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# The influence of the particle shape of falling rock-mass on the maximum travel distance

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## ABSTRACT

In the safety evaluation of nuclear facilities surrounded by slopes, it is necessary to evaluate the behavior of the rock mass falling due to slope failures caused by earthquake. At present, much research on the behavior of single rocks is being conducted, but there are few studies on behaviors when many rocks fall at the same time under the effect of interaction with other rocks. Therefore, in this research, the experiments were conducted with the purpose of revealing factors that influence the maximum travel distance when a rock mass collapses in a group. In addition, a numerical analysis (distinct-element method) was also performed. From those results, it was revealed that the travel distance of discoid rocks becomes longer due to the presence of other rocks, when discussing the maximum travel distance of a collapsing rock mass. Observation of the behavior of the discoid particles in the numerical analysis revealed that the discoid particles traveling longer stood up like a tire due to interaction with other particles in the rock mass when falling down the slope.

**Keywords:** slope failure; rock mass falling; interaction; discoid shape; maximum travel distance

## 1 INTRODUCTION

In the safety evaluation of nuclear facilities surrounded by slopes, it is important to predict the behavior of the rock mass falling due to slope failures caused by earthquakes. When using the distinct element method (DEM) for this risk evaluation, it is necessary to clarify factors that affect the travel distance of the falling rock mass to set the parameters in the safety side. At present, much research on the behavior of single rocks is being conducted, but there are few studies on behaviors when many rocks fall at the same time.

Tochigi (2010) carried out collapse experiments on rock mass and classified the shape of the particles by Zingg's (1935) method to examine the effect of particle shape on travel distance. In Zingg's method, particles are classified into four types of shape: spherical, bladed, discoid, and rods based on the flatness ratio (c/b) and elongation ratio (b/a), as shown in Fig. 1. As a result of collapse experiments on rock mass and classification depending on particle shape, Tochigi indicated that the travel distance of spherical particles tends to be longer than that of the other particles, and a model using spherical particles evaluated the travel distance on the safety side. Okura et al. (2000) conducted experiments on a real scale and a numerical analysis to clarify the effect of the volume of the rock mass collapsing on the travel distance. Granite blocks were used as the material, and the volume of the rock mass was adjusted by changing the number of blocks in the experiments. As a result of the experiments, it was revealed that maximum travel distance tended to be longer as the volume of rock mass collapsing at once increased.

In this research, the collapse experiments on rock mass were conducted with the purpose of revealing factors that influence the maximum travel distance when a rock mass collapses in a group. In addition, numerical analysis were also conducted to clarify the mechanism of how particle shape affects travel distance.

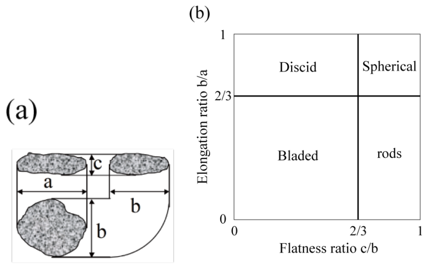



Fig. 1. (a) Definition of each length, (b) classification based on Zingg's method (Zingg 1935).

## 2 COLLAPSE EXPERIMENTS ON ROCK MASS

### 2.1 Materials

Five kinds of materials, crushed stone (small, medium, and large) and cobblestone (medium and large), were used for the experiments. The particle size was 2–9.5 mm for small size, 4.75–19 mm for medium size, and 19–37.5 mm for large size. Each of the materials is shown in Fig. 2.

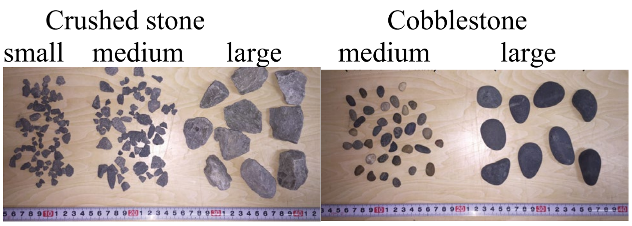



Fig. 2. Used materials.

## 2.2 Outline of the tests

The outline of the apparatus is shown in Fig. 3. The slope of the apparatus was made of wood and installed with an inclination to the horizontal plane of 45°. At the top of the slope with a height of 90 cm, a box for depositing rock mass was installed. The rock mass collapse experiments were carried out by filling the box installed at the upper end of the slope with a predetermined mass (4–12 kg) and opening the front board instantaneously. Because the bottom of this box was inclined at the same angle as the slope, all the rock-mass filled in the box collapsed in the experiments. In this study, the distance in the x-axis direction perpendicular to the lower edge of the slope was defined as the travel distance for convenience, as shown in Fig. 3. In order to make the time for each test short, the deposition mass distribution was mainly measured by using a 30 cm square wooden plate with black lines showing nine 10 cm squares on it. Those plates were spread over the horizontal plane. The weight of rock mass on each plate was measured and a picture of it were taken for future detailed measurement, if needed. Only top three or five particles from the maximum traveling stone were measured by hand individually.

Almost all the test results were conducted by the above mentioned apparatus, but some additional experiments were conducted by using the two extra apparatuses, shown in Fig. 4, by using only the medium size crushed stones in order to confirm influences of the way to fall.

The experiment program is summarized in Table 1. Since those experiments conducted by using the apparatuses shown in Fig. 4 were only to confirm no/subtle influence on the maximum travel distance as a consequence and that was not the main target of this research, the detailed experiment program is skipped to show for those tests and only the results are shown in Fig. 6 later.

In the experiment program in Table 1, almost all the test conditions were tried three times respectively except for the cases using the crushed stone of medium size. Although the number of three is too small to grasp precise characteristics, it seemed to be sufficient to know approximate tendencies and detailed study was conducted only by using the medium size crushed stone. Further, no scaling law was considered for these tests, because these tests were regarded as a small prototype in order to grasp mechanisms to verify a numerical simulation method in future.

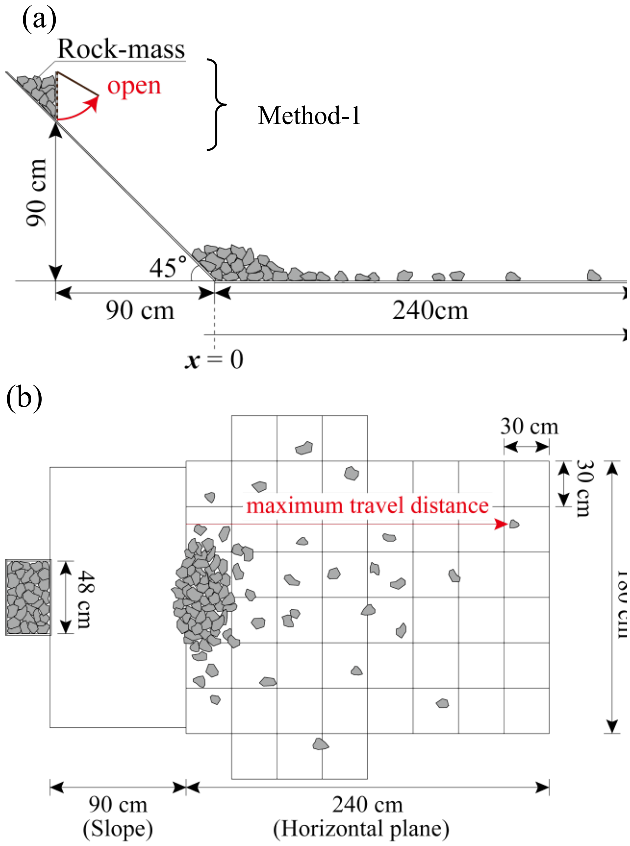



Fig. 3. Sketch of the apparatus: (a) side view, (b) plane view

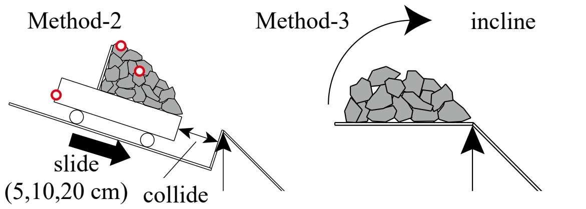



Fig. 4. Two other extra methods to cause falling rock mass.

Table 1. The number of collapse experiments of rock mass by using the apparatus shown in Fig. 3.

| Collapse weight | Material: Crushed stone | | | Material: Cobblestone | |
|---|---|---|---|---|---|
| | *Small* | *Medium* | *Large* | *Medium* | *Large* |
| 4 kg | 3 | 18 | 3 | 3 | 3 |
| 8 kg | 3 | 9 | 3 | 3 | 3 |
| 12 kg | 3 | 6 | 3 | 3 | 3 |

## 2.3 Test results

Fig. 5 shows the relationships between collapse weight and maximum travel distance. As shown in Fig. 5, the cobblestone reaches further than the crushed stone and the 'large' materials seems to travel less in this study. Although the resuls of the small size crushed stone seems to have a tendency that the collapse weight of each test becomes larger, the maximum travel distance also becomes larger, it might be a fake tendency because of the too small trial number. That is, three time trials for all the test conditions led to inequality of total falling amount, a total 12 kg for each test of 4 kg times 3 and a total 36 kg for each test of 12 kg times 3, the former test condition has less chance to reach the real maximum travel distance even under the same probability. It might be proved by the results of the medium size crushed stone. For medium size crushed stone, the numbers of trial for each test condition were adjusted to become the same total amount after all the tests, and consequently there seems to be no such effect of the amount of each test in the results of the medium size crushed stone.

Fig. 6 shows all the results using the medium size crushed stone by the collapsing method-1, 2 and 3. From this figure, the methods to cause rock mass falling did not affect the maximum travel distnce under the conditions tested in this study. In the tests conducted by the method-2, despite the maximum acceleration at the top of crushed stone mound was recorded about 10 m/s$^2$ directly after the collision and the colliding energies adjusted by changing a sliding distance of 5, 10 or 20 cm apparently affected the amount of falling rock mass, the maximum travel distances from those tests were almost same as those obtained by the method-1 and 3.

According to the movie of the experiments, the rocks traveling longer did not collide with other rocks when rolling on the 'horizontal' plane. Moreover, the length of slope-part of the apparatus might be sufficient to erase the influence of the initial condition at the early stage of falling. Therefore, the influences of collapse weight or falling method on the maximum travel distance were not apparent in this study.

Fig. 7 and 8 show the results of classification based on Zingg's method of two types of group of rocks. The longer travel group of rocks that traveled the top three or five in each case using medium crushed stones conducted by the falling method-1 was used as the longer travel distance group (total 84 particles). The other group is the randomly extracted group consisting of 200 rocks that were randomly extracted from all the medium crushed stones in order to represent the parent population of the material.

The distribution of the randomly extracted sample indicated by black dots in Fig. 7 was 41.5% in discoid, 21% in spherical, 23.5% in bladed, and 14% in rods, whereas that of the longer travel distance group indicated by red dots was 66.7% in discoid, 28.6% in spherical, 1.2% in bladed, and 3.6% in rods. The ratios of the longer travel distance group to the randomly extracted group was 1.61 times for the discoid, 1.36 times for the spherical, 0.05 times for the bladed, and 0.26 times for the rods. In this results, the travel distances of discoid rocks and spherical rocks tend to become longer than those of other rocks and the ratio of the discoid rocks is larger than that of spherical rocks.

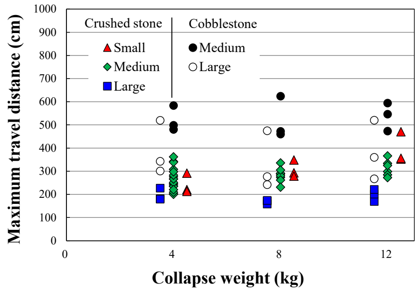



Fig. 5. The relationship between collapse weight and maximum travel distance

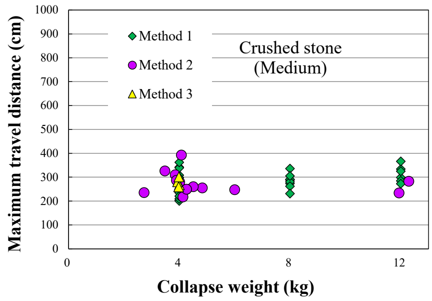



Fig. 6. Influence of the methods to cause falling rock mass

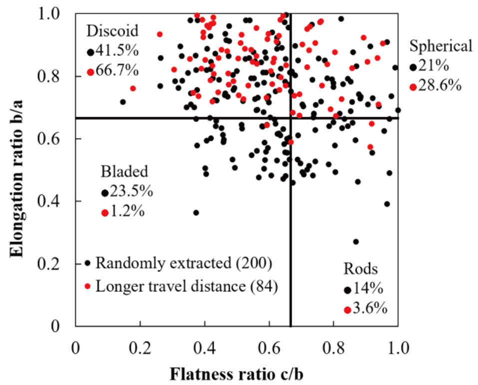
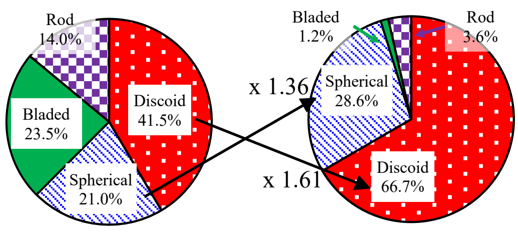



Fig. 7. Results of classification based on Zingg's method




(a)the parent population (b)the maximum travelling particles

Fig. 8. Comparisons of the rates of shapes between the parent population of rock and the amount of the maximum travelling particles in all the tests shown in Table 1

The results of this study are different from those of a previous study indicating that the travel distance of rocks classified as spherical tends to be longer (Tochigi, 2010). This suggest that there might exist some group effect to make the discoid rock to travel further easily in the large number of rock mass.

## 3 NUMERICAL ANALYSIS

### 3.1 Outline

The experimental results show that the discoid rocks travel longer easily when those are falling in a large number of rock mass due to the interaction with other rocks. Thus, to clarify the mechanism by which the travel distance of the discoid rocks becomes longer due to the interaction with other particles, collapse experiments of rock mass were reproduced by DEM, and the behavior of the discoid rocks in the rock mass was investigated. For the sake of simplicity, only two kinds of particle (discoid and spherical) were used in the analysis. The particles used are shown in Fig. 10. The shape of the discoid particles was an ideal disc shape because this analysis was aimed at grasping the outline of the behavior of the discoid rock rather than precisely reproducing the experiments. In this analysis, the density of the materials and the particle size distribution of the spherical particles were the same as for the crushed stone used in the experiments, and the diameter of the discoid particles was same as the maximum diameter of the crushed stone used in the experiment. The composition of the particles used for the analysis is shown in Table 2. The friction coefficient was determined so that the deposition shape after the collapse became the same as in the experiment, because the friction coefficient between rocks and slope or other rocks used in the experiment was not measured.


(a)discoid (b)spherical

Fig. 9. Particles used in numerical analysis

Table 2. Composition of the particles used in the numerical analysis

| | *Size [mm]* | *Weight [kg]* | *Number* |
|---|---|---|---|
| Discoid | 19.0 | 0.4 | 153 |
| Spherical | 4.75-19.0 | 3.6 | 4392 |

### 3.2 Results

Since the state of deposition agreed with the experiment, and the maximum travel distance of the spherical particles was within the range recorded in the rock mass collapse experiments, it is thought that this analysis reproduced the experiments roughly. As shown in Fig. 10, since a discoid rock was arised by the interactions with other particles, which never occurs when the rock falling alone, it is one reason to make a discoid rock reach further easily while rolling in a large number of rock mass.

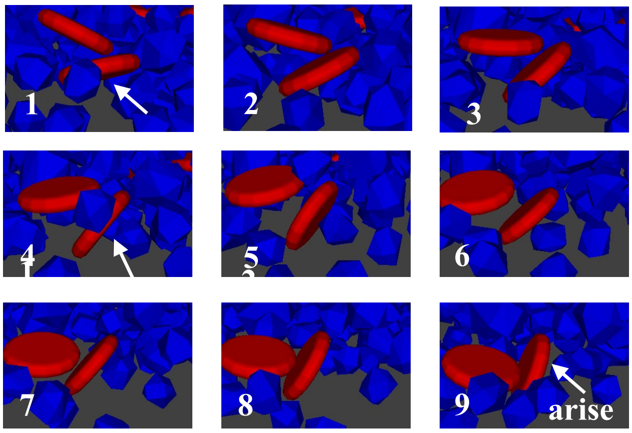



Fig. 10. Process in which discoid particles stand (0.3 s to 0.8 s after collapse start, 1/30 s per frame)

## 4 CONCLUSION

Rock mass collapse experiments and a DEM calculation were conducted to reveal factors that influence the maximum travel distance when a rock mass collapses in a group, the following conclusions were obtained.

- There seems to be no relationships between the amount of falling rock mass at a time and the maximum travel distance under the experimental conditions in this study.
- As the results of shape classification of rocks that traveled long distances in the collapse experiments of rock mass, the ratio of the discoid rocks to the randomly extracted sample is the highest.
- From the observation of the rock mass collapse experiments and the consideration by using DEM, it was found that discoid rocks travel longer easily by interaction with other rocks in a collapsing rock mass.

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