Fundamental study on impact loading characteristic of collapsed soil by Extended Distinct Element Method

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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, the experiment was conducted in order to comprehend the influence of moisture state of soil on its movement and impact load. Next, numerical studies were conducted in order to evaluate the applicability of Extended Distinct Element Method (EDEM) on movement and impact phenomenon of soil. Here, new idea of pore spring was installed into EDEM to express the suction effect between wet sand particles.

2. Experimental approach

2.1 Outline of model experiment

As shown in Fig.1, sands were positioned at the top of the device. When the gate opened, the sands would slide down the 1000mm-long slope and hit the loading plate, under which three load cells would measure the impact load, and the total load would be taken as the experiment result. The volume of the sands was 0.01m^3, and the water percentages were 0% and 10%.

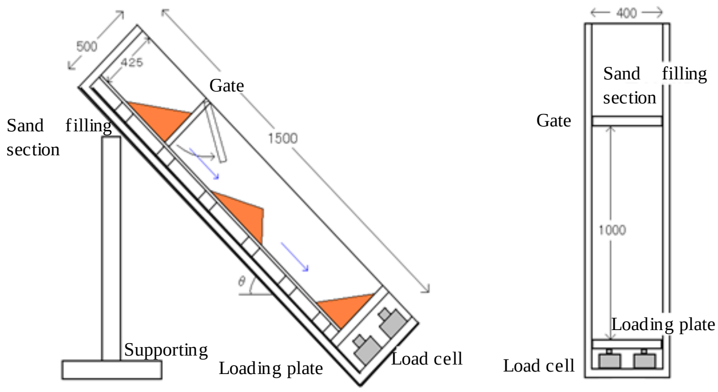


Fig.1 Setting of the model slope experiment (Unit: mm)

2.2 Experiment results

Fig.2 shows the influence of moisture state on load characteristics. Compared to the gentle load rise of the drying sand, there were sharp load rise in case of wet sand with 10% water content. This is because that drying sand is likely to move discretely, which means an gradual load increase during the impact process. While the wet sand with the suction effect of water tends to move in lumps, which brings a large impact load when hitting the loading plate. In case of wet sand, the load characteristic has a stronger impact effect.

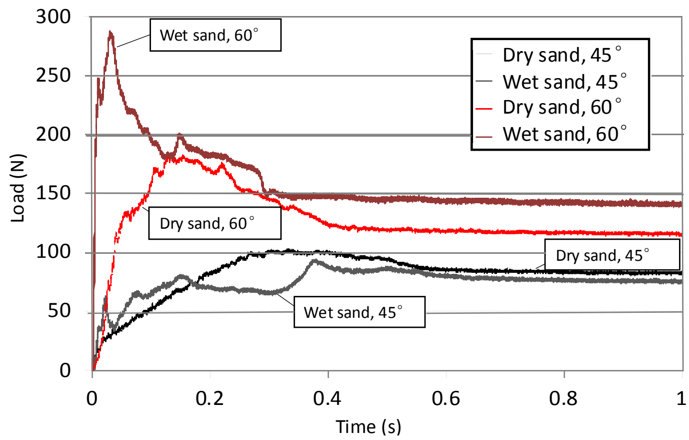


Fig.2 Load time history

3. Numerical approach by EDEM

3.1 Outline of EDEM simulation

A conceptual diagrams of EDEM are shown in Fig.3 and Fig.4. 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 Equation 1, the suction force is given between elements. In the other condition, interaction between elements was calculated by general DEM.

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

Here, r_i and r_j are the radius of elements, α is the constant for the water suction influence range. Fig.5 shows the influence of α on movement behavior of sand. In case of α = 1.00, no virtual water screen is formed, and elements can move discretely. In case of α = 1.10, virtual water screen is formed, and some elements move in lumps, which is similar with the phenomenon in the experiment. As shown in Fig.5, both drying and wet conditions can be expressed by changing α in this method.

3.2 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 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 the time step 1×10^{-5}s. The main parameters are written in Table 1.

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

3.3 Numerical results and discussion

The load time history is shown in Fig.6. 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.

4. Conclusions

1) From experimental results, it is found that while the dry sand moves discretely, the wet sand moves by forming some lumps due to the suction effect provided by water, which results in a rapid load increase.

2) 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. In order to increase accuracy of our EDEM analysis, there is a need to clarify the relationship between water content and α.

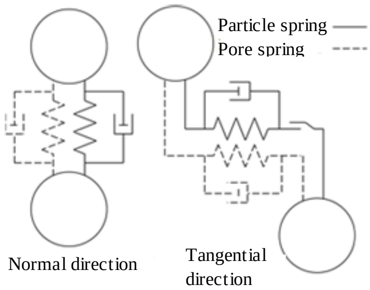


Fig.3 Modeling of interaction

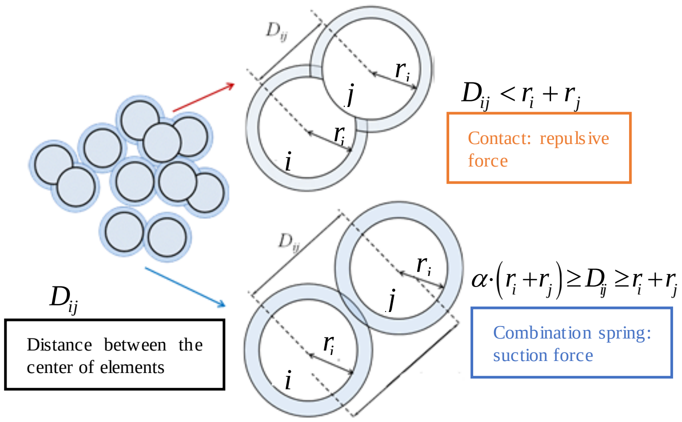
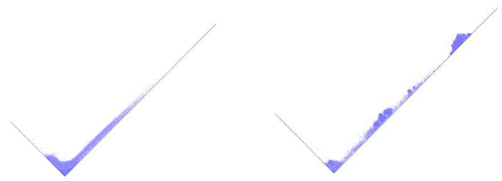
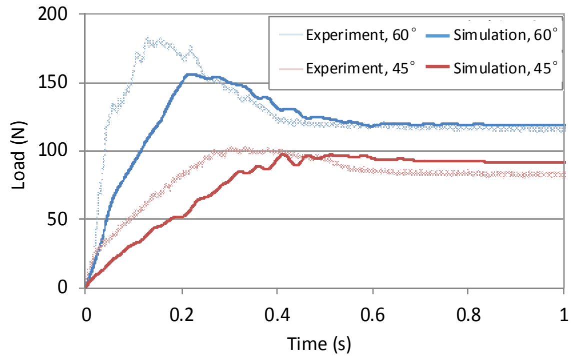


Fig.4 Modeling of suction effect by virtual water screen

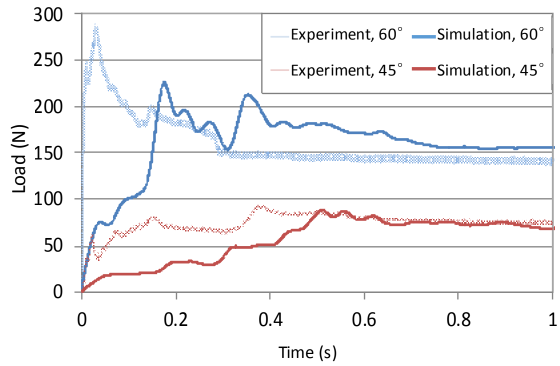


(a) α = 1.00 (b) α = 1.10

Fig.5 Influence of α on movement behavior of sands



(a) In case of dry sand



(b) In case of wet sand

Fig.6 Comparison of load time history