Proceedings of Ninth World Conference on Earthquake Engineering
August 2-9, 1988, Tokyo-Kyoto, JAPAN (Vol.III)

4-2-13

GRANULAR ASSEMBLY SIMULATION FOR DYNAMIC CLIFF COLLAPSE DUE TO EARTHQUAKE

Kazuyoshi IWASHITA[1] and Motohiko HAKUNO[2]

[1]Department of Construction Engineering, Saitama University,
Urawa-shi, Saitama, Japan
[2]Earthquake Research Institute, University of Tokyo,
Bunkyo-ku, Tokyo, Japan

SUMMARY

We simulated the process of the dynamic fracture of a cliff by modifying Cundall's Distinct Element Method (DEM) in which soil is represented as system of numerous discrete particles. The modified DEM consists of two structures; a primary and a secondary one. The primary structure is the conventional DEM; whereas the secondary one presents the continuity of the medium. Results confirm the applicability of our improved DEM for the study of fracture in soil and soil structures such as cliffs.

INTRODUCTION

Conventionally, the dynamic behaviors of soil and of soil structures, e.g. a cliff, are simulated as continuous material. Another method has been developed in which soil is represented as discontinuous material (Refs. 1,2,3). The conventional method simulates the process before fracture takes place, but it is difficult to simulate the fracture process itself. The other method simulates the fracture process sequentially from small cracks to large slides. DEM is one such method. In DEM soil is represented as a system of numerous discrete particles, the dynamic behavior of each of which is calculated individually. This method is based on the concept that each particle satisfies the equation of motion and that their interactions are simple. The DEM method cannot account for the important factors of continuity of the medium and wave propagation. Because of these factors, DEM models are not stable and cannot stand by itself. Many problems which are not solvable by conventional continuous mechanics techniques can, however, be treated with this method. We here report an improved DEM which can take into account the above factors.

METHOD

The new DEM has two structures; a primary and a secondary structure. The primary consists of the conventional DEM and is used to transmit the force though the contact points between particles and to calculate particle movement. This structure does not work when the particles are not in contact. It has two components; a normal and a tangential component. Each component has three elements; an elastic spring, a viscous dashpot and a no-tension joint.

The secondary structure represents the continuity of the medium. Its diagram is shown in Fig.1. The structure is set both between particles in

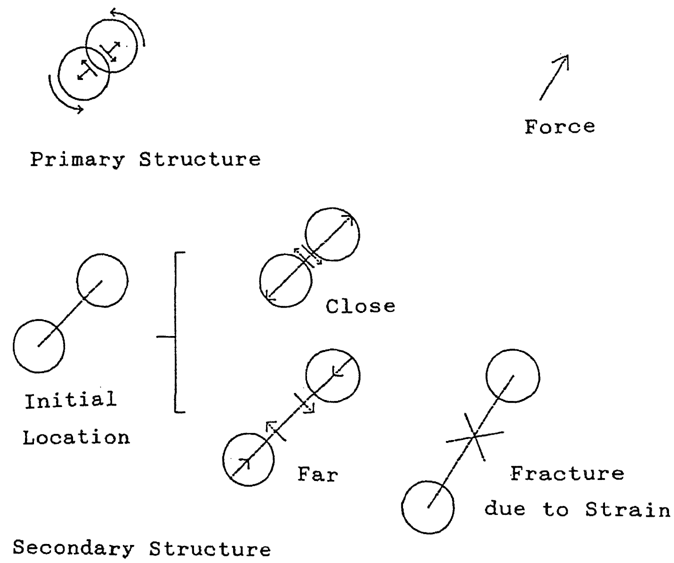


Fig.1 Scheme of the New DEM.

contact and near particles. It has two consistents; a normal and a tangential component. If the medium is a plastic one, the elements of each component will form a Voight model which is a complex of an elastic spring and a viscous dashpot or other physical model. We used an elastic spring for simplicity, as shown in Fig.2. The neutral length of the spring is the distance between two particles at the initial condition. Therefore the reaction of the springs move the particles to the initial location. The secondary structure tends to keep the particles as located.

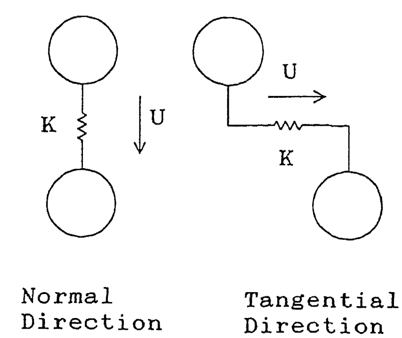


Fig.2 Elements of the Secondary Structure.
(K is the spring constant, U is the displacement.)

In the initial condition the secondary structure does not work. The particles move because of the force of the primary structure, then the secondary structure moves. If the elements of the secondary structure come under critical stress or strain, that structure will break and be unworkable. Fracture in the shear and normal directions can be simulated in this way. For example the first structure might correspond to rock or gravel and the second one to internal clay or pore water. Our new DEM model has double springs in both the normal and tangential directions. The spring constant of the primary structure represents the stiffness of the medium, and the constant of the secondary structure affects the elastic wave velocity. The former value is larger than the latter, therefore, the total stiffness of the model is similar to that of the primary structure. Consequently, it can simulate wave propagation as well as dynamic fracture.

TEST

For testing, our modified DEM was applied to the dynamic fracture of cliffs that was caused by an earthquake. A two dimensional cliff model $3x10\ m^2$ was used. The number of particles was 1000. The particle radius was defined by the Normal random distribution based on a maximum radius of 15cm and a minimum one of 5cm. The applied force was a sinusoidal wave in the horizontal direction that was input from the bottom of the model. In another case, the slope was cut away from the cliff model and the remainder stabilized and used as a bank model.

Particle movement and the distribution of particle velocities are shown in Fig.3; (A) shows the primary structure. At an early stage, small cracks appear then become enlarged ones. Finally fracture lines are formed after which blocks of soil begin to slide. The primary and secondary structures of the cliff model at 0. 2 and 4 sec are shown in Fug.4 (A) and (B). The lines in the secondary structure (B) indicate the stable area which are not broken by the critical strain and the blank space which are shown as faded area are the destroyed area. The secondary structure clearly shows the lengthening of the cracks and the process of sliding. Progressive sliding appears,the soil sliding in blocks. The secondary structure also shows fracture lines.

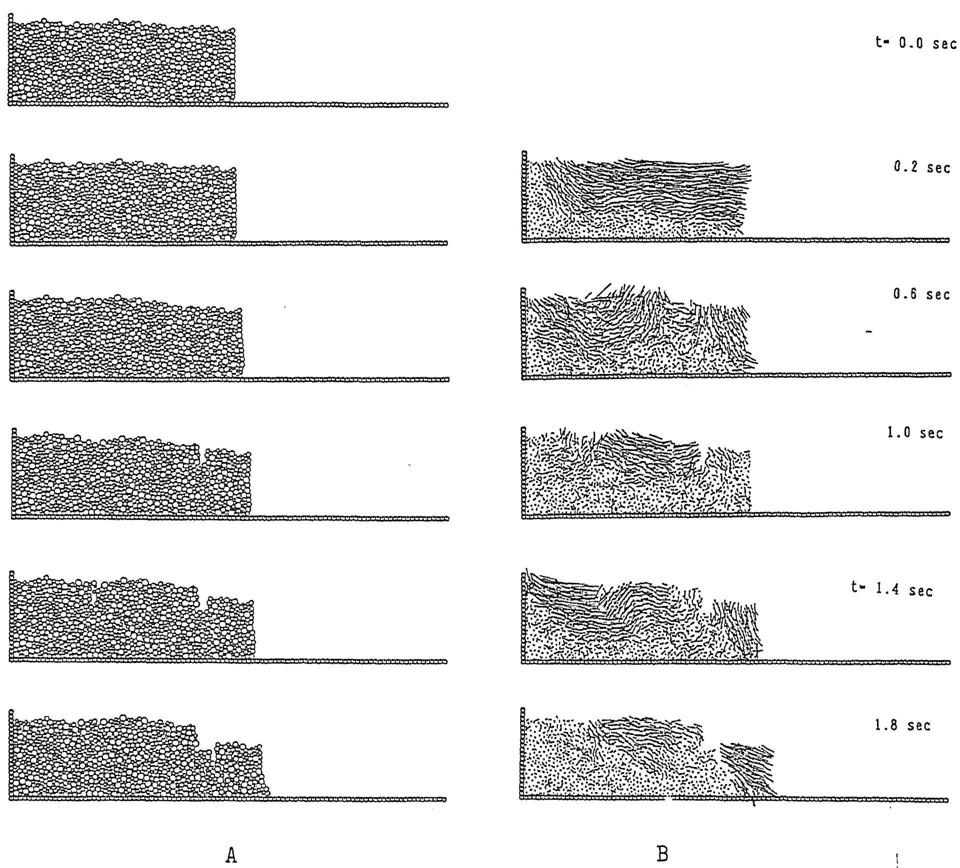


Fig.3 Dynamics of Cliff Collapse.
(MOvement of particles [A] and distribution of velocity [B])

Effects of the secondary structure are shown in Fig.5. Results of 3 cases are given; without the secondary structure, with the secondary structure but no applied force, and with the secondary structure and applied force. The original DEM could not distinguish the broken from the stable area.

Figs.6 and 7 show the fracture process for banks with slope angles of 45 and 30 degrees. The steep bank is soon broken. The secondary structure shows some cracks perpendicular to the slope. Fracture lines are clear, and the bank slides along those lines. These results are similar to the actual observed sliding caused by an earthquake.

CONCLUSIONS

The secondary structure of the improved DEM model can detect crack and fracture lines and discriminate broken from stable areas. These results indicate that the modified DEM method can be used to study fracture problems of soils and soil structures.

ACKNOWLEDGMENTS

All computations were made with the HITAC M280H computer at the Earthquake Prediction Center of the Earthquake Research Institute, the University of Tokyo. We thank Dr. Takano and Dr. Kohketsu (ERI) for their kind help with the computer and their user-friendly program 'ETERM'.

REFERENCES

1. Cundall P.A., "A Computer Model for Simulating Progressive, Large Scale Movement in Blocky Rock System", Symp. ISRM, Nancy, France, Proc.2, pp. 129-136, (1971)
2. Hakuno M. and T. Hirao, "A Trial Related to Random Packing of Particle Assemblies", Proc. Japan Society of Civil Engineering, Vol. 219, pp. 53-63, (1973)
3. Kiyama H. and H. Fujimura, "Analysis on Gravity Flow of Rock Granular Assemblies by Cundall Model", Proc. Japan Society of Civil Engineering, Vol. 333, pp.137-146, (1983)

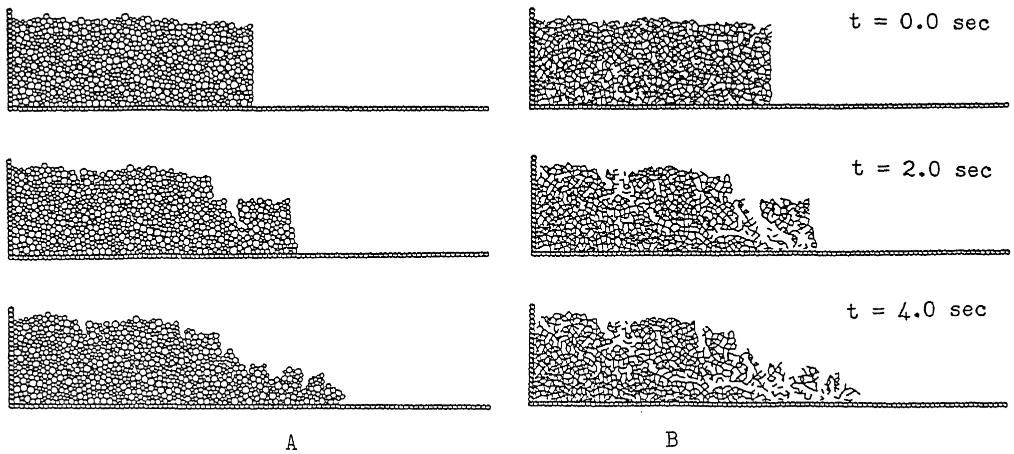
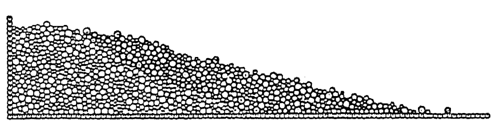
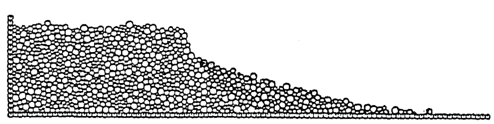


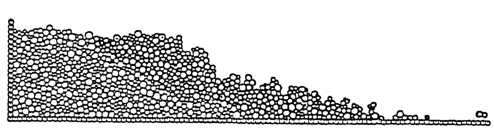
Fig.4 The Primary (A) and Secondary (B) Structures of the Cliff.



Without a Secondary Structure and Without Applied Force.



With a Secondary Structure, but Without Applied Force.



With a Secondary Structure and an Applied Force.

Fig.5 Effects of the Secondary Structure.
(Toned particles move from the initial position.)

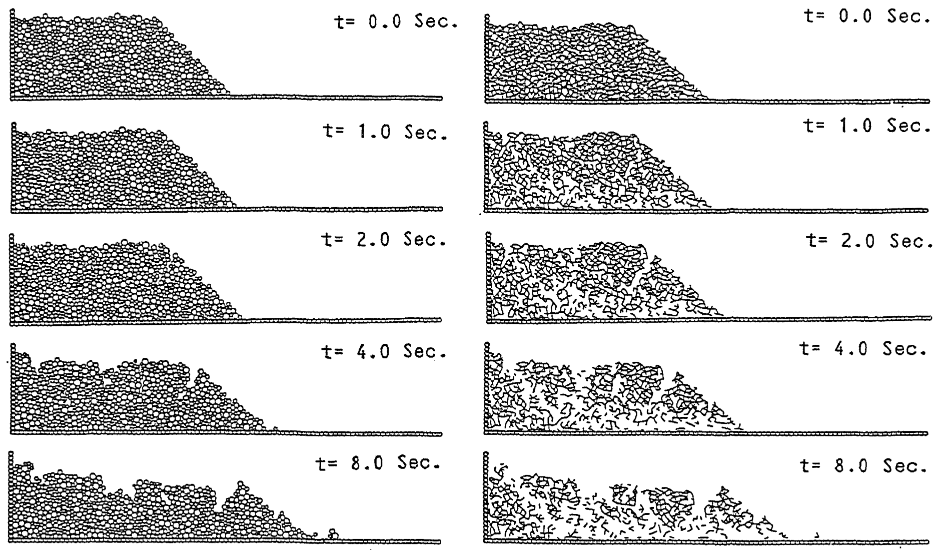


Fig.6 Dynamics of Bank Collapse Caused by an Earthquake.
(Angle of the slope, 45 degrees.)

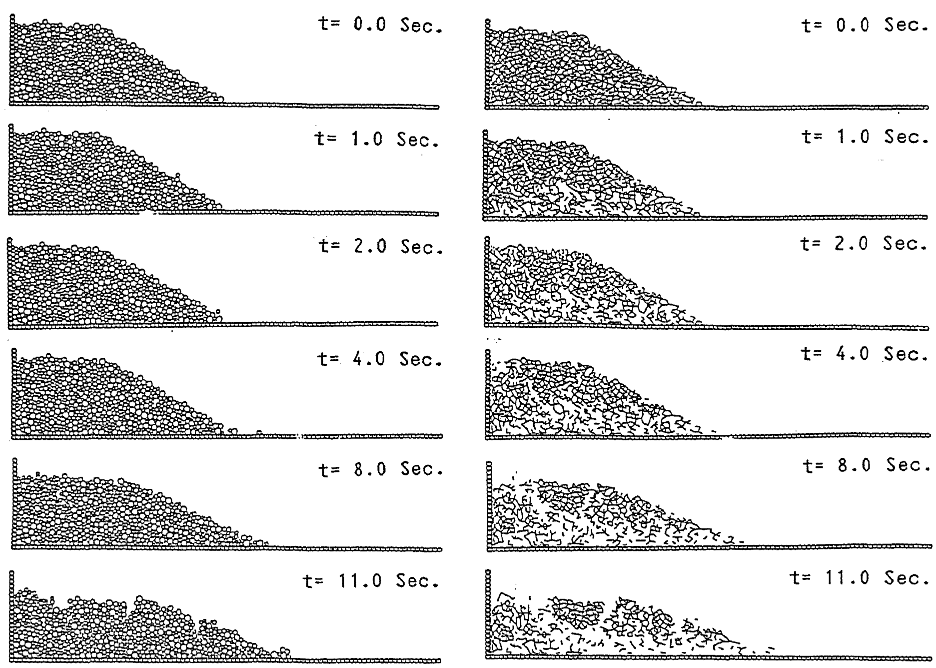


Fig.7 Dynamics of Bank Collapse Caused by an Earthquake.
(Angle of the slope, 30 degrees.)