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論 文

[1208] Surface Resistance and Pressure Distribution of High Fluidity Concrete

Craig HANNAH*, Hiromi FUJIWARA*, Yoshihide SHIMOYAMA* and Akito DOUZONO*

1. INTRODUCTION

Although High Fluidity Concrete, HFC, has the ability to fill a form without vibration, there is a limit to its performance. The factors affecting its filling ability include surface resistance and deformational resistance--around corners and reinforcement. To predict the flowing potential of HFC it is necessary to quantify its limiting factors.

In this study, the surface resistance of HFC and the pressure distribution in various form configurations was measured (reinforcement was not included in this study). If the pressure loss attributable to surface resistance is subtracted from the total pressure loss then the remainder is due to deformational resistance. It may be possible to predict the filling potential from the surface resistance and yield value, the latter being a measure of static state deformational resistance.

2. STUDY PARAMETERS

In this study, concretes comprising two series were used. In the one, three coarse aggregate volume fractions, X_v, were tested: 0.25, 0.30 and 0.35. In the other series, three levels of viscosity controlling admixture were used, giving three levels of mortar yield value.

The materials used were: ordinary portland cement; polyacrylic type viscosity controlling admixture, HF; naphthalene sulfonate formaldehyde superplasticizer, SP; crushed sand, FM = 2.71 and crushed coarse aggregate, max. size = 20 mm. The proportions were as in Table 1.

TABLE 1. Mix Proportions

unit wt. (kg/m^3)							% by cement wt.	
Cement	Water	W/C	Sand	S/C	Gravel	X_v	HF	SP
488	203		1024		659	.25	2.0	
455	189	.42	956	2.1	791	.30	1.33, 2.0, 2.67	3.0
423	176		888		923	.35	2.0	

*Central Research Laboratory, Nihon Cement Co., Ltd.

3. SURFACE RESISTANCE

3.1 TEST METHOD

The surface friction of ordinary concrete has previously been measured by pulling a sample of concrete--confined in a box--across the surface of a material [1]; or by placing the concrete and box on a tilting table and measuring the angle at which the concrete begins to slide [2]. In these methods the normal stress varies with the depth of concrete; therefore, the adhesive stress and frictional coefficient can easily be calculated. The first of these methods was tried for HFC but found to be too problematic. Paste and sand leaked under the edge of the box: the first component being a very effective lubricant while the second has the opposite effect. As a result, the large fluctuations in the friction of the box precluded accurate measurement of the very small surface resistance of HFC. A TEFLON seal and grease were ineffective in solving the problem.

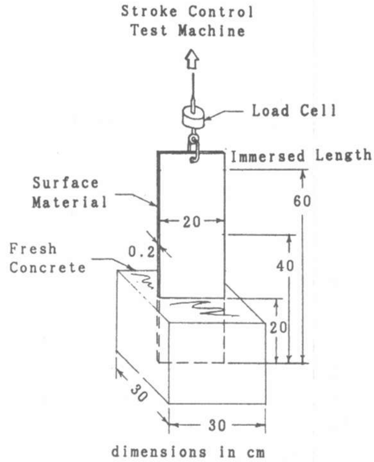

Fig. 1
Surface Resistance Apparatus

The surface resistance was measured by the simple device shown in Fig.1. The plate is pulled up at a constant speed, with the force and displacement continuously recorded. The force increases rapidly, from zero at the beginning of the stroke, and then approaches the maximum value asymptotically, within 2-10 mm of stroke. The maximum force measured is divided by the area of plate immersed in the concrete to give the surface resistance, τ_h. Reduction in buoyant force and plate area, as the plate is pulled up, were accounted for in the calculations. The average pressure normal to the surface is taken as the concrete density, ρ, multiplied by half of the concrete depth, h. Internal stress, resulting in reduced lateral pressure, was removed by gently tapping the concrete container prior to each stroke: pressure measurements confirmed this.

3.2 EXPERIMENTAL RESULTS AND DISCUSSION

Fig.2 shows the surface resistance of HFC on different materials --with various surface treatments on the steel--versus the average normal stress. On a vertical surface, the resistance does not vary with normal stress: indicating that for HFC the surface resistance is flowing in nature and not slipping as it is for ordinary concrete. Release agent did not have an appreciable effect on the surface resistance. As the concrete is flowed into the form the release agent is wiped from high spots (but remains in crevices where it prevents hardening concrete from taking hold). The surface resistance increases with surface roughness and softness. For a smooth, hard surface the resistance is governed largely by a thin boundary layer, paste; but as the roughness and softness increase the fine and then coarse aggregates begin to take hold.

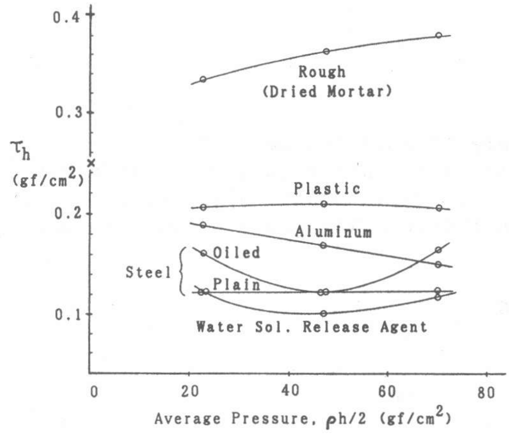

Fig. 2 Surface Resistance of Various Materials

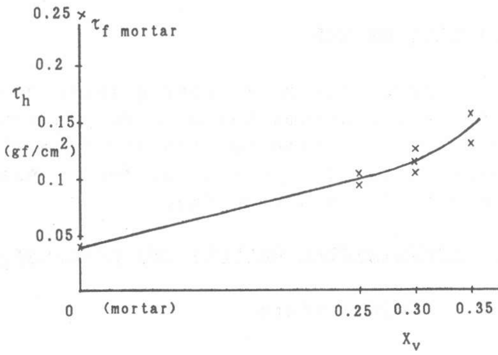

Fig. 3 Surface Resistance vs X_v

Fig.3 shows the relationship between X_v and surface resistance. Initially, resistance increases linearly with X_v; but beyond about 0.30 surface resistance begins to increase more rapidly with increasing X_v.

As is shown in Fig.4, as the HF is increased--with a resulting increase in mortar yield value--the surface resistance does not increase significantly. Aqueous HF polymer solution, as well as being highly viscous, is extremely slippery. The nature of the surface resistance is changing towards slipping for higher HF dosages. Also, there is a thicker attached layer of mortar around aggregate particles with increasing dosages of HF. [3]

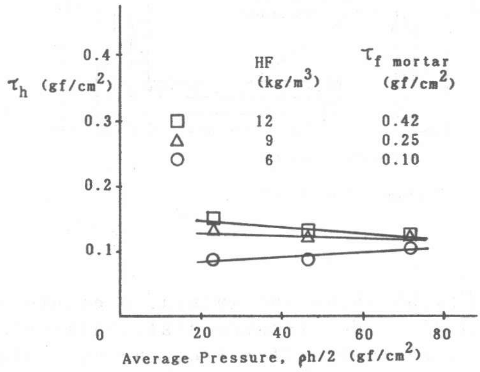

Fig. 4 Surface Resistance with Various HF Dosages

The speed of the plate was varied from 0.125 mm/min to 500 mm/min, Fig.5. Below about 10 mm/min viscosity was not prevalent. At very slow speeds, the interplay of dilatant and thixotropic behaviors [4,5] is seen.

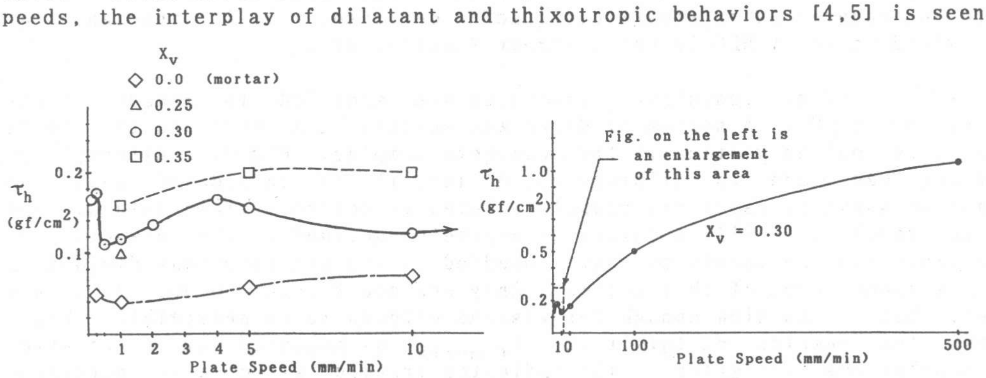

Fig. 5 Variation of Surface Resistance with Plate Speed

4. PRESSURE DISTRIBUTION

4.1 TEST METHOD

Three formwork configurations were tested: "column", "L" and "U". Each was instrumented with 20 miniature electronic pressure transducers. Concrete was lowered into the form with a small bucket, with care being taken not to vibrate the form. When the form was full, the pressure distribution was recorded.

4.2 EXPERIMENTAL RESULTS AND DISCUSSION

4.2.1 "Column"-form

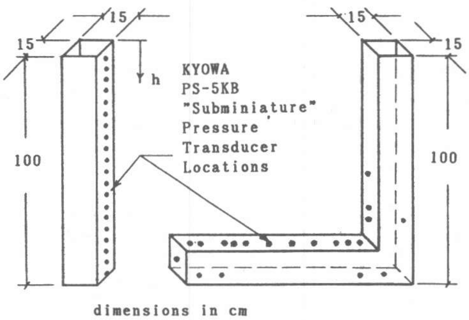

Fig. 6a "Column"-Form & "L"-Form

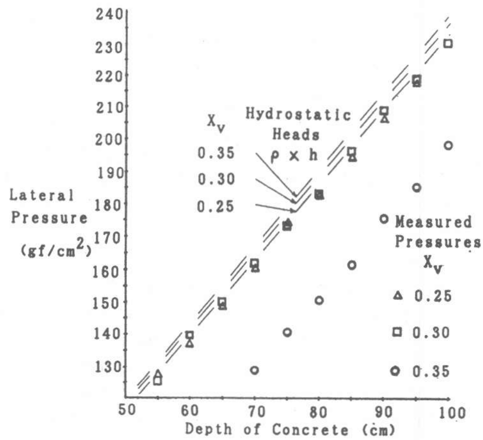

Fig. 6b "Column"-Form Pressure Distribution vs X_v

Fig.6b shows the lateral pressure distributions for X_v of 0.25, 0.30 and 0.35. The pressure distributions are nearly linear, and for X_v less than 0.30 they differ from the hydrostatic head by only a small amount. For X_v between 0.30 and 0.35, the concrete is beginning to deviate from a nearly liquid behavior. Because the interparticle spacing varies linearly with X_v, some researchers have found that for ordinary concrete the yield value is a linear function of X_v [6]. However, HFC differs from ordinary concrete. It contains a long chain polymer whose effect may be more pronounced as interparticle spacing decreases. It is proposed that the yield value of HFC is not a linear function of X_v.

The surface resistance apparatus was modified to measure shear stresses in HFC. A series of discs was mounted on a shaft and the shaft was then pulled vertically from concrete samples, Fig.7. Although no attempt was made to calibrate the device, it is considered that the measured shear stresses are closely related to concrete yield values. The force required to lift a column of concrete--defined by the diameter of the discs and the length of shaft embedded in the concrete--was divided by the surface area of that column. Only one shear rate, 0.001 s^{-1}, was used, but it was slow enough for viscous effects to be negligible. Fig.8 shows the results of this test. $\tau_{f\ mortar}$ as measured by a rotating viscometer was 0.35 gf/cm^2. The indicated trend of yield value increasing as a power function rather than a linear function of X_v is likely.

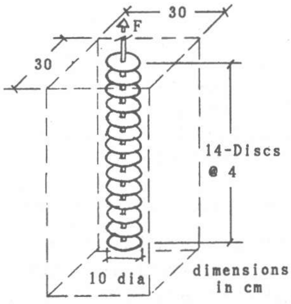

Fig. 7 Shear Stress Device

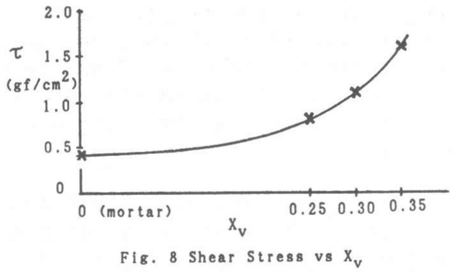

Fig. 8 Shear Stress vs X_v

For the three levels of HF tested there was no discernible change in the pressure distribution in the "column"-form, and only a slight change was observed in the "L"-form. The pressure distributions measured in the "L"-form for the three levels of X_v showed the same trend as those in the "column"-form, and so are not presented here.

4.2.2 "U"-form

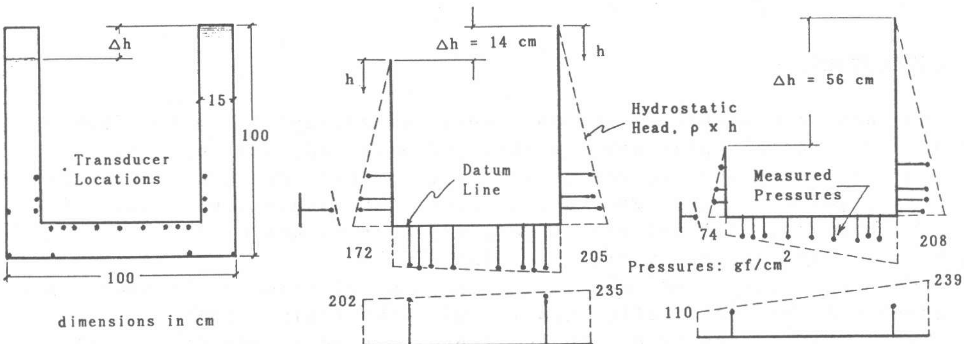

Fig. 9a "U"-Form

Fig. 9b X_v = 0.30

Fig. 9c X_v = 0.35

Fig. 9 Pressure Distributions Measured in the "U"-Form

Fig.9b shows the measured pressure distribution and calculated hydrostatic head for X_v = 0.30. The difference in height between the two legs was 14 cm, equating to a pressure differential of 33 gf/cm^2: 10 gf/cm^2 of which is attributable to surface resistance. If 23 gf/cm^2 is due to deformational resistance at the two corners then this would represent the stress differential, as shown on Mohr's circle, Fig.10, which is twice the yield stress ,τ, as calculated from the Mohr-Coulomb equation:

$$\tau = \tau_f + \sigma_n \times \tan \phi \quad \text{............} \quad (1)$$

where : σ_n is the average pressure.

The angle between the measured pressure distributions and the hydrostatic head can be attributed to interference between the aggregate particles (corresponding to ϕ, the internal friction angle of the Mohr-Coulomb shear failure model). If τ_f is estimated to be 1 gf/cm^2 and tanϕ to be 0.03 (from data similar to Fig.6b), with the pressure taken to be 220 gf/cm^2 at the first corner and 190 gf/cm^2 at the second, then the shear stresses, from eqn.(1), would be 7.6 and 6.7 gf/cm^2. The pressure differential is twice the shear stress, so the total pressure pressure drop for the two corners is twice the sum or 28.6 gf/cm^2. This is in agreement with that measured.

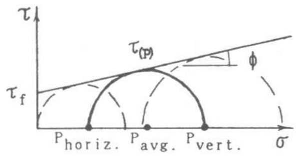

Fig. 10 Mohr-Coulomb Diagram

When X_v was increased to 0.35 the pressure distribution was as shown in Fig.9c. The height difference between the two legs was 56 cm: the pressure differential being equal to 134 gf/cm^2: 11 gf/cm^2 of which is due to surface friction. If τ_f is taken to be 1.6 gf/cm^2 and $\tan\phi$ as 0.09, then the pressure drop at the first corner is estimated to be about 43 gf/cm^2. But the measured value was more than two times this value. It is considered that the discrepancy is due to segregation. There is a "dead-spot" at the outside of the corner where coarse aggregate would tend to accumulate. As subsequent particles add to the accumulating aggregate, some structure would tend to form due to the high degree of angularity of the crushed aggregate. As X_v is increasing locally, τ_f would increase excessively in that region to where unaided flow would become restricted.

5. CONCLUSIONS

1) Surface resistance of HFC on a vertical surface is more flowing in nature than the slipping usually observed with ordinary concrete.
2) Surface resistance increases with X_v, and with surface roughness and softness; while release agent and increased HF dosage have little effect.
3) Further study is required to determine the nature of the relationship between X_v and concrete yield value for HFC.
4) For self-compacted HFC, the maximum difference between lateral pressure and the hydrostatic head is twice the yield stress.
5) For a static condition, the total pressure head loss can be calculated from the surface friction and deformational resistance at corners.
6) HFC is segregation resistant; but in areas of perturbed flow, a local increase in X_v, and thereby τ_f, may severely reduce flowing potential.

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