V－513 **TWO DIMENSIONAL NUMERICAL SIMULATION OF FLOW BEHAVIOR OF FRESH CONCRETE BY DEM METHOD**

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## 1. Introduction

Research on flow mechanism of fresh concrete is one of the theoretical needs in producing HFC (High Flowing Concrete) with a high workability that can self-fill forms completely and sections of concrete components even with heavy reinforcements. The flow property of fresh concrete is so complicated that it is extremely difficult to use ideal mechanical models to calculate the realistic picture of internal forces of fresh concrete during flowing. Numerical simulation method offers some shortcuts to the solution.

In this paper the applicability of modified two dimensional Distinct Element Method (DEM for short hereinafter) to simulate the flow behavior of fresh concrete through $O_{75}$ funnel is demonstrated in both theoretical and practical aspects. A set of parameters is given and the relationship between flowing time and allowance of tension, dashpot coefficient is discussed respectively.

## 2. Mechanism of DEM

DEM is a discrete numerical method which can deal with elastic spring, viscous dashpot and slide on contact point of rigid bodies. The force, moment and motion of rigid element can be derived by the following equations:

$$F = \Sigma f_c + \Sigma f_{body} + \Sigma f_{bound} = m\ddot{u} \quad .....(1)$$

$$N = \Sigma m_c + \Sigma m_{bound} = I\ddot{\psi} \quad ................(2)$$

where F is element's resultant force, M is quality of element, u is displacement of element, $\Sigma f_c$ is interaction between elements (inclusive of spring and dashpot forces), $\Sigma f_{body}$ is volumetric forces such as gravity, $\Sigma f_{bound}$ is summation of surface force. N is resultant moment, I is inertia modulus of element, $\psi$ is rotational displacement, $\Sigma m_c$ is moment due to element's interaction, $\Sigma m_{bound}$ is moment due to surface forces.

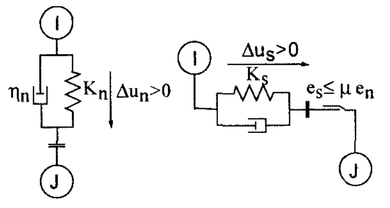


Fig. 1 Model of DEM Contact Point

The mechanical model of contact point of two arbitrary spherical elements *I* and *J* at time t is illustrated in Fig. 1. A more detailed description of DEM method can be found in literature [1].

## 3. Modeling DEM for fresh concrete

When well mixed and proportioned fresh concrete acquires a satisfactory consistency of plasticity, good flowability, sufficient resistance to segregation which can be regarded as Bingham fluid. However this consideration is partially true on the condition that rich paste concrete undergoes a limited deformation of flowing, in real condition, concrete always depicts some symptoms of interparticle interference between coarse particles of its component such as dilatancy, thixotropy expressed in rheological terms. Interparticle interference proves DEM to be a potential good numerical simulation method to deal with the flowing properties of concrete. Nevertheless two aspects of modification is attempted to make DEM applicable to coarse aggregate component of fresh concrete.

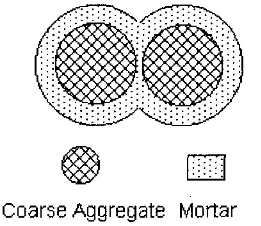


Fig 2. Scheme of Calculation Coarse Aggregate

❶ Calculation diameter of coarse aggregate. The basic consideration is to treat fresh concrete as two-phased material with mortar acting as outlayer binding agent and coarse aggregate as surrounded skeleton of matrix which is illustrated in Fig. 2. The shape of coarse aggregate is defined as sphere as first approximation. The volumetric fraction of mortar is included in the calculation diameter of coarse aggregate by which each coarse aggregate is equally magnified by a factor to take the outlayer mortar into

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account. ❷ Interaction mechanism between calculated coarse aggregate. In calculation model coarse aggregate is two-layered composite with internal solid kernel coated by approximately plastic mortar. The external layer is soft enough to undergo a large deformation and the kernel is much less deformed subjected to the same forces. Therefore two differing sets of parameters are designated for different part of composite coarse aggregate, some parameters of kernel being usually ten times larger than that of outlayer.

A typical set of parameters for a DEM model is manifested in Table 1 whose physical meanings are fully discussed in literature [2]. The diagrammatized simulation results of such model taking the parameters listed in Table 1 are illustrated in Fig. 3. $O_{75}$ funnel is a cone-like apparatus with 10 liters capacity.

Table 1. A Set of Parameter of a DEM Model

| | | | |
|---|---|---|---|
| Spring Constant of Normal Direction | 30 kg/mm | Friction Coefficient between Particles | 0.01 |
| Spring Constant of Tangential Direction | 7.5 kgs/mm | Friction Coefficient between Wall and Particle | 0 |
| Dashpot Coefficient of Normal Direction | 2.85 kgs/mm | Allowance of Spring Tension | 0.01 |
| Dashpot Coefficient of Tangential | 3.5 kgs/mm | Time Step | $10^{-5}$ |
| Particle Number | 650 | Simulation Time | 11.5s |

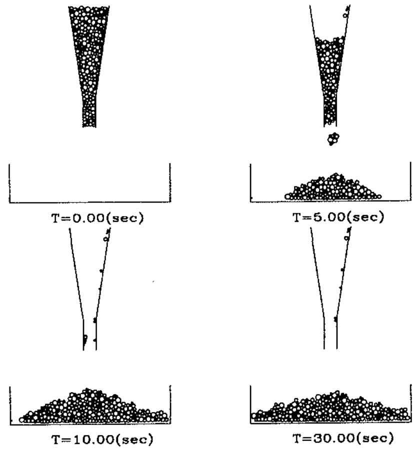


Fig. 3 A DEM simulation of Fresh Concrete through $O_{75}$ Funnel

### 3. *Discussion of DEM simulation*

❶. The relationship of allowance of tension with flowing Time. From Figure 4 we can draw a conclusion that flowing time increases at an approximately exponential rate until allowance of tension reaches the threshold value of a little larger than 5.5%. Above this threshold fresh concrete will stagnate and phenomenon of incomplete flowing will inevitably results.

❷. Relationship between Dashpot Coefficients and Flowing Time. In granular numerical simulation dashpot is designed as a mechanism for energy dissipation of plastic components. For numerical simulation of fresh concrete dashpot coefficients are of vital significance because the properties thereof demonstrate a fairly approximation of plastic body when fresh concrete is proportioned to act as self-filling material. We can clearly see in Fig. 5 that the relationship is nonlinear and $\eta_n$ has a threshold of 9.8kgs/mm, exceeding of which will cause the incomplete termination of flowing of fresh concrete through $O_{75}$ funnel.

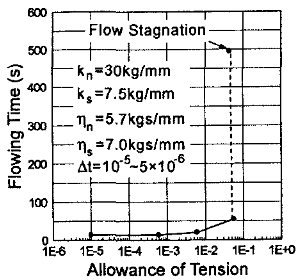


Fig. 4. Relationship between Allowance

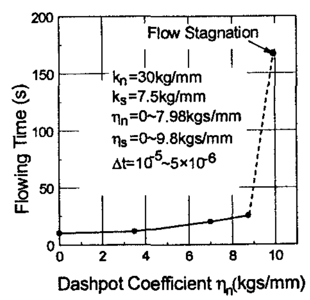


Fig. 5. Relationship between Dashpot Coefficient $\eta_n$ and Flowing Time

## 4. Conclusion

DEM is applicable to numerical simulation of fresh concrete flow from the viewpoints of theoretical and practical aspects. Allowance of tension and dashpot coefficient are two of the most factors which show nonlinear relationship with flowing time.

## 5. Reference

[1]. Technical Committee on Mechanics of Granular Material : Mechanics of Granular Material, The Japanese Society of Soil Mechanics and Foundation Engineering, pp 283-286, 1993.

[2]. Nabeta, K., Machida, A., Iwashita, K., Sasaki, T., : Numerical Simulation of Fresh Concrete Flow by Distinct Element Method, Proc. of Japan Concrete Institute, Vol. 16, No. 1, pp 479-484, 1994.