3-D SIMULATION OF SHOTCRETE WITH SINGLE-PHASE PARTICLES: EFFECT OF SHOOTING VELOCITY AND MORTAR BY COARSE AGGREGATE RATIO

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1 INTRODUCTION

Shotcrete has been used for over 30 years in Japan, especially for tunneling projects and slope stabilization. The quality of shotcrete is well known to fluctuate under various conditions of construction and materials used. Computer-based simulation becomes a very useful tool to reduce the cost of research on shotcrete whose experiments need huge finance and labor. In this research, a three-dimensional numerical analysis using Distinct Element Method [1] (hereafter, DEM) was utilized to model the shotcrete process. A great improvement of this simulation is that the target wall was simulated as a single object, not by an assembly of ball. This helps reduce the calculation time drastically. The effect of shotcrete velocity on rebound was considered in this simulation. The calculated results show that DEM is a potential tool to simulate the shooting process, qualitatively and quantitatively. For the current work, this simulation provides a fundamental knowledge and understanding about shotcrete process.

2 FUNDAMENTAL CONCEPTS

The DEM was introduced by Cundall (1971) for the analysis of rock-mechanics problems and then applied to soils by Cundall and Track (1979). In the DEM, the interaction of the particles is treated as a dynamic process with states of equilibrium developing whenever the internal forces balance.

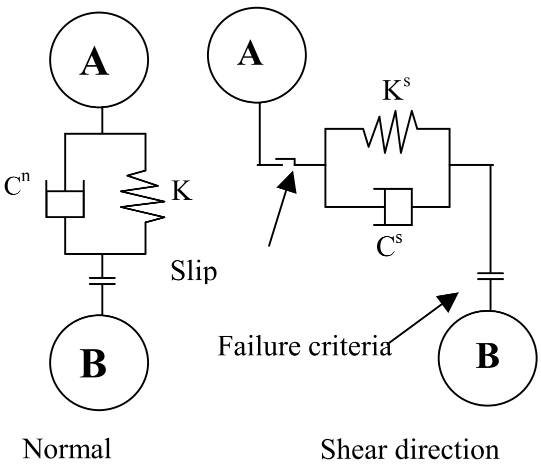

Figure 1. Viscous damping contact

In this research, the simulation of shotcrete was carried out using single-phase particles model: mortar and coarse aggregate were modeled by separate particles. A viscous damping contact model was applied and bonding behavior was considered in any contacts in which at least one mortar particles involves. In this simulation, a great reduction in calculation time was seen when the target wall was treated as a single object (Fig. 2). In previous 2-D simulation [3], target wall was created by an assembly of particles, requiring huge computer memory and calculation time as well.

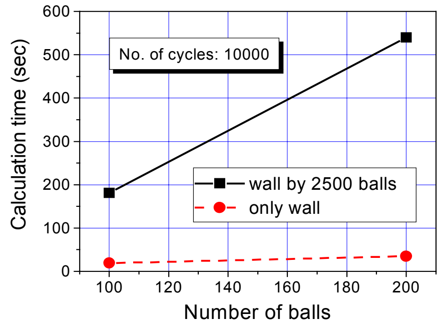

Figure 2. A drastic reduction in calculation time when shooting wall is treated as a single object, like a ball

3 SIMULATION PROCEDURE

3.1 Simulation outline

At the beginning of simulation, parametric study was carried out to obtain the DEM parameters of fresh shotcrete. Size of balls stiffness, density, etc. was given as initial condition. Afterward, concrete particles (mortar and coarse aggregate) were generated at the nozzle position with the obtained parameters. Shooting velocity was applied to these balls to shoot them to the target wall. At the nozzle, the effect of accelerator was considered using the model proposed by Puri [3]. Finally, the rebound ratio and porosity were evaluated and simulation on new materials or shooting conditions will be carried out if required.

Keyword: Distinct Element Method, Viscous Damping Contact Model, Shotcrete.
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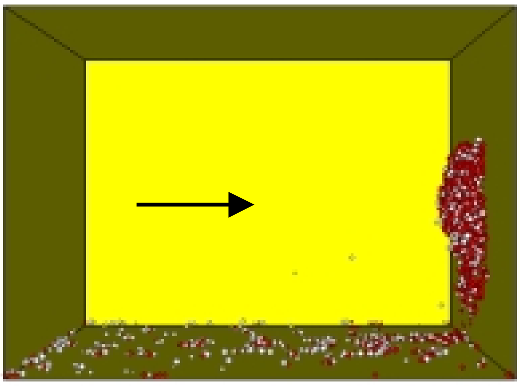


Figure 3. A view in shooting simulation, balls in dark color are mortar and white balls are coarse

3.2 Shooting velocity

Velocity of shotcrete is a governing parameter in shooting process: it decides how strong the impacting force of shooting particles against the target wall. Depending on the bonding behavior, shooting distance, characteristics of target wall, the rebound ratio can be different from case to case. It is difficult to say how much a suitable shooting velocity would be. In such a case, simulation is a potential tool to predict and point out the optimum velocity for shooting.
The velocity of was found to have a linear relationship with shooting airflow: the larger the airflow, the higher the velocity of shotcrete [4].

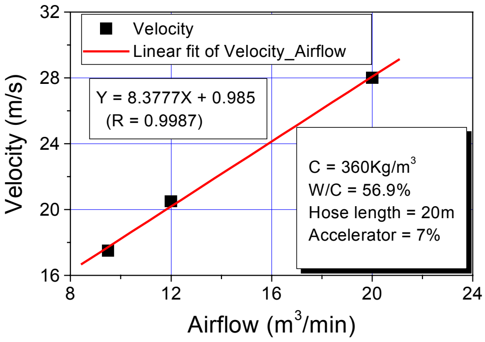
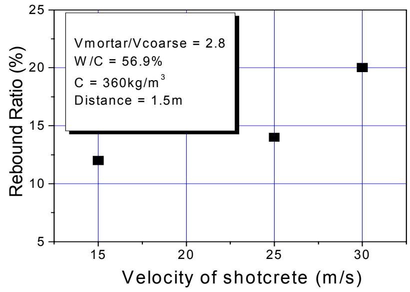


Figure 4. Concrete velocity vs. shooting airflow

4 RESULTS AND DISCUSSION

Figure 5 shows that at constant shooting distance of 1.5m, the rebound just increases a bit when velocity increases from 15 to 25 m/s but drastically goes up when shooting velocity reaches 30 m/s. For a given mix proportion, there should be an optimum shooting velocity and simulation is to solve that problem without the need to carry out huge experiment.
In Figure 6, it is clear that the larger the mortar by coarse aggregate (M/C) ratio, the smaller is the rebound loss. However, at a certain value of M/C ratio, around 5, the increase in M/C ratio will hardly have effect of rebound of shocrete.



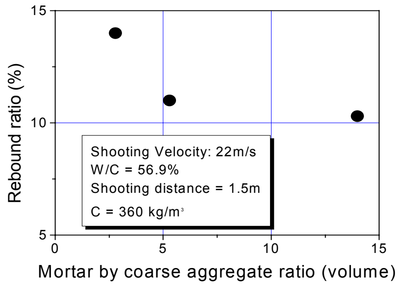


Figure 6. Effect of mortar by coarse aggregate ratio on rebound ratio

5 CONCLUSIONS

- A drastic reduction in calculation time can be obtain by using a wall as a single object in DEM simulation
- It was seen in the simulation hat the rebound ratio increases with the increase of shooting velocity
- Model with single-phase particles separately for mortar and aggregate enable the consideration of different rebound ratio for mortar and coarse aggregate.
- The change in M/C ratio just has effect on rebound rate only up to a certain value. Over that value, the increase in W/C is meaningless.

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