

論文

# [1146] ポンプ圧送時におけるフレッシュコンクリートの変形性を表わす数学的モデル

## MATHEMATICAL MODELING OF DEFORMATION FOR FRESH CONCRETE IN PUMPING

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### 1. INTRODUCTION

This paper reports a visual test carried out to obtain information on two phase material flow in tapered pipes and discusses the segregation process and blockage. Studying the sensitivity of viscosity to the kinematics of model concrete, the authors simulated the segregation process based on one dimensional computational model for pipe flow of fresh concrete.

### 2. VISUAL TEST

#### 2.1 TEST METHOD

In order to observe the mechanism of blocking due to aggregate particles as the solid phase deformation in two phase material flow, the visual test developed by Hashimoto [4] was adopted.

A rectangular pipe section which consists of straight and tapered portions made of transparent acrylic panel was used (Fig.1). Transparent polymer was used as the paste media. Plastic balls (25 mm in diameter) and light weight aggregates (approx.15 mm in diameter) were used as coarse aggregates for model concrete. Cellulose was utilized for changing the viscosity of polymer paste.

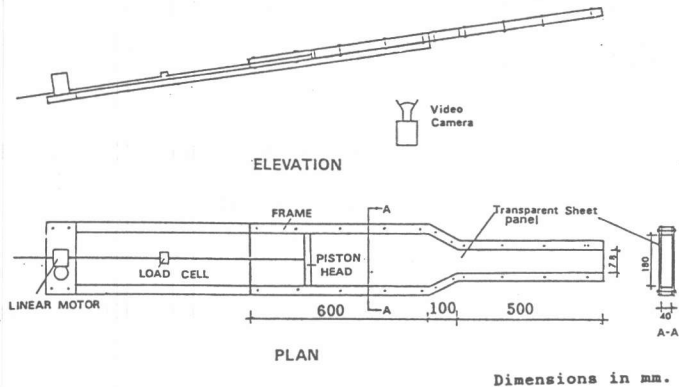
After placing the polymer and particles as shown in Fig.2.a, the piston head was moved at a constant speed while recording the particle movement by video camera and the pumping force by a load cell. The experiment was carried out by changing the viscosity of paste for both light weight aggregates and plastic balls.

#### 2.2 OBSERVATIONS AND DISCUSSION

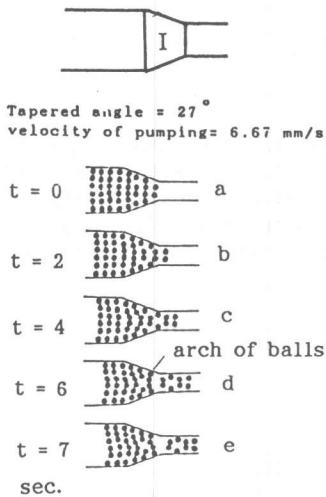
Fig.2 shows the process of arch formation by plastic balls which initiate blocking in tapered pipes. In the case of light weight aggregates as aggregate phase, complete blockage occurred after the formation of

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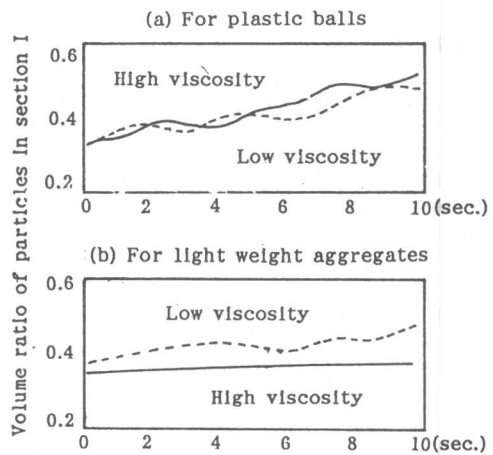
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Fig(1) Apparatus for pumping



Fig(2) Flow pattern and formation of arch



Fig(3) Volume ratio of particles in the tapered section vs time

the arch, while the blocking did not take place in the case of plastic balls. This was due to the higher friction and interlocking between particles since light weight aggregates had irregular configuration on surfaces.

As shown in Fig.3, the rate of volume increase for plastic balls in the tapered section is found to be independent on the polymer viscosity while the particle accumulation of light weight aggregates highly depends on viscosity of polymer. Due to the turbulence and rearrangement of balls in low viscosity paste, additional stress dependent on the surface condition should be produced on particles. Since plastic balls have smooth surfaces, even though the balls contact and slide each other, the contact stress developed in plastic balls may not increase appreciably. The wall friction and the normal reaction from the pipe wall acting on balls, which are functions of the contact stress, are expected to govern no appreciable change in accumulation of balls in the tapered section. High aggregate contact stress developed in lightweight particles is expected due to rough irregular surfaces. Accordingly, it should be simulated that the paste viscosity be effective on accumulation of particles with high inter-particle actions.

### 3. TWO PHASE MODEL FOR FLOW AND SEGREGATION OF FRESH CONCRETE

#### 3.1 CONCEPT OF THE PROPOSED MODEL

The aggregate phase is assumed to be uniformly distributed throughout the cross sectional area of the pipe and to maintain continuity as shown in Fig.4. The mortar phase is assumed as the disperse medium filling the space between aggregates.  $\rho_a$  and  $\rho_m$  are Volume ratios of aggregate phase and mortar phases per unit concrete volume. Assuming incompressibility of concrete, we have

$$\rho_a + \rho_m = 1 \quad (1)$$

The mean sectional areas of the aggregate and mortar phases are modeled as  $A\rho_a$  and  $A\rho_m$ , where  $A$  is the total cross-sectional area of the pipe line. The forces acting on aggregate and mortar phases are defined as  $A\rho_a\sigma_a$  and  $A\rho_m\sigma_m$ . Then, the total pressure  $p$  is given by

$$p = \rho_a\sigma_a + \rho_m\sigma_m \quad (2)$$

#### 3.2 AGGREGATE CONTACT STRESS

The aggregate contact force which may arise from interparticle collision or frictional sliding is resolved in the axial and the radial directions of the pipe. The axial contact stress  $\sigma_c$  is defined as the axial contact force  $F_c$  on the aggregate phase per unit cross sectional area of the pipe and the radial contact stress,  $\sigma_{rc}$ , is assumed as a function of axial contact stress as follows:

$$\sigma_c = F_c/A \quad (3)$$

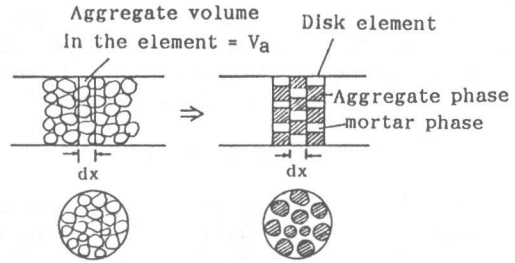
$$\sigma_{rc} = k\sigma_c \quad (4)$$

where  $k$  depends mainly on the aggregate shape and the frictional property. The mean aggregate stress  $\sigma_a$  is evaluated as the mortar stress plus the interparticle stress as shown in Fig.5, then,

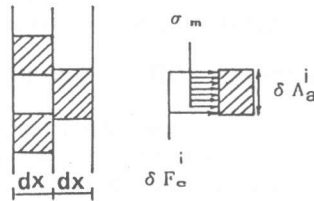
$$p = \sigma_m + \sigma_c \quad (5)$$

#### 3.3 CONSTITUTIVE MODEL FOR AGGREGATE CONTACT STRESS

The inlet pumping pressure is reported to increase with the increase of aggregate content under the same flow rate of pumping [1]. Then, the aggregate contact stress is assumed as a exponential function of aggregate volume ratio and the function was selected in such way that it represents the test results[1] qualitatively. Further modifications were introduced regarding with velocity and



Fig(4) Idealization of aggregate phase and mortar phase



Fig(5) Forces acting on aggregate phase