論文 Verification of Application of DEM to Fresh Concrete by Sphere Dragging Viscometer

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ABSTRACT: A trial was carried out to prove the validity of applicability of DEM to simulating the mechanical behavior of fresh concrete in sphere dragging viscometer. Given special cares to the devices and data handling, experiments covered the fresh concrete, screened mortar and aggregate to acquire viscosity and yield value. It was found that even for high fluidity concrete such interaction as collusion, friction etc. between sphere and aggregate was obviously observed, which to some extent proved the applicability of DEM. Although DEM can precisely simulate the behavior of aggregate, it needs further modification to more precisely simulate the behavior of fresh concrete.
KEYWORDS: DEM, fresh concrete, sphere dragging viscometer, yielding value, viscosity

1. INTRODUCTION

DEM method as a discrete approach to simulate properties of fresh concrete even with high fluidity needs to be verified and at the same time the parameters should be determined theoretically. Although this problem has been solved for granular assemblage in soil mechanics, there has not been any available experimental way for fresh concrete. Here sphere dragging viscometer has been used to investigate the mechanical behaviors of fresh concrete, mortar and aggregate. It is found that even in high fluidity concrete, such interaction as collusion, friction etc. between sphere and aggregate can be obviously observed, which somewhat proves the applicability of DEM.

Moreover considering the intrinsic limitation of devices such as the speed retardation of motor and the systematic errors of A/D converter, special cares were given to the experiment and elaborate data handling to obtain rather precise yielding value and viscosity.

By using approximate parameters for aggregate, the behavior of sphere being dragged through aggregate assemblage was rather precisely simulated by DEM. However for fresh concrete the result of simulation was not so satisfactory that further modification of DEM is highly expected by taking the effect of mortar into account more reasonably .

2. EXPERIMENTS

2.1 MATERIALS

In this research ordinary portland cement, gravel, viscous agent and superplasticizer were used and their properties are listed in Table 1.

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2.2 DESCRIPTION OF EXPERIMENT

(1). Apparatus

Sphere dragging viscometer is designed with its components as shown in Fig. 1.

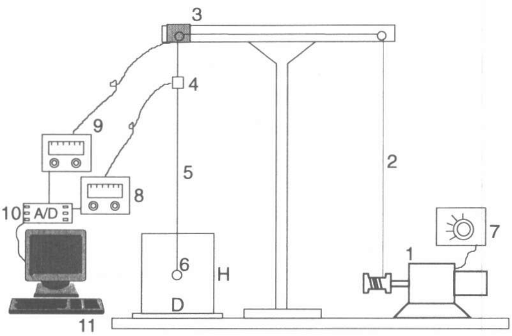
(2). Equipment handling

Although there is no clear description about the necessary procedures to utilize sphere dragging viscometer in previous researches, special cares should be given by taking the following limitation of devices into account:

- Prior to experiment motor has to be started for a certain length of duration larger than t_0 in order to get constant required speed as shown in Fig .2.
- Motor speed can not be exactly set by speed controller via naked eyes, therefore displacement transformer is attached to record the actual movement of dragged sphere.
- The initial value of load cell should be set to zero when sphere is emerged into fresh concrete, mortar and aggregate.
- When systematic errors are caused by A/D converter etc. the fluctuation of displacement recorded by displacement transformer should be filtered out by using least squares as demonstrated in Fig. 3.

Table 1. Properties of material

Material	Specific gravity	F.M.	Absorption
O.P.C.	3.15	-----	------
Sand	2.51	2.45	2.25%
Gravel(Gmax=20mm)	2.58	6.73	1.62%
Superplasticizer	SP-8N (polycarboxylate polymer)		
Viscous agent	Cellulose series		



Components:
1. Motor with gearbed; 2. Stiff steel string;
3. Displacement transformer; 4. Small load sensor;
5. Cylindrical acrylic container: Inner D=200mm, H=200mm
6. Steel ball: D=30mm, Weight=0.139kg;
7. Speed Controller; 8. Amplifier; 9. Encoder; 10. A/D converter;
11. Computer;

Fig 1. Setup of sphere dragging viscometer

(3). Experimental Procedures

Before starting to make concrete, in some cases aggregate components were placed into the viscometer to measure the sphere force-displacement curve at approximate rate of 3,6,15 and 30 mm/s respectively. Then fresh concrete was mixed in the 100 liter mixer. Afterwards sphere force - displacement curves were measured for fresh concrete at the rate ranging from 3 ~ 30mm/s with

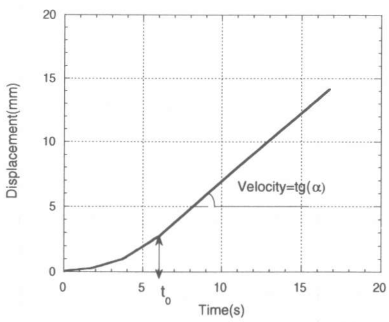


Fig 2. Control of motor speed

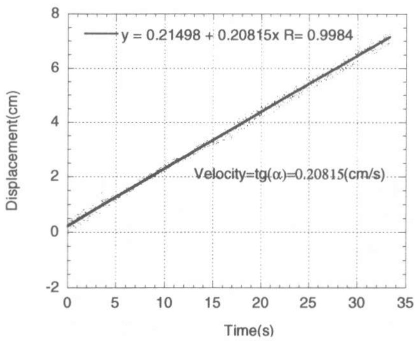


Fig 3. Determination of dragging speed

Table 2. Mix proportions and results

No.	W/C	s/a	w(kg)	c(kg)	s(kg)	g(kg)	VA(%)	SP(%)	τ_f(Pa)		η(Pa.s)	
									M	C	M	C
2	0.4	0.45	160	400	749	941	0.3	3	27.6	38.9	133.5	158.6

Note: W/C-water cement ratio; s/a- sand aggregate ratio; w-water; c---cement; s---sand; g-gravel; VA-viscous agent as percentage of water; SP-superplasticizer as percentage of cement; M-mortar; C-concrete

3mm/s increment at each step. Finally mortar extracted by screening was tested to find the yield value and viscosity in the same approach as fresh concrete.

(4). Mix proportion and results

16 cases were carried out to investigate the Bingham parameters of both fresh concrete and mortar. Here only the results of case No. 2 are shown in Table 2 while others are expected to be reported later because of the limitation of pages and focusing on the main purpose of this paper .

2.3 DISCUSSION ON EXPERIMENTAL RESULTS

(1). Data analysis

Fresh concrete is conventionally regarded as Bingham fluid which can be described by yielding value τ_f and viscosity η. The two parameters can be calculated by the two following equations.

$$\dot{\gamma} = \frac{v}{2r} \tag{1}$$

$$\tau = \frac{F}{12\pi r^2} \tag{2}$$

where

$\dot{\gamma}$: strain rate; v: dragging speed of sphere; r: radium of sphere; τ: stress; F: dragging force.

By using the method mentioned previously to eliminate the fluctuation of sphere displacement, 10 force - displacement curves with speed from 3 to 30mm/s are diagrammatized in Fig. 4. All of the curves show nearly the same trend, that is, the force of the initial portion starts from zero and quickly increases to relatively large magnitude and then begins to fluctuate at nearly constant level. This phenomenon can be explained as follows; sphere needs time to develop the full contact with the surrounding concrete after it is placed into the position and dragged. For ideal Bingham fluid the dragging force should be kept constant after initial stage, however, fluctuation occurs due to such interaction as collusion, fraction etc. between sphere and aggregate. In high concentration of aggregate this influence will become more and more evident. This phenomenon somewhat supports the applicability of DEM to the simulation of the behavior of fresh concrete.

At the meantime the screened mortar from No. 2 was used to carry out the same experiment as fresh concrete mentioned above, whose results are demonstrated in Fig. 5. Mortar depicts the same trend as fresh concrete and with the similar shape of initial stage. However the fluctuation is considerably reduced compared with that of fresh concrete. Therefore mortar is more approximate to Bingham fluid from this point of view.

As a comparison, aggregate of mixed sand and gravel was put into the container and the similar measurements were undertaken with different speed of 3, 6, 15 and 30mm/s respectively. From the curves shown in Fig. 6 different trends from fresh concrete can be observed. One is that the peak value at initial stage is considerably larger in aggregate and after peak value the force decreases immediately without keeping the relatively constant level as in fresh concrete and mortar. This phenomenon can be explained as follows; the binder among aggregates disperses the assemblage and increases the clearance between aggregates and hence reduces the possibility of direct collusion

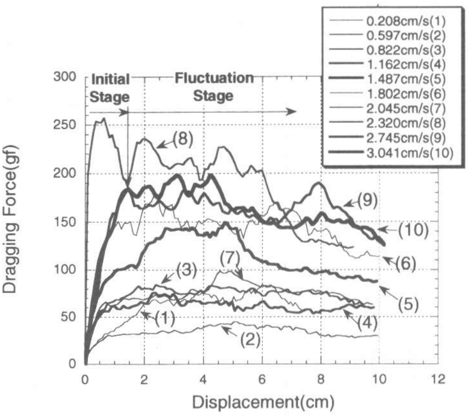


Fig. 4 Displacement and force curves for concrete No. 2

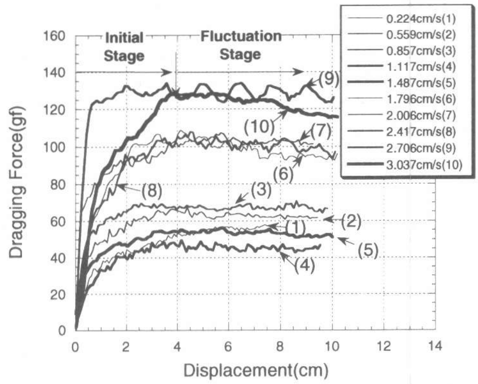


Fig. 5 Displacement and force curves for screened mortar from No. 2

between aggregate particles. The other reasons maybe come from the smoothing effect of binder which reduces the friction coefficient among aggregates. These reasons result in dramatical reduction of the internal stress developed in concrete and featuring quite different characteristics between concrete and aggregate assemblage.

In order to calculate yielding value and viscosity the averaged values of force within the fluctuation stage have to be obtained for 10 different curves at different speed shown in Fig. 4 and Fig. 5. Converting the 10 averaged forces and dragging speeds according to Eqn. 1 and Eqn. 2, 10 points can be plotted as shown in Fig. 7. The intercept with stress axis represents the yielding value while the reciprocal of the tangent of the slope is viscosity.

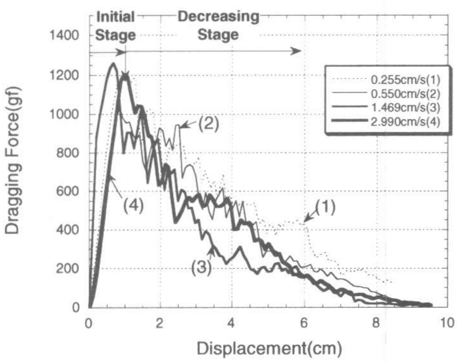


Fig. 6 Displacement and force curve for mixed sand and gravel

3. DEM SIMULATION

DEM is a discrete numerical method which is capable of handling the mechanics of granular assemblage. The principal mechanical components between elements are spring, dashpot and slider [1] as shown in Fig. 8. To make it applicable to fresh concrete, allowance of tension is added to take the ductility of mortar into account.

The determination of DEM parameters for fresh concrete is quite difficult and indirect. Such efforts are now being focused. However for soil mechanics Hertz theory is commonly used to calculate the spring constant as given in Eqn. 3 and Eqn. 4.

$$\frac{1}{E^*} = \frac{(1-\upsilon_1^2)}{E_1} + \frac{(1-\upsilon_2^2)}{E_2} \tag{3}$$

$$k_n = 2E^* a \tag{4}$$

where:
E_i, υ_i (i=1,2): elastic properties of two spheres
k_n: spring normal constant;
a: radius of the circular area of contact.

To carry out the simulation systematic way has been set up [2] as described hereinafter.

3.1 DATA PREPARATION

Packing is the first step for DEM approach to simulate the behavior of fresh concrete. This procedure resembles the realistic process of filling concrete into container. Fig. 9 demonstrates the packing procedure with parameters tabulated in Table 3.

3.2 DISCUSSION OF SIMULATION RESULTS

One example of simulation result is demonstrated by plotting displacement, velocity and force in Fig. 10. From the displacement and velocity distribution we can visualize the sphere dragging process to some extent.

From the available results obtained from limited number of simulation of current stage it can be said that although DEM can simulate the trend of force - displacement curve developed in concrete within the initial stage it shows quite different behavior in fluctuation stage as given in Fig. 11. However in Fig. 12 DEM can depict the behavior of aggregate assemblage quite well. That means that DEM can simulate the interaction among aggregate but can not simulate the properties of mortar perfectly. In other words DEM is useful in simulating the aggregate interaction in concrete while more

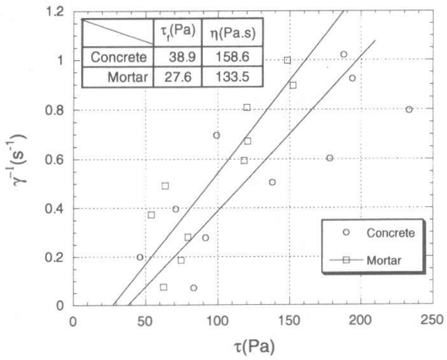


Fig. 7 Yielding value and viscosity of concrete and mortar

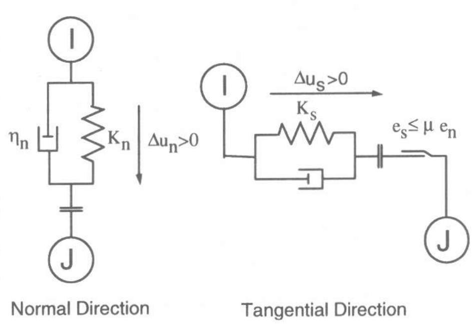


Fig. 8 Mechanical components of DEM element

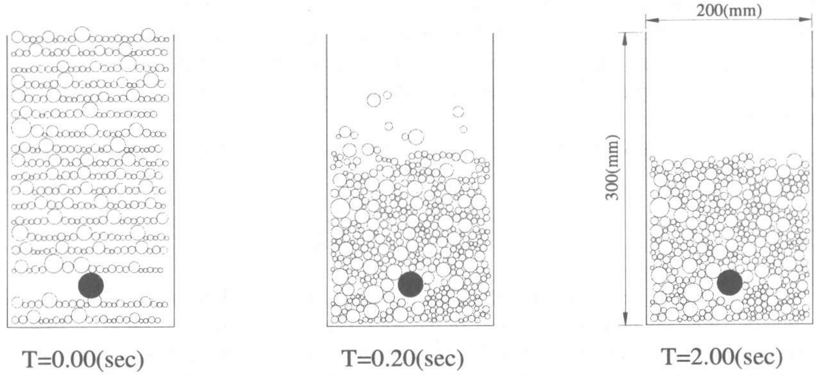


Fig. 9 Packing particles for sphere dragging viscometer simulation

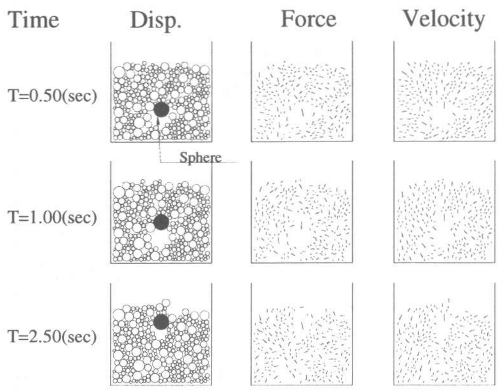


Fig. 10 One simulation result of viscometer

Table 3. DEM parameters

Spring constant Normal K_n	1.2×10^4 N/m	Friction coef. of particles μ_p	0.4
Spring constant Tangential K_s	0.3×10^4 N/m	Friction coef. of wall and particle	0.4
Dashpot coef. Normal η_n	5.7N·s/m	Allowance of spring tension λ	0%
Dashpot coef. Tangential η_s	7.0N·s/m	Time step Δt	10^{-5}s
Particle no. Nel	476	Simulation time	2.5s

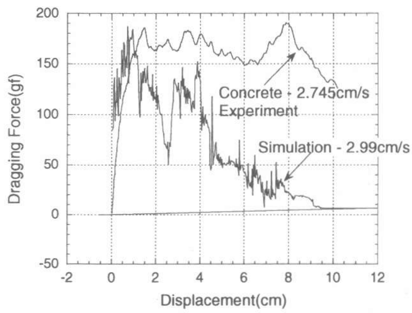


Fig. 11 Concrete and simulation result comparison

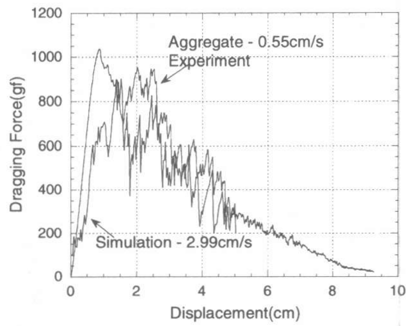


Fig. 12 Concrete and simulation result comparison

reasonable modeling of mortar in DEM is further required.

4. CONCLUSIONS

From the above research, the following conclusions can be drawn.

(1). DEM is quite capable of simulating the behavior of aggregate assemblage, which means its useful utilization in describing the interaction between particles in concrete.

(2). Although DEM can partially simulate high fluidity concrete, there needs more consideration for the modeling of mortar.

(3). Special cares in experiment should be given to device adjustment, handling and data processing.

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