Slope stability analysis of soil-rock-mixture using the coupled 2D DDA-SPH method

Kyushu University, Japan Student member Li Changze
Kyushu University, Japan Regular member Chen Guangqi

Introduction

Soil-rock mixture (SRM), which is mainly composed of rock blocks and fine soil, is widely distributed over nature, especially in mountainous area. It is necessary to study the mechanical behaviors of SRM for the prediction and mitigation of landslide disasters, however, which is still a challengeable issue. In previous studies, due to its heterogeneity and complex physical and mechanical properties, this geomaterial was commonly simplified as a uniform media without considering the influence of rocks. In this study, the 2D coupled DDA-SPH method is used for the applications of stability analysis of SRM slopes. A series of numerical analyses are carried out to investigate the effects of rock size on the stability analysis of the SRM slope. Through these numerical simulations, some conclusions and suggestions can be reached.

Numerical Method

DDA is a powerful numerical method proposed by Shi, which can be applied to analyze the movement and deformation of blocks in condition of both static and dynamic. Recently, numerous studies have shown that DDA is a powerful method in simulation of rigid blocks.

In SPH method, the continuum media can be discretized into a set of particles carrying physical properties of material and moving with the material velocity computed according to the governing equations. The interaction between particles is calculated by a kernel function. Through kernel and approximation functions, the governing equations and the constitutive equation become a set of ordinary differential equations that only rely on the variable of time. The fundamental principle of the strength reduction method is to gradually reduce the shear strength of material until the failure occurs to the slope.

In the coupled 2D DDA-SPH method adopted by Peng et al.[1,2], the SPH particles are employed to simulate the mechanical behaviors of soil, and DDA blocks are employed to model rocks and structures, viewed as moving boundaries for SPH particles. A penalty method is employed to calculate the interaction force between the SPH particles and the DDA blocks. As shown in **Fig. 1**,when a SPH particle approaching an edge of DDA blocks, regarding as a vertex-to-edge contact since the volume of SPH particles is much smaller than that of DDA blocks, repulsive forces of equal magnitude but in opposite directions will be applied to the contacted SPH particles and DDA blocks.

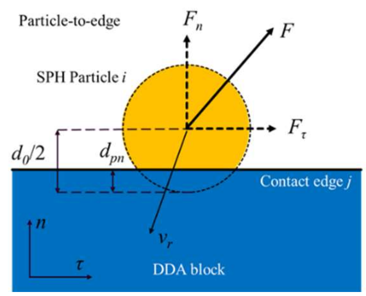

Fig. 1 Schematic view of the particle-to-block contact force.

To investigate the influence of rock content, rock size and rock density on the stability of SRM slope, a series DDA-SPH models of SRM slope inclined at 26.57° are presented in this section, see **Fig. 2**. These models are analyzed under pure gravity load. The initial friction angle ϕ_{cf} between particles and blocks is equal to the friction angle of soil. The number of edges of each rock is 4-7. The other parameters are listed in **Table. 1**. The size of rock blocks is featured by the equivalent radius, that is, the radius of a circle having the same area. Four numerical models with different rock size ranges are built to investigate the effect of rock size on the mechanical behavior of SRM slopes. The rock content of each model is 20%. Notably, the rock content (RC) is calculated by the proportion of the area of the rocks. The center of mass of the rocks are set the same as the centroid of the slope. The rocks distribute through the slope evenly.

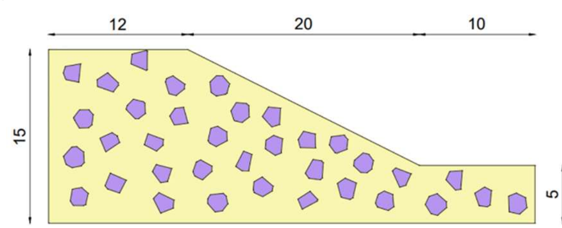

Fig. 2 Geometry of a representative SRM slope.

Table 1 Material parameters of the SRM slope model

DDA block	Density(kg/m^3)	Poisson's ratio	Young's modulus(GPa)	Maximum displacement ratio	Spring stiffness (GPa)
	2300	0.2	10	0.001	20
SPH particle	Density(kg/m^3)	Poisson's ratio	Young's modulus(MPa)	Initial friction angle of particles (°)	Initial cohesion (kPa)
	2000	0.3	100	20	10

Simulation Results

The FOSs of the SRM slope models with respect to the rock size are shown in **Fig. 3**. From this figure, it can be seen clearly that the stability of the SRM slope is greatly affected by the size of the rocks. When the size of rock is less than the average equivalent radius of 0.63 m, the effect of the rocks on the stability of SRM slopes is negative. However, when the rock size reaches 0.78 m, the stability of SRM slope is enhanced by the rocks. Herein, for convenience, we define the rocks with equivalent radius less than 0.7 m as small rocks, and greater than 0.7 m as large rocks.

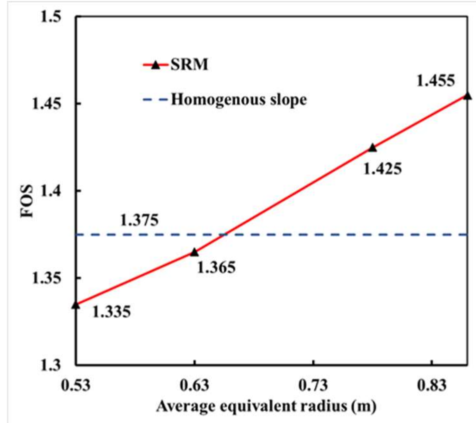

Fig. 3 FOS of SRM with respect to rock size.

Furthermore, as shown in **Fig. 4**, the distribution of the local failure at the critical unstable state is obviously affected by the rock content. From the comparison, we can find that, unlike the homogenous slope, the plastic zone of the SRM slope is unsmooth and possibly form from the contact area between the rock blocks and the soil particles instead of the toe of the slope. This phenomenon can be ascribed to the fact that the stress becomes concentrated in the contact zone between soil and rocks because of different shear strengths, and thus, the plastic zone surrounds the rocks, which is so-called rounding rock effect. 3.With the decreasing rock size, the local failure of SRM slope tends to be extended through the slope, and the plastic deformed area become larger.

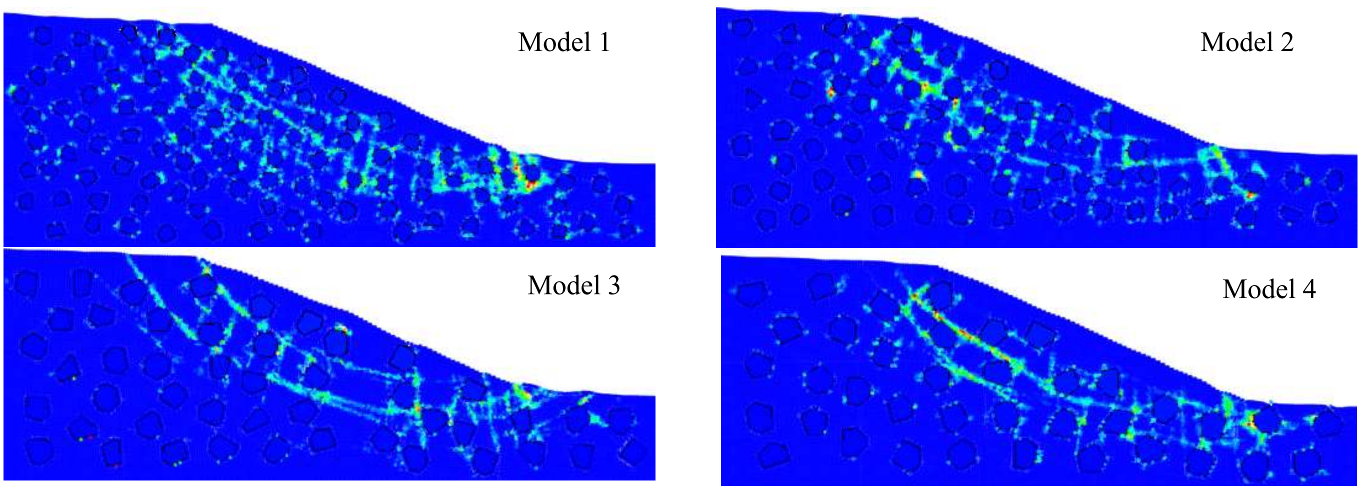

Fig. 4 Plastic zone distribution in SRM slope models at critical shear strength with different rock size.

Summary

1. The SRM slope stability was greatly affected by the size of the rocks. There was a threshold value of the rock size for positive or negative effects on the stability. When the size of rock was less than the threshold value, the effect of the rocks on the stability of SRM slopes was negative. However, when the rock size exceeded the threshold value, the stability of SRM slope was enhanced by the rocks.
2. The rock content had an obvious effect on the distribution of the local failure at the critical unstable state. Unlike the homogenous slope, the plastic zone of the SRM slope was unsmooth and possibly formed from the contact area between the rock blocks and the soil particles instead of the toe of the slope.
3. With the decreasing rock size, the local failure of SRM slope tends to be extended through the slope, and the plastic deformed area become larger.

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