Experimental study on high fluidity concrete for massive concrete structures

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Summary

In recent years, high-fluidity concrete has greatly contributed to the rationalization of the construction of concrete dam that is a typical massive concrete structure, specifically through its use to execute discharge conduits, their surrounding structures, and other parts reinforced with steel bars. In order to expand the range of its application to the main part of dam bodies, its thermal stress must be limited by minimizing the heat of hydration of cement in concrete. We have, therefore, carried out a study on high-fluidity concrete with the lower unit cement content.

This paper introduces a proposed mix design method for high-fluidity concrete that can be applied when large coarse aggregate is used. Next the characteristics of high-fluidity concrete by this design method with the larger maximum size of the aggregate (MSA = 40 mm) are shown and then, we discuss the properties of high-fluidity concrete with low cement content.

Keywords : High-fluidity concrete, Low cement content, Ratio of water to binding material, Fly ash replacement ratio.

1. Introduction

Large quantities of steel reinforcing bars are installed in complex arrangements around discharge conduits, inspection galleries and temporary discharge channels inside concrete dam bodies. Because a lot of labor and considerable time are required to construct these parts, their execution methods must be extensively improved. Using high-fluidity concrete to construct these parts is an effective method of lowering the quantity of labor and shortening the time required for their construction, and high-fluidity concrete has already been used at many dams. We, the Dam Structure Research Team of the Public Works Research Institute of Japan, have been carrying out research to develop mix design methods of high-fluidity concrete for dams and to apply the high-fluidity concrete to main body of concrete dams.

The specially required performance of high-fluidity concrete for dams is the resistance for thermal cracking. Effective ways to lower the unit cement quantity used in order to reduce its calorific value are increasing the maximum aggregate size and the fly ash replacement ratio. For the above reasons, we have studied the fluidity, self-filling ability, and material segregation resistance of high-fluidity concrete prepared by increasing the maximum aggregate size and raising the fly ash replacement rate. This paper begins by introducing a mix design method of high-fluidity concrete for massive concrete [1]. Next it describes the results of experiments of high-fluidity concrete prepared using aggregate with maximum coarse aggregate size of 40 mm and with its fly ash replacement ratio increased, and discusses the characteristics of high-fluidity concrete with low cement content.

2. Mix Design Procedure

Figure 1 shows the mix design procedure for viscosity-modifying admixture type high-fluidity concrete for dams proposed by the Public Works Research Institute [1]. This procedure is based on the concept that it is necessary to select a mix of mortar with appropriate quality to obtain concrete with a specified fluidity, resistance to material segregation, and self-compacting ability as well as a required strength.

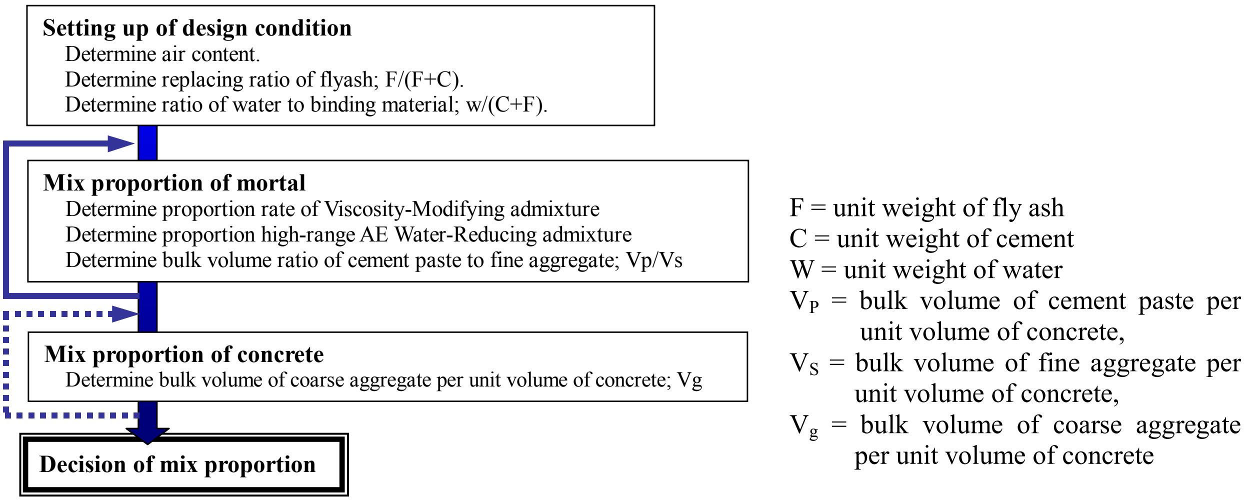

Fig.1 Flow chart of mix design procedure

For the selection of the mortar mix proportion, the fluidity measured with the mortar flow test, is important for evaluation criteria. The mortar flow test was a test based on the Japanese Industrial Standard [2]. But because the test was performed for high-fluidity concrete, the flow value was set assuming that the frequency of the falling motion applied to the flow table was zero. The mortar flow value of 240mm is an criterion for good mortar. The mortar's material segregation resistance was evaluated based on the state of the mortar after a mortar flow test. The state of the distribution of the fine aggregate and cement paste in the mortar was evaluated in five grades [1], and grade 4 or 5 is index for enough segregation resistance. Grade 5 shows "fine aggregate is uniformly distributed to the leading edges and forwarded cement paste is not noted", and grade 4 shows "fine aggregate content of leading edges is slightly below but forwarded cement paste is not noted".

The testing in the fresh state of concrete included a U-shaped filling test to estimate its filling ability and a large-scale slump flow test to estimate its fluidity. The U-shaped filling test based on the standard of Japan Society of Civil Engineers [2]. The U-shaped filling test is for concrete with maximum aggregate size up to 40 mm. For the high-fluidity concrete for massive concrete, the pass through test was done by removing the flow obstruction.

The large-scale slump flow test is for concrete with maximum aggregate size up to 80 mm proposed by the Public Works Research Institute. Figure 2 is a schematic diagram of the large-scale slump flow test.

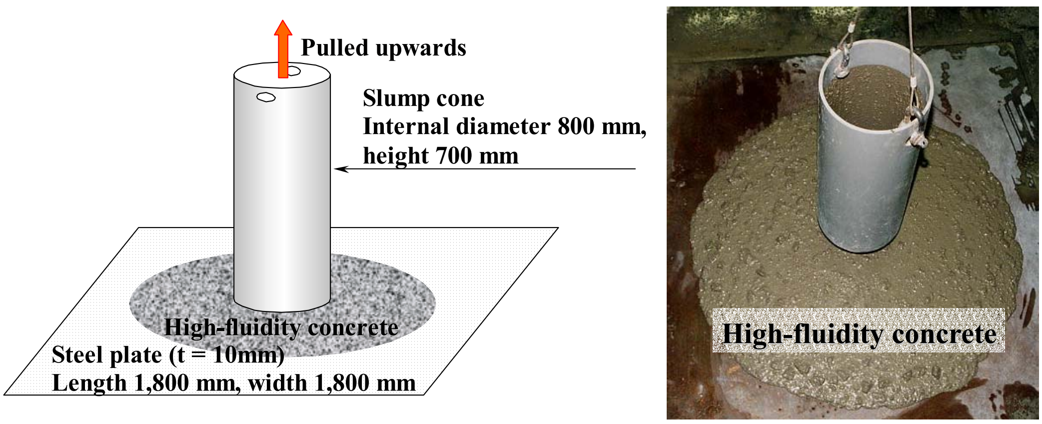

Fig.2 Large-scale slump flow test equipment

The concrete's material segregation resistance was evaluated after the standard slump flow test. The state of the distribution of the mortar and fine aggregate in the concrete was also evaluated in five grades, and grade 4 or 5 [1] is index for enough segregation resistance. Grade 5 shows "coarse aggregate is uniformly distributed to the leading edges", and grade 4 shows "coarse aggregate content is slightly below at the leading edges of flow ".

3. Mix Proportion Conditions to Study Properties of High-Fluidity Concrete

The mix proportion design of high-fluidity concrete was done setting the mix proportions with the ratio of water to binding material W/(C+F) at 50% and 60% respectively, and the fly ash replacement ratio F/(C+F) at 30%, 40%, and 50% respectively. The moderate heat Portland cement, the admixtures were high range AE water reducing admixture (polycarbonate acid type) and viscosity-modifying admixture (water soluble cellulose ether type) were used for this study.

Table 1 shows the mortar mix proportions selected for the above mix. The mortar by these mix proportion have good fluidity and material segregation resistance.

After selecting the mortar mix proportion, concrete mix proportion selection was performed varying the volume of coarse aggregate Vg as shown in Table 1.

Table 1Results of testing to select mortar mix proportion

Water-binding material ratio W/(C+F) (%)	Flyash replacing ratio F/(C+F) (%)	Determined mortar mix proportion			Concrete mix condition for testing	
		High-range AE water reducing admixture (%/(C+F))	Viscosity modifying admixture (%/W)	Bulk volume ratio of cement paste to fine aggregate (Vp/Vs)	Bulk volume of coarse aggregate per unit volume of concrete Vg (l/m^3)	Unit quantity of cement (kg/m^3)
50	30	1.2	0.4	0.9	330-410	243-211
	40	1.2	0.3	0.9	330-410	204-179
	50	1.2	0.4	0.95	330-410	173-151
60	30	1.2	0.4	0.85	330-410	211-184
	40	1.2	0.4	0.85	330-410	178-155
	50	1.2	0.4	0.85	330-410	147-128

4. Fresh Concrete Properties

The relationships of the volume of coarse aggregate Vg with the large-scale slump flow value at a ratio of water to binding material W/(C+F) = 50% and 60% is shown in Figures 3 and 4 respectively. These figures show a tendency for the large-scale slump flow value to decline when the volume of coarse aggregate increases. A rise in the fly ash replacement rate (a decrease in the unit cement content) has little effect on the large-scale slump flow value in the case of W/(C+F) = 60% as compared with W/(C+F) = 50%. This means that the lower the ratio of water to binding material, the greater the effect of fluctuation of the volume of coarse aggregate on the fluidity.

Figure 5 shows the correlation between the large-scale slump flow value and the filling height by U-shaped filling test. When the large slump flow value drops under 130cm, the filling height is rapidly decreases. The large slump value flow of 130cm, therefore, seems to be one of limit indices to identify the good fresh properties of high-fluidity concrete. In this experimental study, the 370 l/m^3 of Vg is considered a critical value for good fluidity, and in that case, concrete also had a good segregation resistance.

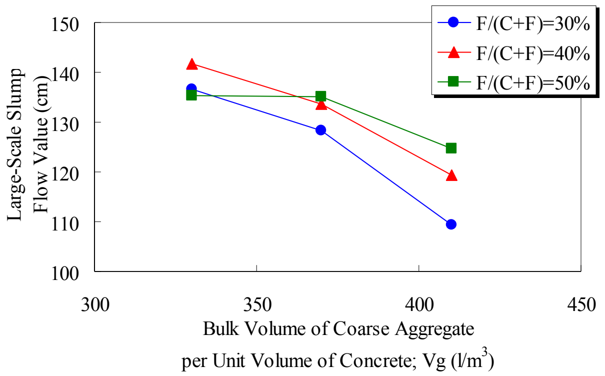

Fig.3 Relationship between volume of coarse aggregate and large-scale slump flow value; W/(C+F) = 50%

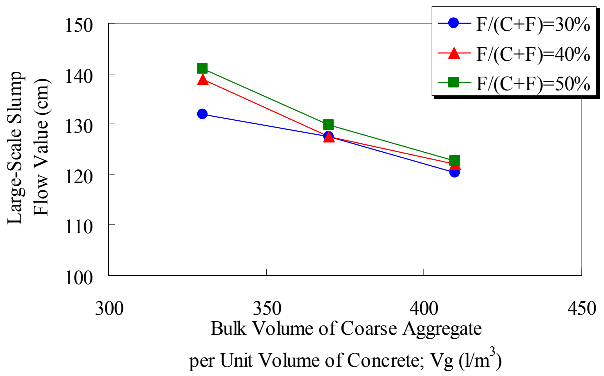

Fig.4 Relationship between volume of coarse aggregate and large-scale slump flow value; W/(C+F) = 60%

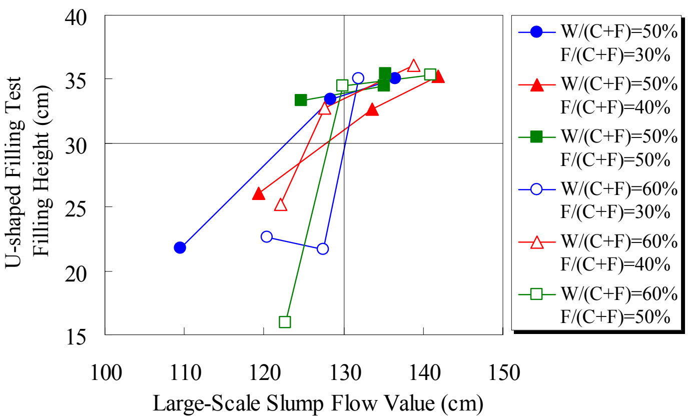

Fig.5 Relationship between large-scale slump flow value and U-shaped filling height

5. Hardened Concrete Properties

5.1. Results of Strength Testing

The relationships of the unit cement content with the compressive strength at a ratio of water to binding material W/(C+F) = 50% and W/(C+F) = 60% are shown in Figures 6 and 7 respectively. The compressive strength is a result of unconfined compressive test at 7-day, 28-day and 91-day ages. Regardless of the ratio of water to binding material W/(C+F), as the fly ash replacement ratio F/(C+F) rises, the strength falls. When the fly ash replacement ratio F/(C+F) is constant, the quantity of coarse aggregate has very little effect on the strength.

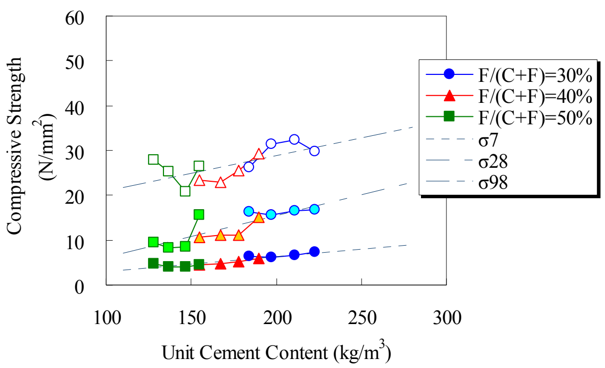

Fig.6 Relationship between unit cement content and compressive strength; W/(C+F) = 50%

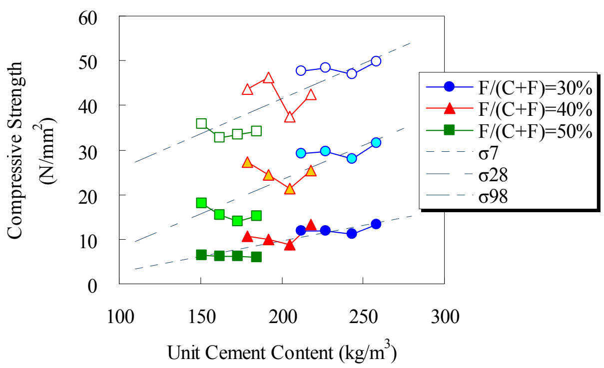

Fig.7 Relationship between unit cement content and compressive strength; W/(C+F) = 60%

5.2. Features of Compressive Strength of High-Fluidity Concrete with Reduced Unit Quantity of Cement

Figure 8 shows the relationship of the unit cement content with the compressive strength at volume of coarse aggregate Vg = 370 l/m^3. A comparison of the results for cases where the ratio of water to binding material is constant shows that, as would be expected, the smaller the ratio of the water to the binding material W/(C+F), the higher the compressive strength at the same unit cement content. It also shows that the effects of the unit cement content on the compressive strength are little greater when the ratio of water to binding material W/(C+F) is small. As the unit cement content approaches 130 kg/m^3, the compressive strength at early age, that is 7-day or 28-day ages, is expected to be constant regardless of the ratio of the water to binding material.

A comparison with the results for cases where the fly ash replacement ratio F/(C+F) is constant shows that the larger the quantity of aggregate, the more conspicuous the effects of the unit cement content on the compressive strength. But the higher the fly ash replacement ratio, the lower the effects of the unit cement content on the compressive strength.

The mix proportion that should be selected varies according to the required fresh state and the required compressive strength. So in a case where the 7-day compressive strength was assumed to be 3.5 N/mm2, it was possible to lower the unit cement content to between 130 and 140 kg/m^3 at a mix proportion with ratio of water to binding material W/(C+F) = 60%, fly ash replacement ratio F/(C+F) = 50%, and volume of coarse aggregate Vg = 370 l/m^3.

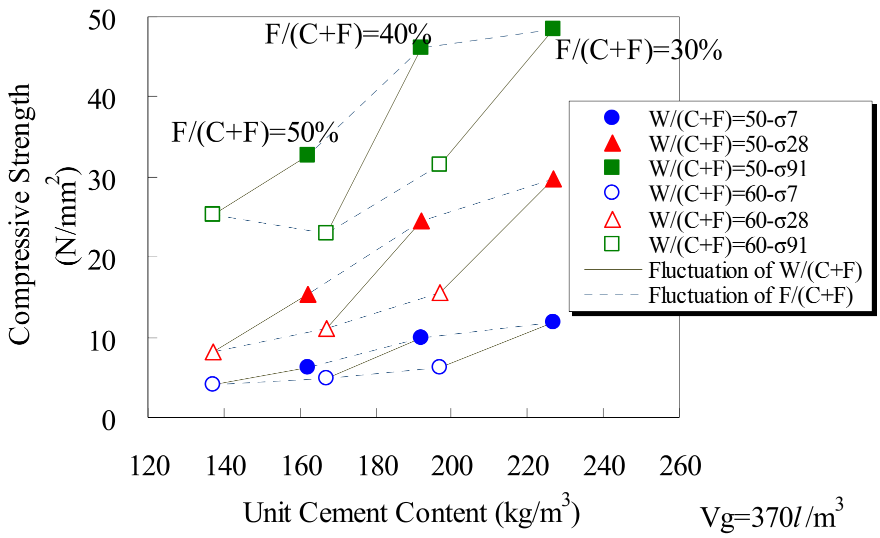

Fig.8 Relationship between unit cement content and compressive strength; Vg = 370 l/m^3

5.3 Freeze-Thaw Test of High-Fluidity Concrete with Reduced Unit Quantity of Cement

Figure 9 shows the result of the freeze and thaw test in the case of Vg=330 l/m^3. This test was done under condition that test specimens were wrap with vinyl sheet and were obstructed to contact to water (sealed freeze-thaw test). This condition simulates the situation inside the dam body. When the W/(C+F) is 50%, the larger the flyash replacement ratio, the higher the degradation speed is. When F/(C+F) is 30%, the greater the W/(C+F) is, the higher the degradation speed is. The compressive strengths at 91-day age and the degradation speed in the case of W/(C+F)=50% and F/(C+F)=50% are about same as those in the case of W/(C+F)=60% and F/(C+F)=30%. But the unit cement content is much smaller in the case of the former case. So, for good durability for the freeze and thaw action, the ratio of water to binding material should not be reduced excessively.

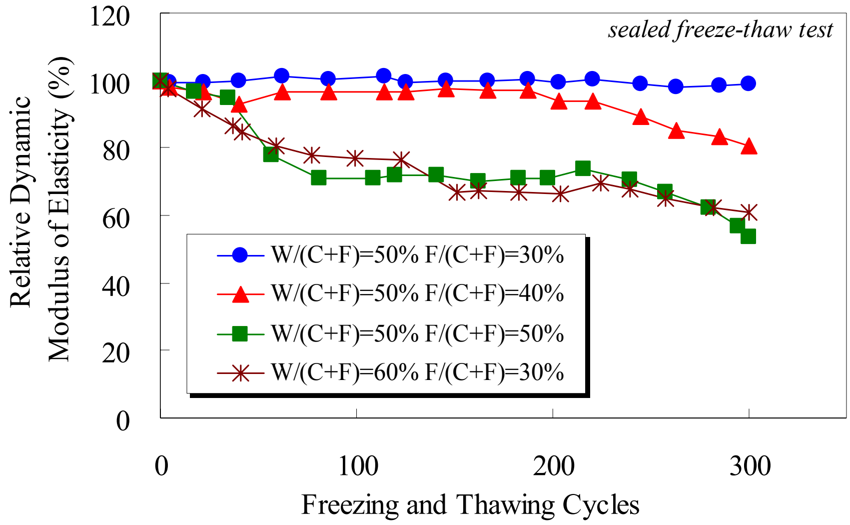

Fig.9 Relative dynamic elastic modulus in freeze-thaw test under condition of blocking off the water contact; Vg = 330 l/m³

6. Conclusions

The results of the research described in this paper are summarized below.

(1) In fresh state, the lower the ratio of water to binding material, the greater the effects on the large-scale slump flow value of the fluctuation of the volume of coarse aggregate.

(2) A factor that has a great effect on strength is the ratio of water to binding material, and the lower the ratio of water to binding material, the more susceptible the strength is to the effects of the fly ash replacement ratio.

(3) A comparison of the strength for cases where the ratio of water to binding material is constant shows that when the ratio of water to binding material is smaller, the effects of cement content on the compression strength is greater.

(4) At a mix proportion with ratio of water to binding material W/(C+F) = 60%, increasing the fly ash replacement ratio F/(C+F) =50% can lower the unit cement content to between 130 and 140 kg/m^3.

(5) For good durability for the freeze and thaw action, the ratio of water to binding material should not be reduced excessively.

References

[1] Hitoshi YOSHIDA, Takashi SASAKI, Munehisa MACHIDA, Experimental Study on High-fluidity Concrete for Dams, 2001 Second International Conference on Engineering Material, JSCE and CSCE, Vol.2, August 2001, pp.55-66

[2] Japan Society of Civil Engineers, Standard Specifications for Concrete Structures-2002, Test Method and Specifications, March 2002

[3] Takashi SASAKI, Toshihide KOBORI, Yoshikazu YAMAGUCHI, Experimental Study on Reduction of Cement Content in High-Fluidity Concrete for Massive Concrete Structure, 2003 International Symposium 'Cerebrating Concrete', Institute of Concrete Technology and ACI International, September 2003, pp.477-487