A study on flow and impact loading characteristics of collapsed soil by Extended DEM

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1. Introduction

In Japan, we often suffer from sediment-related disaster as represented by slope failure and debris flow. There is a counter-fort type retaining wall in many types of protective structures to protect living areas against its disaster. However, the design formula of load by collapsed soil has several problems. Especially, the influence of moisture state of soil on its movement and impact load is not reflected in the design formula. So, our ultimate goal is to develop more rational design formula of load by collapsed soil taking into account the properties of soil such as the moisture state. In this study, at first, new idea of pore spring was installed into Extended Distinct Element Method (EDEM) to express the suction effect between wet sand particles. Next, numerical studies were conducted in order to evaluate the applicability of EDEM on movement and impact phenomenon of soil.

2. Outline of numerical analysis

2.1 Outline of EDEM

For the simulation of an aggregation of particles, DEM is often used. In DEM, the imaginary displacement of the contacting elements are dynamically solved with imaginary springs and dashpots as shown in Fig.1, but the force between the elements is limited to repulsive force. A conceptual diagrams of EDEM are shown in Fig.2. EDEM, proposed by Hakuno, is a numerical method applicable both to discrete elements and to complex and continuous media. Based on DEM, EDEM was developed by the introduction of customizable pore-springs and varieties of material parameters to extend the application of DEM. With the application of pore-spring, the suction effect between elements or bending moment in continuous media become able to be expressed.

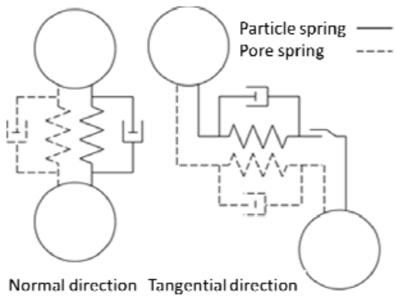

Fig.1 Modeling of interaction between elements by EDEM

2.2 Modelling of unsaturated soil (moisture state)

In this study, the pore spring was used to express the suction effect between wet sand particles. When the distance between elements D_{ij} satisfies the condition given in Eq.1, the suction force is given between elements. In the other condition, interaction between elements was calculated by general DEM.

$$r_i + r_j \leq D_{ij} \leq \alpha\left(r_i + r_j\right) \qquad (1)$$

Here, r_i and r_j are the radius of elements, α is the constant for the water suction influence range. In case of α = 1.00, no virtual water screen is formed, and elements can move discretely. In case of α > 1.00, virtual water screen is formed, the elements should move in lumps due to the suction force, as it is shown in the phenomenon in the experiment. As shown in Fig.2, both drying and wet conditions can be expressed by changing α in this method.

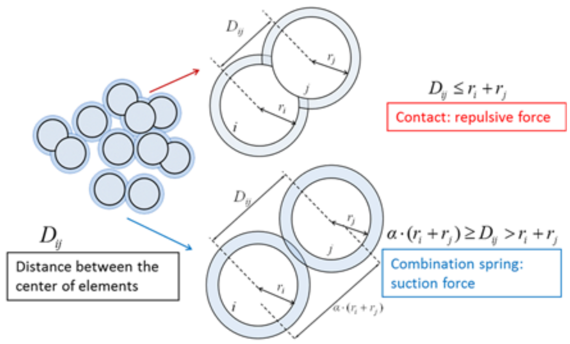

Fig.2 Modeling of suction effect by virtual water screen

2.3 The determination of analysis parameters

In this 2-dimensional analysis, the shape of element is a 1mm-radius circle. The spring coefficients were decided from the wave propagation velocities, which are first calculated according to Young's modulus, Poisson's ratio, and the

Table 1. The main parameters in the simulation

Particle spring coefficient(normal)	k_n	263N/mm
Particle spring coefficient(tangent)	k_s	52N/mm
Pore spring coefficient(normal)	k_{sn}	10N/mm
Pore spring coefficient(tangent)	k_{ss}	40N/mm
Damping coefficient	h	0.00001

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density of the simulation object. Assuming that the wave propagation velocities are related with the spring coefficients, the spring coefficients were solved from one-dimensional wave equations and vibration equations. The friction coefficient was set to 0.58 by the repose angle experiment. Central differential method was used, with time step 1×10^{-5} s. The main parameters are listed in Table 1.

3. Numerical simulation for flow and impact characteristics of collapsed soil

3.1 Verification

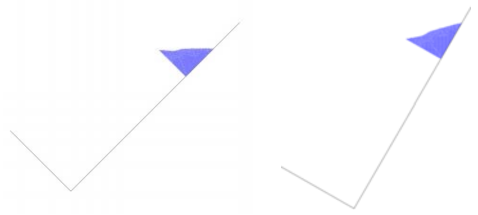
In order to verify the applicability of the EDEM simulation on the flow and impact of collapsed soil, analysis based on the models as shown in Fig.3 were performed. The total number of the elements is 8951, and the slope angles are 45 degrees and 60 degrees. In case of wet sand, the water suction influence range α is set to 1.10. The load-time history at the bottom of the slope and the snapshots are taken as output results of the analysis, which are shown in Fig.4 and Fig.5. In case of drying situation, it can be said that the analysis and the experiment results are in good agreements. In case of wet sand with 10% water content, although the maximum load and the deposition load are in good agreement with experimental results, our analysis results are not able to express the rapid load increase observed in the experiment. In order to increase accuracy of our EDEM analysis, there is a need to clarify the relationship between water content and α.

3.2 The results of analysis with different α value

In order to investigate the influence of water suction influence range, analyses with different α value were performed. By changing the value of α, the suction force between elements can be changed, and the results of the analyses are greatly influenced. As it is shown in Fig.5 and Fig.6, the suction effect becomes greater with the increasing of α. When the constant α is set near 1.00, the suction force between elements becomes lower, and it is easy for the elements to move discretely. While when water suction influence range α is set near 1.20, strong suction forces generate between elements, and more elements stay at the top of the slope. Of course, the different movement characteristics result in the difference in the load-time history.

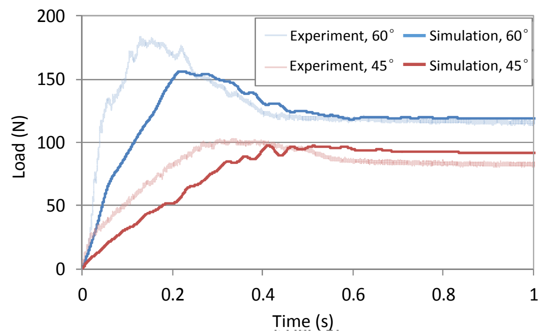
4. Conclusion

By using EDEM with the pore spring to express the suction effect between elements, the maximum load and the deposition load are in good agreement with experimental results, our analysis results are not able to express the rapid load increase observed in the experiment. Because the water suction influence range result in great influence on the result of our analysis, and in order to increase accuracy of our EDEM analysis, there is a need to clarify the relationship between water content and α.

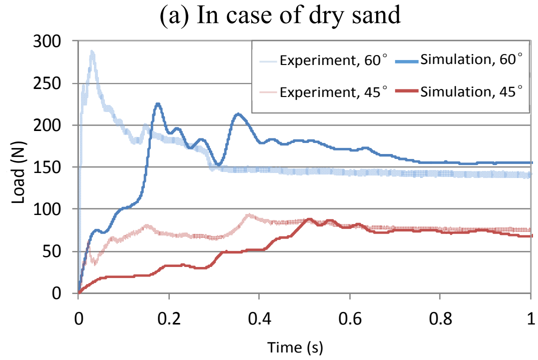


45 degrees 60 degrees

Fig.3 Simulation model

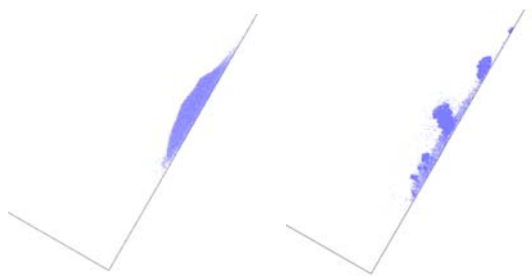


(a) In case of dry sand



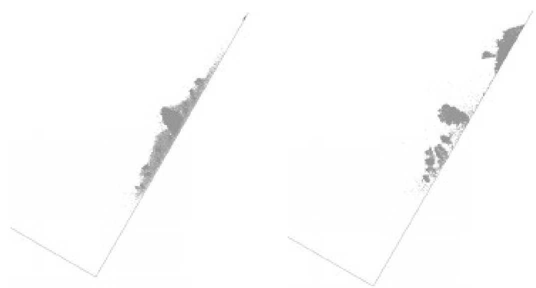
(b) In case of wet sand

Fig.4 Comparison of load time history



Dry ($\alpha = 1.00$) Wet ($\alpha = 1.10$)

Fig.5 Simulation results of flow state (0.4 (s))



$\alpha = 1.05$ $\alpha = 1.20$

Fig.6 The influence of water suction influence range (0.4 (s))