PERFORMANCE OF CONCRETE TRANSPORTATION SYSTEM USING DEM ANALYSIS

MISUZU YOSHIKUNI[1], YOSHITAKA KATO[2]
AND TAKETO UOMOTO[2]
[1]Department of Civil Engineering, University of Tokyo,
Graduate Student, Japan
[2]International Center for Urban Safety Engineering,
Institute of Industrial Science, University of Tokyo, Japan

ABSTRACT

Concrete for dam is usually transported to the casting site by a crane, a dump truck or a belt conveyer. However, there are many problems from the environmental and safety aspects: danger, noise, dust, environment, etc. A new concrete transportation system is developed to overcome these problems and the system is now being used to transport concrete for a dam. This equipment can carry concrete or soil, stone in large quantities continuously and safety by rotating circular pipe with spirally attached blades.

The combination of the number of blades, angle of blades, slope of pipe, rotation speed, etc. which influences the performance of transportation are numerous. However, selection of the combination has been done on limited number of experimental result using the actual concrete transportation system. Therefore, analysis was performed using DEM to examine the optimal combination of these factors.

As a result, it is confirmed that there is a possibility to simulate the state of concrete transportation by DEM and experimented result can be reproducible to some extent. Further, consideration is needed not only the pouring velocity but also the segregation of concrete.

1. INTRODUCTION

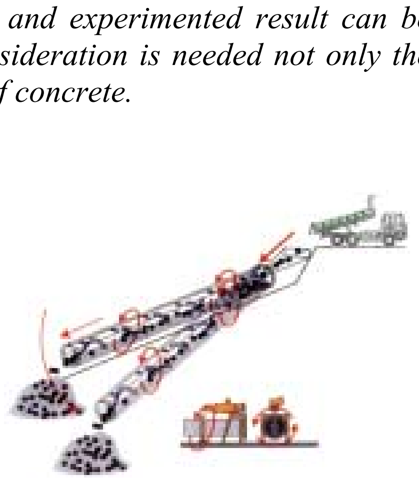

Figure 1: Outline of concrete transportation system

At present, the concrete for a dam is transported to the casting place by a crane, a dump truck, a belt conveyer, etc. However, there are many problems in all cases. For example, danger and noise during transportation due to enormous size and movement of these equipments, the natural environment may be changed in a large scale especially plants, noise, dust, etc. This is why a new concrete transportation

Figure 2: Attachment of blades inside the pipe

Figure 3: Concrete in the transportation pipe

system called SP-TOM is developed (see Figure 1). The new concrete transportation system is now being used to transport concrete such as RCD concrete for a dam with maximum size of 40mm to 150mm. This equipment can carry concrete, stone or soil in large quantities continuously and safety by rotating circular pipe with spirally attached blades. The attached blades are shown in Figure 2 and transported concrete inside the pipe is as shown in Figure 3. The combination of the factors, such as number of blades, angle of blades, slope of pipe, rotation speed, etc., which influences the performance of transportation are numerous. However, selection of the combination of these factors has been done on limited number of experimental results using actual concrete transportation system. Therefore, there is a need to examine the optimal combination analytically using DEM analysis.

2. PRINCIPLE OF DISTINCT ELEMENT MODELING (DEM)

The Distinct Element Modeling is a well-known numerical method pioneered by Cundall and Strack for the granular flow modeling as a particulate system. Recently several researches have well shaped this numerical method. It has been already used for simulating liquefaction of sandy soil, fracture of cohesive soil, rock avalanches, debris flow, fracture of material, material modeling, impact and blasting problems, hydraulic problems etc., from 2D to 3D and from circular element to polygonal elements. It is now capable of simulating homogeneous and perfect discrete media to complex, heterogeneous and continuous media.

The basic principle of DEM has been originated from the equation of motion used in particle dynamics. The equation of motion of an element, i, having the mass, m_i, and the moment of inertia, I_i, can be written as

$$m_i \cdot \ddot{u} + C_i \cdot \dot{u} + F_i = 0 \tag{1}$$

$$I_i \cdot \ddot{\phi} + D_i \cdot \dot{\phi} + M_i = 0 \tag{2}$$

In this equation, F_i is the sum of forces acting on the element, i. Mi is the sum of all moments acting on i. C_i and D_i are the damping coefficients, and u, ϕ are the linear and rotational displacement vectors respectively.

3. ANALYSIS METHOD

3.1 Model

Although the length of actual transportation-pipe is about 200m, simulation is done only on the basic part of transportation-pipe (see Figure 4). The transportation-pipe has a diameter of 700mm, a length of 5.5m and five blades. The slope of transportation-pipe changes from 20 to 40 degree. Although the shape of the actual transportation-pipe is circle, it is considered as tetra icosagon. The shape of blades is a trapezoid and shows the angle of 120 degrees by projection to transportation-pipe. The rotation direction of transportation-pipe is clockwise downward.

At first, the hopper is made at the upper part of transportation-pipe and concrete is filled up in the hopper. The concrete is assumed as a mixture of coarse aggregates with different size of sphere particles randomly packed in the hopper due to difficulty in reproducing the actual particle-size distribution. After that, the wall dividing between the hopper and the transportation-pipe is removed and the concrete started to fall freely.

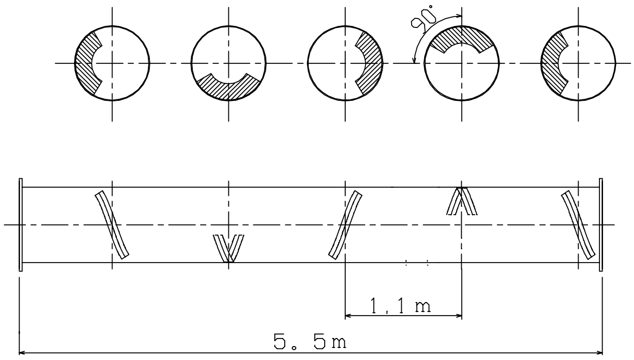

Figure 4: Basic structure part of transportation-pipe

3.2 Parameters estimation

The mixture simulated is shown in Table 1. The parameters simulated are shown in Table 2. The concrete is RCD concrete and the property of fresh concrete is greatly influenced by the amount of coarse aggregate. Considering this fact, analyzed RCD concrete is assumed as a mixture of coarse aggregates. The simulation parameters are decided by wave propagation equation. The number of elements is one thousand. The sizes of coarse aggregates are chosen based on particle-size distribution of concrete. The formula for estimating parameters is shown below.

$$\mu_1 = G = \frac{E}{2(1+E)} \tag{3}$$

$$\lambda_1 = \frac{E\upsilon}{(1+\upsilon)(1-2\upsilon)} \tag{4}$$

$$V_s = \sqrt{\frac{G}{\gamma}} \tag{5}$$

$$V_p = \sqrt{\frac{\lambda_1 + 2G}{\gamma}} \quad (6)$$

$$k_n = \frac{1}{4}\pi\rho V^2{}_p \quad (7)$$

$$k_s = \frac{1}{4}\pi\rho V^2{}_s \quad (8)$$

In this equation, μ_1 and λ_1 are the Lame's constants. G is the shear modulus. E is the Young's modulus. v is the Poisson's ratio. V_s and V_p are the velocities of shear and compression waves, respectively. γ is the unit weight. k_n and k_s are the spring stiffness in normal and tangential directions.

Table 1: Concrete mixture

Unit Volume (kg/m^3)					
W	C	S	G		
			G1	G2	G3
83	120	724	639	479	479

Table 2: Parameters

Spring constant (N/m)		dashpot coefficient (Ns/m)		Friction
Normal	Shear	Normal	Shear	
1×10^5	5×10^4	0.01	0.01	0.01

4. SIMULATION RESULTS AND DISCUSSIONS

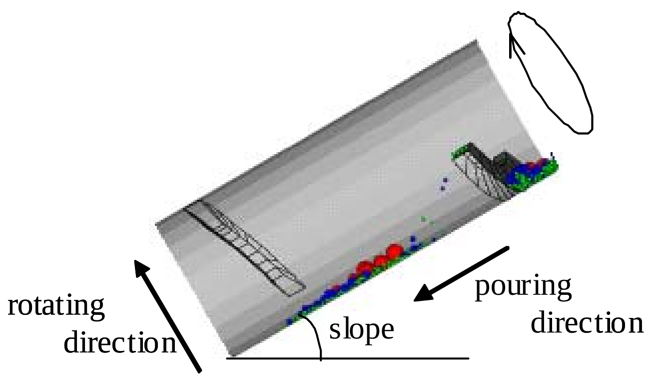

Figure 5: Index definition

The flow velocity vectors obtained from analysis are dividing to pouring direction and rotating direction, as the vectors are useful to show

Figure 6: Transporting situation

the mechanism of concrete flow (see Figure 5). The best transportation volume can be obtained when (a) the pouring direction velocity is large to some extent and constant and (b) the segregation not occurred.

An example of the analyzed case (slope of pipe: 40 degree and rotation speed 30 rpm), is shown in Figure 6. The figure shows in time step from left to right. Concrete disperses when they are in between the blades, but when they reach the next blade, they gather again at the blade. This tendency is the same in all the cases.

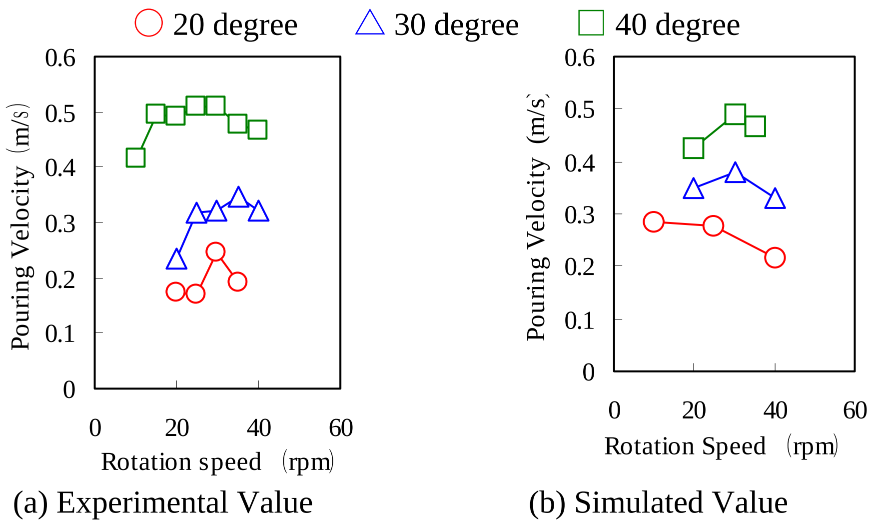

Figure 7: Transporting Power of Concrete

The pouring direction velocity is shown in Figure 7. The experimental value is calculated from the maximum transporting amount assuming the filling ratio of concrete in the pipe one third. The simulated value is the average of pouring direction velocity. The pouring direction velocity increases with increase of rotation speed and decreases when the rotation speed reaches certain value in all the cases. This is caused by the relation between the gravity and the centrifugal force. In case the rotation speed is small, the influence of gravity is stronger than that of centrifugal force, and in case the rotation speed is large, the influence of centrifugal force is stronger than that of gravity. From these results, this analysis can reproduce the tendency of experimental result to some extent. On the other hand, one of the reasons why the value disagrees is that the amount of concrete in the simulation is not enough compared with in the experiment.

The standard deviation of pouring direction velocity of concrete is shown in Figure 8. The standard deviation increases with increase of the slop of pipe. In case the slop of pipe is 40 degree, the standard deviation does not change much in the rotation speed, though, in case of 20 and 30 degrees, the standard deviation changes. Therefore when this transportation system is used actually in the field, we should decide the rotation speed of pipe considering not only the pouring velocity but also the segregation.

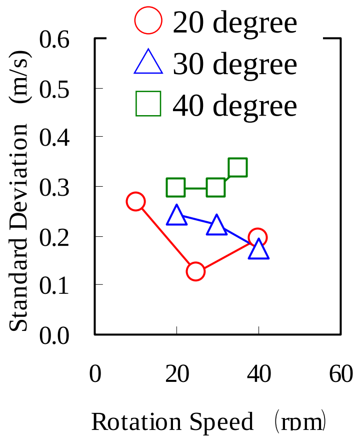

Figure 8: Dispersion of Pouring Velocity

5. CONCLUSION

Analysis were performed on concrete during transportation using DEM. Following conclusions were obtained within this research.

(1) It is confirmed that there is a possibility to simulate the state of concrete transportation by DEM. This analysis can produce the tendency of experimental result to some extent.

(2) During transportation in the pipe, when concrete exists in between the blades, the concrete is dispersed. When concrete reaches the blades, the concrete gathers.

(3) In case this transportation system is used actually in the field, we must decide the rotation speed of pipe considering not only the pouring velocity but also the segregation.

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