Outline of Laboratory Evaluation Test Method for Pumpability of Concrete Based on Pressurization History

「加圧履歴に基づいたコンクリートの圧送性の室内評価試験方法に関する研究」の概要


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1. Introduction

Concrete pumping is an important technique in modern construction and determines the quality of the constructed results. Therefore, a quantitative method for evaluating the pressure-feeding performance of concrete is desirable. However, there is currently no well-established laboratory test method for this; thus, evaluation instead depends on pressure-feeding tests at actual construction scale, which are costly and labor-intensive.

The aim of this study was to evaluate the pressure-feeding performance of concrete with slumps of 8–21 cm in laboratory tests. To that end, a test apparatus that models the characteristics of concrete flow in piping was designed and fabricated, and the possibility of field application was examined.

2. Development of Test Equipment

As shown in **Fig. 1**, the test apparatus comprises a U-shaped transport pipe (straight and vent pipes connected to each other) with a cylinder connected to each open end (cylinders A and B). Concrete is made to flow reciprocally in the pipe by alternately moving pistons A and B in and out. A pressure gauge attached to the transport pipe measure the pressure history in the pipe [1].

Non-uniformities arise in the concrete as a result of the bleeding phenomenon with repeated pressurization. As pumping progresses, the unevenly distributed aggregate particles become increasingly enmeshed until finally the reciprocating movement of the concrete in the pipe becomes impossible under the force of the pistons. The integral of concrete pressure over time until the pistons are unable to sustain reciprocal motion is defined as the allowable integrated pressure, i.e.,

$$CP_T = \int_0^T P_t dt - P_0 T, \tag{1}$$

where CP_T is the allowable integrated pressure (MPa·min), T is the pressure-feeding time until the pistons stop moving (min), P_t is the pressure at time t (MPa), and P_0 is the initial pressure (MPa).

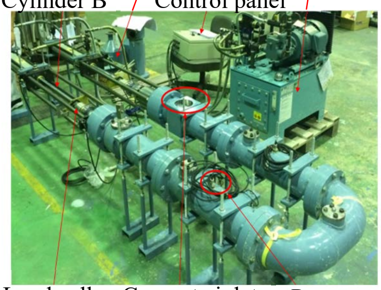

Fig. 1 Test apparatus

3. Evaluation of Maximum Piping Length

Assuming that the pumping pressure is $P_{th}-P_r$ at the base of the pump, zero at the tip of the pipe, and decreases uniformly between these two locations, the integrated pressure on the concrete as it is pumped from the pump base to the pipe tip can be obtained as

$$CP = \frac{1}{2}\times(P_{th}-P_r)\times(L_S\times S)/m_t, \quad (2)$$

where CP is the integrated pressure (MPa·min), m_t is the discharge rate in the concrete pumping plan (m^3/min), L_S is the planned horizontal equivalent pipe length in the pumping plan (m), S is the cross-sectional pipe area (m^2), P_r is the pressure loss to the pump base, and P_{th} is the pump pressure in the pumping plan (MPa).

To prevent blockage during pumping and ensure the quality of concrete at the end of the tube, it is necessary to reduce the integrated pressure acting on the concrete during pumping to below the allowable integrated pressure. Therefore, in this study, the pump pressurization during construction planning is evaluated using

$$CP_T \geq CP = \frac{1}{2}\times(P_{th}-P_r)\times(L_S\times S)/m_t. \quad (3)$$

In fact, as the pumping distance increases, CP increases as well. To determine the distance over which the concrete can be pumped without blockage, it is assumed that the discharge rate m_t is constant, that the horizontal equivalent distance over which the concrete can be pumped without blockage is L_x, and that the pump root pressure at this time is P_x. Then, P_x can be expressed as

$$P_x = (P_{th}-P_r)\div L_S\times L_x, \quad (4)$$

where P_x is the pump root pressure at the pumping distance L_x (MPa) and L_x is the maximum horizontal equivalent distance over which the concrete can be pumped without blockage (m).

Replacing $P_{th}-P_r$ with the variable P_x, replacing L_s with the variable L_x, and rearranging gives the following equation [2]:

$$L_x \leq \sqrt{[\frac{2CP_t\times L_s\times m_t}{(P_{th}-P_r)\times S}]}. \quad (5)$$

The application of this method to the long-distance pumping of lining concrete in shield tunnel construction is presented here as an example. The horizontal equivalent distance L_S of the piping in the pumping plan for this work was 1000 m, P_{th} and P_r of the selected pumps were 9.8 MPa and 2 MPa, respectively, the discharge rate m_t determined in the pump pumping plan was 14.2 m^3/h, and the slump of the concrete to be pumped was 21 cm. Concrete was to be supplied from three mixing plants, and the diameter of the pumping tube was 125 mm.

Table 1 Concrete mix and measurement results

Plant	Slump (mm)	Unit quantities (kg/m^3)					CP_T (MPa)	L_X (m)
		W	C	S	G	AE		
A	210	175	308	682	1179	6.16	114	751
B		175	310	772	1083	6.20	127	793
C		175	316	804	1038	6.32	133	811

Table 1 shows the concrete mix, the allowable integrated concrete pressure measured using the equipment shown in **Fig. 1**, and the horizontal equivalent distance that can be pumped without blockage as estimated using Equation (5). This makes clear that the compressible horizontal equivalent distance for concrete with 21-cm slump from plants A, B, and C estimated from Equation (5) is 750 m, 794 m, and 810 m, respectively.

Cross checking these results against the actual construction work, it was found possible to pump without blockage up to the horizontal equivalent pumping distance of 800 m, but blocking began to occur when the horizontal equivalent pumping distance exceeded 800 m.

4. Conclusion

The conclusions of this study are as follows. After verifying this method against actual concrete pumping work, it is considered that the horizontal equivalent distance that can be pumped without blockage can be evaluated quantitatively using Equation (5) based on laboratory test results. Equation (1) can be used to identify the optimum fine aggregate ratio and unit cement content for pumping performance by evaluation based on the allowable integrated pressure.

The authors intend to further verify and refine this evaluation method in the future.

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