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Experimental simulation of bleeding under a high concrete column

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ABSTRACT

The quality of fresh concrete and durability of hardened concrete are affected by the bleed water of the fresh mixture including internal and external bleeding. The concrete mixture is pressurized during pumping for transportation or placing at high height. Variation of pressure influences the bleeding properties such as the amount and rate of bleeding water, which are determined from the oedometric modulus and diffusivity of the concrete mixture. However, with the conventional test it is difficult to estimate the bleeding phenomenon of fresh concrete under high pressure based on the bleeding properties. This study proposed a prediction model and experimental setup to evaluate the bleeding of freshly mixed concrete under high pressure. The pressure change, compressibility, and flow-out bleed water were obtained, and their variation was discussed with bleeding properties according to different types of fresh mixtures.

1. Introduction

Bleeding is a phenomenon where water in a freshly mixed cement-based material is drained out to the surface when solid components of the mixture consolidate in a form [1]. The bleeding influences the quality of fresh concrete and durability after the concrete hardened. The amount and rate of drained-out water are considered to be two important bleeding parameters, which are mainly determined by the dimensional properties of the concrete mix, environmental conditions where it stands, mix proportion and protocol, and characteristics of the constituents such as the size and shape of cement as well as aggregates [1–3].

The conventional test methods to measure the bleeding of cement-based materials adopt a self-weight consolidation, and consequent bleeding is manually measured [4–6]. The volume of bleeding water per surface area or per net mixing water has been suggested to describe the bleeding phenomenon. Several theoretical models have been proposed to describe the bleeding parameters and to predict the bleeding phenomenon based on the self-weight consolidation theory [1,7–13], and recently a comprehensive model was additionally proposed based on small-strain theory of linear poroelasticity to understand and predict the internal bleeding of a concrete mixture [3].

Previous studies also investigated the influence of permeability on the self-weight bleeding test of cement-based materials [14,15]. Permeability is one of the significant properties to characterize the bleeding parameters as well as rheological properties. Picandet et al. [16] attempted to measure the permeability of fresh cement paste using a permeameter and displacement-controlled oedometer, which are frequently used in the field of geotechnical engineering. The permeability measured with a cement paste sample has been analyzed with the void ratio (void-to-solid volume fraction). Test results for freshly mixed concrete were also reported, where the amount of bleed water has a nonlinear relationship with the initial height of the concrete mixture [11]. Variation of the mixture height induces different levels of vertical pressure. For example, a vertical pressure of 1 bar (100 kPa) is generated at the bottom of a concrete column due to its self-weight when concrete mixture having the unit weight of 25 kN/m^3 is placed for 4 m-high formwork. The pressure would exceed 300 bar (30 MPa) when the concrete mix is transported by pumping [17,18]. The bleeding depends on the overhead pressure, and the amount of concrete in the field, which is generally under a certain pressure, cannot be estimated with the properties measured by the conventional test methods. Therefore, a prediction model and an experimental setup are needed to identify the bleeding of fresh concrete under a certain pressure.

This study attempts to evaluate the bleeding of freshly mixed concrete under high pressure. A prediction model for the bleeding phenomenon at a given stress state was proposed based on the linear poroelasticity. A pressure vessel was also fabricated to experimentally measure the bleeding under high pressure, which allowed the measurement bleeding of fresh cement paste, mortar, and concrete mixtures under high pressure. As a result, several important measurements such as pressure change, compressibility of each sample, and flow-out bleed water were obtained according to different types of powder, different sizes of gravel, and different mix proportions. Additionally, bleeding properties of fresh concrete, such as the oedometric modulus,

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diffusivity, and permeability, were discussed based on the proposed model.

2. Sample preparation and pretest

2.1. Cement-based materials

Seven samples of freshly mixed cement-based materials were produced with 10 min of mixing. The mix proportions and volume fractions of each raw material are reported in Tables 1 and 2, respectively. Fresh concrete samples were prepared with different mix proportions, which were classified according to the used gravel, labeled C and D. Cement paste (denoted as P1) was mixed with a water-to-powder weight ratio (w/p) of 66% and it is the paste constituting concrete sample C1. Mortar (denoted as M1) was also mixed corresponding to C1 without gravel. Its fine aggregate-to-cement ratio is 2.45. In the concrete sample C1, 35% mortar by volume is replaced with coarse aggregate. Sample C2 incorporates ground-granulated blast-furnace slag (GGBFS; its specific density and Blaine number are 2.95 and 4140 cm^2/g) replacing 50% cement by volume. Type I Portland cement and river sand were used for all of the mixes. The specific gravity and Blaine number of cement were 3.14 and 3350 cm^2/g, respectively. The specific gravity of sand was 2.31 in a surface-dry saturated condition. For samples C1 and C2, crushed gravel was used. Its maximum nominal size is 19 mm and the specific gravity is 2.72 in an oven dry condition and 2.73 in a surface-dry saturated condition (water absorption of 0.55%), respectively. The fine and coarse aggregates in samples C1 and C2 were prepared in an air dry condition. On the other hand, for samples D1, D2, and D3, crushed gravel having a maximum nominal size of 25 mm was prepared in a surface-dry saturated condition to minimize water absorption error to bleeding.

2.2. Flow measurement

The flow and consistency of the mixtures were measured by a flow meter in accordance with ASTM C1362 [19] prior to the bleeding measurement. The test results provide workability and degree of compaction of the mixture. The conventional slump could be calibrated: multiplying the flow measurement by 30 gives the estimated slump in mm [20]. Fig. 1 shows the test setup of the flow meter, and the estimated slumps of the prepared mixtures are reported in Table 3. The slump increases with an increase of water content and by incorporating GGBFS, as expected [21].

2.3. Self-weight bleeding test

Self-weight bleeding tests were performed for the concrete samples. The test setup illustrated in Fig. 2 was proposed by Yim et al. [3]. A sample was placed in a cylindrical mold with a height of 170 mm and a diameter of 150 mm, and surface measurement was then performed. Two sensors detect the vertical movement of the floating probe and anchored probe individually. The floating probe traces the water level on the external bleed water, and another probe is anchored at the top surface of the mixture to measure settlement of the mixture. The measured signal from the noncontact laser sensors is recorded at 1 point per minute. The temperature and relative humidity in the lab were respectively maintained at 22 °C and 35% during the measurement. The measured water evaporation rate is 0.0025 mm/min, which value is used for calibration of measured water level.

Table 1
Mix proportions of the prepared samples.

Label	Water (kg/m^3)	Cement (kg/m^3)	GGBFS (kg/m^3)	Sand (kg/m^3)	Gravel (kg/m^3)	W/P (%)
P1	686	1040	–	–	–	66
M1	323	492	–	1204	–	66
C1	211	322	–	787	945	66
C2	211	161	148	787	945	68
D1	240	529	–	721	762	45
D2	229	433	–	687	917	53
D3	234	339	–	701	970	69

Table 2
Volume fraction of raw materials (%).

Label	Water	Cement	GGBFS	Sand	Gravel
P1	67	33	–	–	–
M1	32	16	–	52	–
C1	21	10	–	34	35
C2	21	5	5	34	35
D1	23	17	–	30	28
D2	23	14	–	30	33
D3	23	11	–	30	36

Fig. 3 shows the surface measurement, where the dotted line and the dashed line represent the measured displacement of the water level by the floating probe and settlement of the mixture by the anchored probe, respectively. The solid line shows the amount of external bleeding water, which is calculated by subtracting the water level from the settlement. The theoretical prediction of the water level is invariable [3], but the measured water level shows slight fluctuation of less than 0.5 mm by experimental error. Settlement occurred from placement of the mixture for 20 min or 120 min, depending on the samples' characteristics. A few kinks observed on the settlement were due to abrupt movement of the coarse aggregate under the anchored probe [3]. The result of C2 in Fig. 3 (b) (partially replaced GGBFS) does not have a remarkable influence on the total amount of bleed water than the result of C1 in Fig. 3(a). However, incorporating GGBFS increases the rate of bleeding and leads to rapid decay upon sedimentation. As can be seen in the results of Fig. 3(c) to (e), mixtures having high water content gave large amounts of bleed water, as expected, and show high rates of bleeding and rapid decay upon sedimentation. This indicates that incorporating GGBFS and the use of high water content lends high permeability to the mixture. The final settlement ($\hat{s}$) values and accumulated bleeding water of the samples are listed in Table 4 with their unit weights (γ).

The authors' previous study reported that the oedometric modulus (M) of freshly mixed concrete is higher than that of freshly mixed mortar, and the oedometric modulus obtained by a theoretical prediction is always larger than the experimental value of a concrete mixture [3]. This means that the difference between the ideal value and the measurement by a self-weight bleeding test is due to the occurrence of

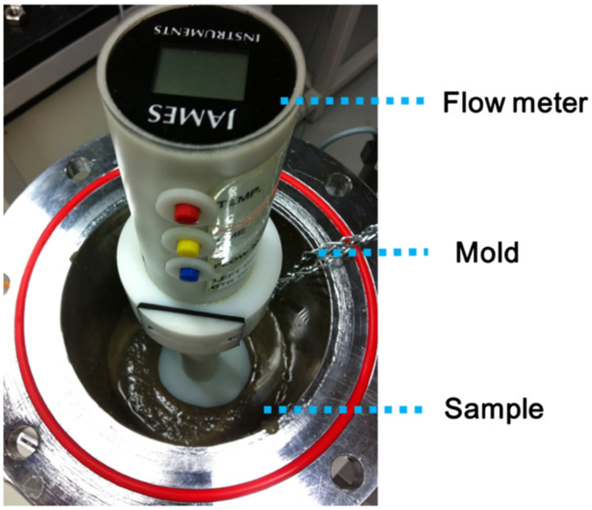

Fig. 1. Test setup for flow meter.