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DEVELOPMENT OF A THREE-DIMENSIONAL SIMULATION OF SHOTCRETE USING DISTINCT ELEMENT METHOD
個別要素方法による吹付けコンクリートの三次元シミュレーション

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1. INTRODUCTION

Shotcrete, or sprayed concrete, is a technical term representing a method for placing concrete rather than a particular type of concrete. Shotcrete is used in tunnelling, hydropower projects, slope stabilizations, mining operations and event in civil construction works. Its quality is well known to fluctuate under various conditions of construction and materials. Computer-based simulation becomes a very useful tool to reduce the cost of research on shotcrete whose experiments need huge finance and labour. In this research, a three-dimensional numerical analysis using Distinct Element Method (DEM) was utilized to model the shotcrete process. This simulation provides a fundamental knowledge and understanding about shotcrete.

2. SIMULATION MODEL

The DEM was introduced by Cundall (1971) for the analysis of rockmechanics 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. The contact forces and displacements of a stressed assembly of particles are found by tracing the movements of the individual particles. In this model, shotcrete process was simulated with two kinds of particles representing coarse aggregate and mortar. This simulation set up allows the consideration of high rebound rate of coarse aggregate at the beginning of shooting when only mortar remains at the target surface. The effect of shooting distance, pressure, mix proportion, accelerator was considered in this simulation. The assumption was made that all particles are spherical in shape. This two-phase-in two-particle model was firstly successfully used in the simulation of flowable concrete in our laboratory [4]. In this simulation, viscous damping, slipping models and bonding behaviours were integrated at the contact between particles during calculation.

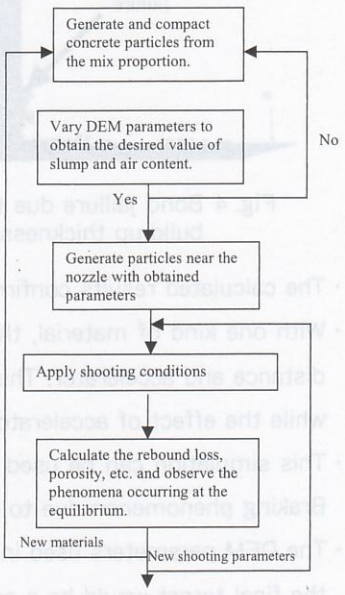

Fig. 1 Flowchart of simulation

3. CALCULATED RESULTS AND DISCUSSIONS

One actual case was picked up from shotcrete experiments. The initial velocity applied on particles in simulation can be obtained

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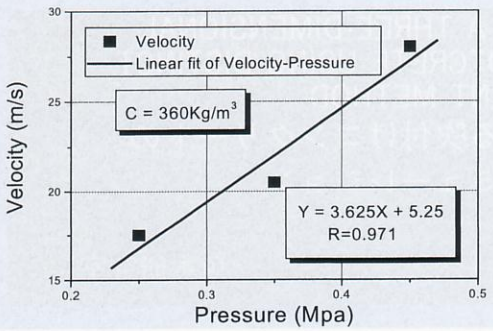

Fig. 2 Relationship between concrete velocity at the nozzle and shooting pressure

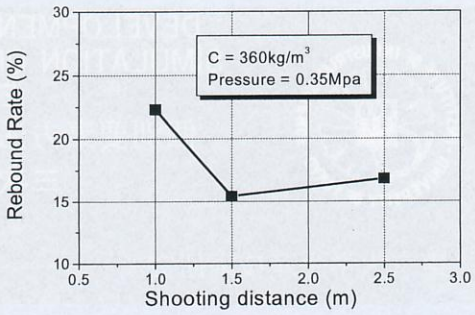

Fig. 3 Effect of shooting distance on rebound rate at pressure of 0.35 Mpa

from fitting curve in Figures 2. The velocities in this figure were obtained by analysing images of super high-speed video camera. Shooting distance was varied to study its effect on the rebound loss as well as on the porosity of shotcrete. It was found that the rebound loss increases at shorter shooting distance (Fig. 3) (under different shooting pressures, this may not be the case) Accelerator is added to shotcrete to shorten the setting time and, as a result, increase the build-up thickness. However, there should be a threshold for that build-up thickness. Figure 4 shows a large shotcrete block dropped down after bond-contact has broken at the weakest position. In order to investigate the effect of shooting pressure on the rebound rate, calculations were carried out with three values of pressure : 0. 25, 0.35, and 0.45Mpa. As can be seen in Figure 5, the rebound rate increases at higher pressure.

4. POTENTIAL APPLICATIONS AND NECESSARY IMPROVEMENTS

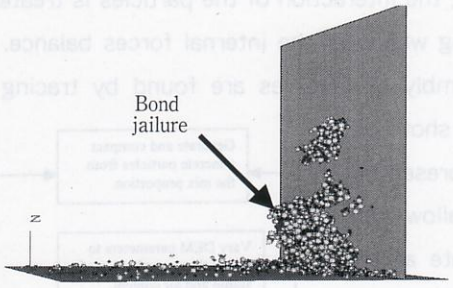

Fig. 4 Bond jaillure due to excessive build-up thickness.

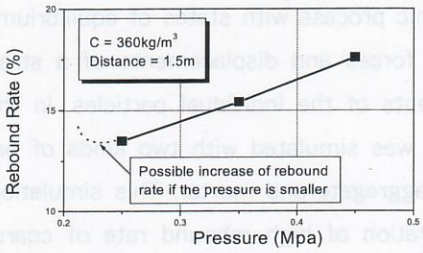

Fig. 5 Effect of shooting pressure on the rebound rate

- The calculated results confirm that DEM is a potential tool to simulate shotcrete process.
- With one kind of material, the rebound rate of shotcrete depends on shooting pressure, shooting distance and accelerator. This model enables the prediction of the effect of distance and pressure while the effect of accelerator needs more consideration.
- This simulation can be used to support the design as well as the shooting process of shotcrete. Braking phenomenon due to high build-up thickness was successfully simulated.
- The DEM parameters used in the simulation were obtained from try-and-error approach. Therefore, the final target would be a correlation between actual materials and DEM parameters.