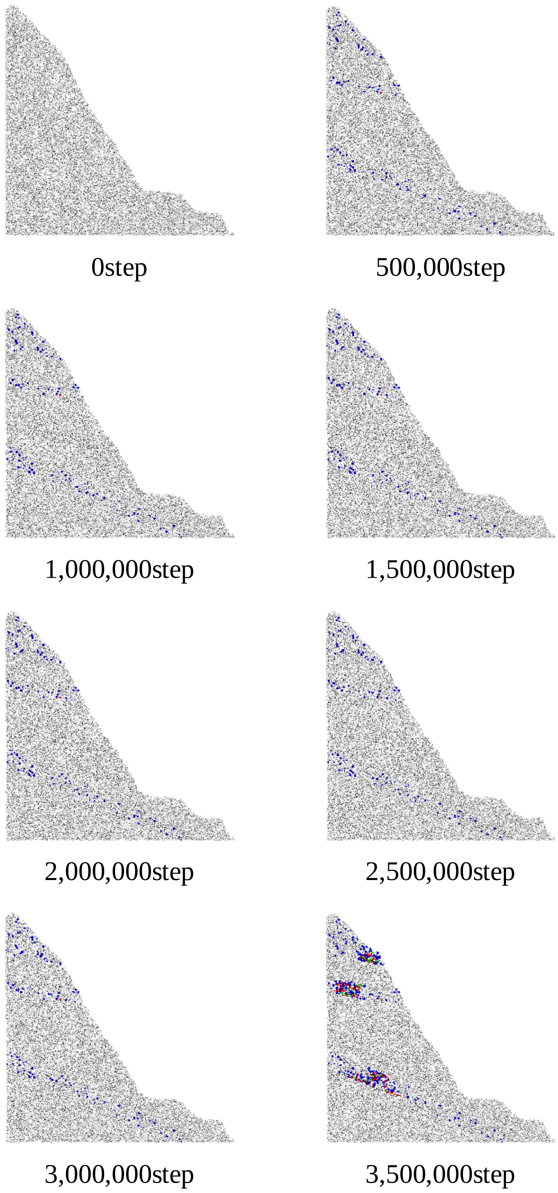


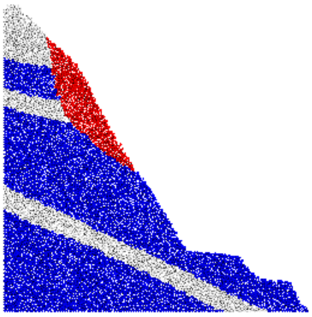

Figure8. The development of the fracture

the result of this analysis, it is recognized that there is proportional connection between the uniaxial compressive strength and the bonding radius (see Figure6). Therefore, we decided that the bonding radii of the sandstones are rb1=0.03, rb2=0.06 and those of the mudstones are rb1=0.01, rb2=0.02. In this study, the ratio of rb1 to rb2 was fixed at twice.

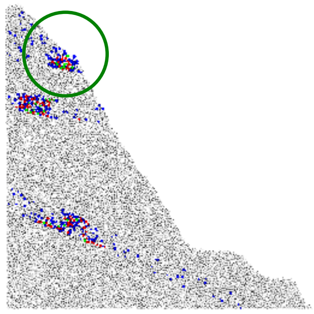
## 5. ANALYTICAL RESULTS

**(1) Ruptures of interparticle bonding force**

Figure7 shows the number of ruptures of interparticle bonding force obtained by the analysis. As seen in this result, it increases exponentially at about 3,000,000 steps. Therefore, it is estimated that large fractures are formed at this time.



(a)



(b)

Figure9. Comparisons with the actual phenomenon

**(2) Fracture propagation**

In this analysis, the number of ruptures of interparticle bonding force increases in the failure process of the slope. By visually expressing it, the fracture propagation under failure was visualized. Figure9 shows the development of the fracture. The particles colored with blue, red and green are the ones which interparticle bonding force were broken, which means that they show the locations of the fractures. It is recognized that ruptures of interparticle bonding force concentrate in the vicinity of the bedding planes and that the large fractures are formed on the surface and in the rock slope at 3,000,000 step.

**(3) Comparisons with the actual phenomenon**

Red particles of Figure 9(a) show the failed rock mass of the actual phenomenon. The upper part of these corresponds with the fracture formed slope surface. From this result, it is supposed that this fracture is one of the factors in the failure.

## 6. CONCLUSIONS

In this study, the rock slope failure was simulated by DEM using the bonding force, and its failure process was supposed. Knowledge obtained by this study is stated as follows.

Modeling the rock slope composed of the sandstones and the mudstones, the bonding radii led by the result of laboratory test were able to be acted on each layer.

Furthermore, as an estimation of the failure process, it is supposed that fractures have progressed by the bedding planes and a weight of the rock slope, and that the failure arose because of the fractures formed both on the surface and in the rock slope.

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