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Influence of mix proportions on the segregation resistance of flowable concrete

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ABSTRACT

Flowable concrete, when it is well-proportioned, can facilitate construction work and be readily consolidated to form a durable structure in an economical manner. Unlike self-compacting concrete, flowable concrete is made by adding a super-plasticizer to concrete of ordinary mix design. Then, it is very important how to provide sufficient segregation resistance to flowable concrete. This paper discusses the influence of mix proportions of concrete on the segregation resistance of flowable concrete. Through experimental examination and analytical investigation, the following are found: 1) for reducing the bleeding ratio of mortar, it is necessary to appropriately select the volume of fine aggregate in mortar, and 2) flowable concrete made of mortar with little bleeding has high filling performance in formwork.

Keywords. Flowable concrete, Segregation resistance, Bleeding ratio, Funnel flow time, Filling height

1. INTRODUCTION

In recent years, a more economical concreting method has been required to construct a durable concrete structure. Since seismic design is essential in Japan, a large amount of reinforcement is apt to be arranged in concrete structures. It results in congestion of reinforcing bars (Photo 1), and flowable concrete without segregation is necessary for consolidation of concrete.

For solving this problem, the current tendency of concrete technology in Japan is to make ordinary concrete with standard mix proportions more flowable by taking two measures: the addition of a certain amount of a super-plasticizer and the use of a vibrator during placing in situ. This technology is certainly economical but has difficulty in ensuring resistance of concrete to segregation (Photo 2).

In this study, the authors experimentally investigated how the mix proportions of mortar and concrete influence segregation of flowable concrete. The study began with mortar tests to examine how water-cement ratio (W/C) and fine aggregate (sand)-mortar volume ratio (Vs/Vm) influence segregation of mortar. Based on the mortar test results, the experimental tests extended to concrete to examine how the Vs/Vm influences the quality of flowable concrete.

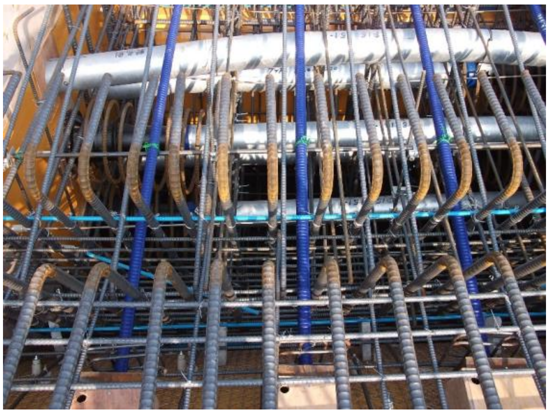


Photo 1. An example of congested reinforcing bars

Photo 2. An example of segregated flowable concrete

Table 1. Factors and levels of mortar experiment

Examination factor	Mortar flow (mm)	Level		Type of admixture
		W/C(%)	Vs/Vm	
Water-cement ratio (W/C)	190±5	40, 45, 50, 55, 60	0.535 (constant)	Super-plasticizer with and without viscosity agent
sand-mortar volume ratio (Vs/Vm)		45, 50, 55	0.485～0.575	Super-plasticizer with viscosity agent

Table 2. Properties of materials

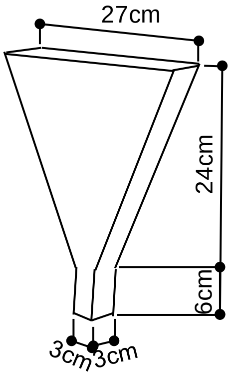
	Sign	Physical property
Cement	C	Ordinary Portland cement, density 3.16g/cm^3
Fine aggregate	S	Land sand, saturated surface-dry particle density 2.63g/cm^3 absorption ratio 1.18%, F.M. 2.49
Admixture	SP	Super-plasticizer (Polycarboxylate)
	VA	Super-plasticizer with viscosity agent (Super-plasticizer : Polycarboxylate, viscosity agent : Glycol)

2. MORTAR TESTS

2.1 Experiment outline

The factors of the experiment are shown in Table 1. The properties of materials are shown in Table 2. The factors include water-cement ratio (W/C = 40~60%) and sand-mortar volume ratio (Vs/Vm=0.485~0.575). The dosage of the chemical admixture (a super-plasticizer or a super-plasticizer containing a viscosity agent) was adjusted to achieve a constant mortar flow of 195±5mm. Note that a preliminary experiment revealed that a mortar flow of 195mm is equivalent to a concrete slump flow of approximately 45cm.

Mortar was mixed according to JIS R 5201. Mortar flow tests, funnel flow time tests as shown in Figure 1 (Okamura, et al, 1993) and bleeding tests (JSCE-F522) were conducted.



1) Mortar sample is filled in a test container.
2) The time to the point when all the sample flows out and light is seen through the lower opening is measured.

Figure 1. Test funnel for funnel flow time of mortar

2.2 Experiment results and discussion

Funnel flow time of mortar. Figure 2 shows the funnel test results. The funnel flow time of mortar increases as the W/C decreases, due to the increased viscosity of cement paste. On the other hand, the funnel flow time decreases as the Vs/Vm increases, presumably because the increased sand volume makes the sand more prone to interlocking. Therefore, it is thought that the funnel flow time of mortar is subject to the influence of both W/C and Vs/Vm.

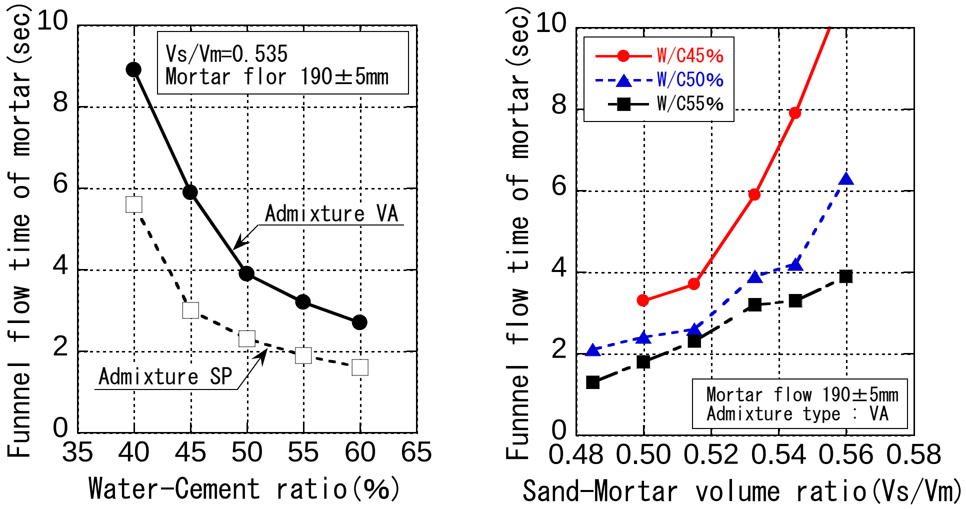


Figure 2. Mortar funnel flow time related to water-cement ratio (W/C) and sand-mortar volume ratio (Vs/Vm)

Bleeding ratio of mortar. Figure 3 shows the bleeding test results. The bleeding ratio of mortar decreases as the W/C decreases and when a super-plasticizer containing a viscosity agent (VA) was used as a chemical admixture. These results demonstrate that the amount of bleeding water can be reduced by improving the viscosity of cement paste.

Though the bleeding ratio decreases with the increase in the Vs/Vm in the beginning, it rapidly increases when the Vs/Vm exceeds 0.54. To achieve a constant mortar flow of 195 mm in these tests, it was necessary to reduce the viscosity of cement paste, in order to increase its mobility. When the sand content was excessively high, the low viscosity of paste presumably caused segregation, resulting in the high bleeding ratio. The Vs/Vm value at which the bleeding ratio turns up is nearly the same for all W/C levels. It is thought that this value depends on the quality (particle-size distribution and shape) of sand.

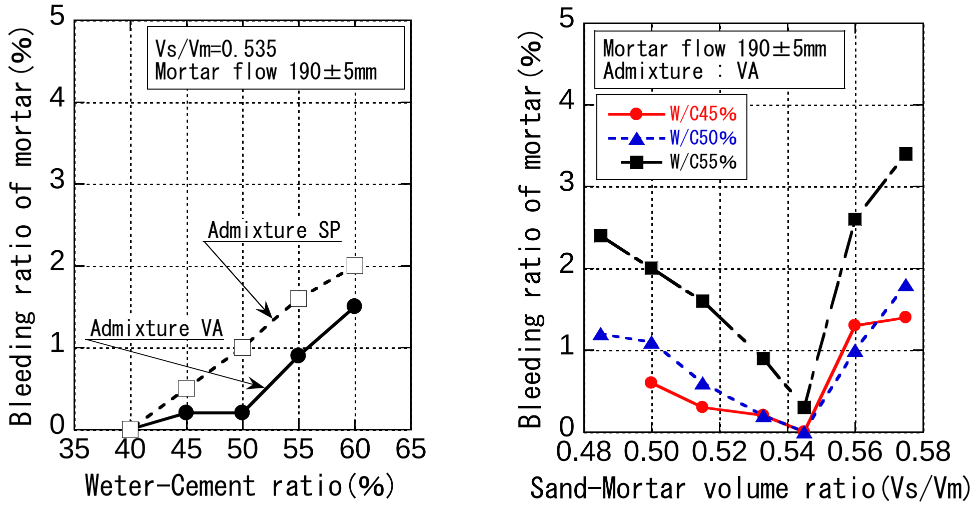


Figure 3. Mortar bleeding ratio related to water-cement ratio (W/C) and sand-mortar volume ratio (Vs/Vm)

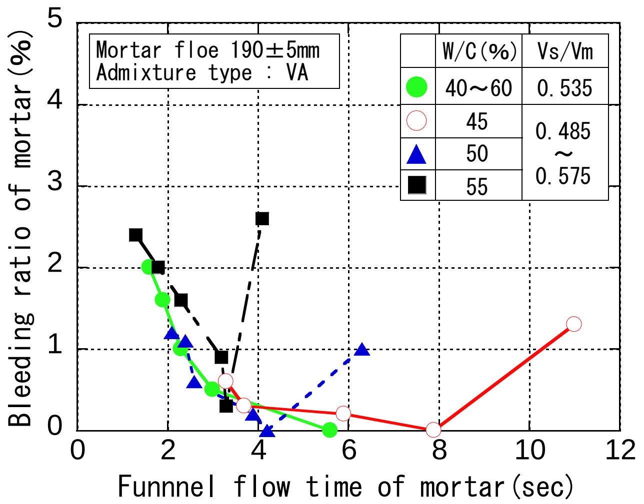


Figure 4. Relationship between funnel flow time and bleeding ratio of mortar

These results are summarized in Figure 4 with respect to the funnel flow time and bleeding ratio. When setting the Vs/Vm constant and changing the W/C, the bleeding ratio decreases with the increase in the funnel flow time. It is found that the bleeding ratio can be reduced by improving the viscosity of cement paste.

On the other hand, when setting the W/C constant and changing the Vs/Vm, the bleeding ratio decreases and then increases as the funnel flow time increases. The range of funnel flow time with little bleeding becomes narrower as the W/C increases. In order to minimize the bleeding ratio of mortar, it is found necessary to set up Vs/Vm appropriately, particularly for mixtures made of paste with low viscosity.

3. FLOWABLE CONCRETE TESTS

3.1 Experiment outline

The authors then investigated the effect of concrete proportioning on the quality of flowable concrete. The mix proportions of concrete are shown in Table 3. The Vs/Vm was selected as the factor of experiment. The coarse aggregate content (unit volume of gravel, Vg) was set constant at 320(L/m^3). The dosage of the admixture (super-plasticizer with viscosity agent) was adjusted, so that the slump flow of concrete would be set constant at 45±2cm.

The materials are the same as those used for the mortar experiment (shown in Table 2). Coarse aggregate was crushed stone (maximum size 20mm, saturated surface-dry density 2.65g/cm^3). A super-plasticizer with a viscosity agent (VA) was used as the chemical admixture. Concrete was produced by the following procedure: First, cement, sand and gravel were put into the mixer and mixed for 10 seconds. Water and the admixture were then added and mixed for 90 seconds. The test items are shown in Table 4.

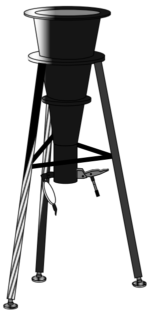
Table 3. Mix proportions of concrete

No.	Slump flow (cm)	Air content (%)	W/C (%)	s/a (%)	Vp (L/m^3)	Vg (L/m^3)	Vs/Vm	Unit weight(kg/m^3) W	C	S	G	admixture VA (C×%)
1	45±2	4.5±1.5	58.3	52.7	323	320	0.53	180	309	939	849	1.1
2				53.3	315		0.54	175	300	959		1.4
3				53.7	307		0.55	170	292	979		1.6
4				54.2	300		0.56	165	283	999		1.8
5			50.0	52.2	331	320	0.51	175	350	919	849	1.0
6				52.8	323		0.53	170	340	940		1.2
7				53.3	314		0.54	165	330	962		1.5
8				53.9	306		0.55	160	320	983		1.9
9				54.4	298		0.56	155	310	1004		2.4

*Vp : unit volume of paste consists of unit volume of air, unit volume of water and unit volume of coment
*Vs : unit volume of fine aggregate (sand)
*Vg : unit volume of coarse aggregate (gravel)
*Vm : unit volume of mortar in concrete is the sum of Vp and Vs

Table 4. Test items and methods

Test item	Test methodology (Conforming standard)
Slump flow	JIS A 1150
Air content	JIS A 1128
Bleeding ratio	JIS A 1123
Funnel flow time of concrete	JSCE-F512 (O type shape) Refer to Figure 5
filling height	JSCE-F511 (U type shape, Restriction Rank 1)



1) Concrete sample is filled in a test container.

2) The time to the point when the sample flows out and light is seen through the lower opening is measured.

Figure 5. Outline of funnel flow time test of concrete

3.2 Experiment results and discussion

Funnel flow time of concrete. The relationship between the Vs/Vm and the funnel flow time of concrete is shown in Figure 6. Similarly to the mortar test results, the funnel flow time of concrete increases as the Vs/Vm increases, presumably because sand particles become more prone to interlocking.

Bleeding ratio of concrete. The relationship between the Vs/Vm and the bleeding ratio of concrete is shown in Figure 7. Similarly to the mortar test results, the bleeding ratio is the minimum when the Vs/Vm is around 0.54. These results suggest that, in order to minimize the bleeding ratio of concrete, it is necessary to use mortar with little bleeding.

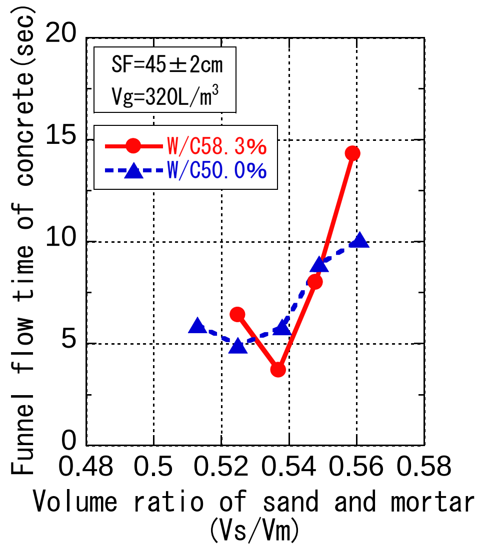


Figure 6. Sand-mortar volume ratio and funnel flow time of concrete

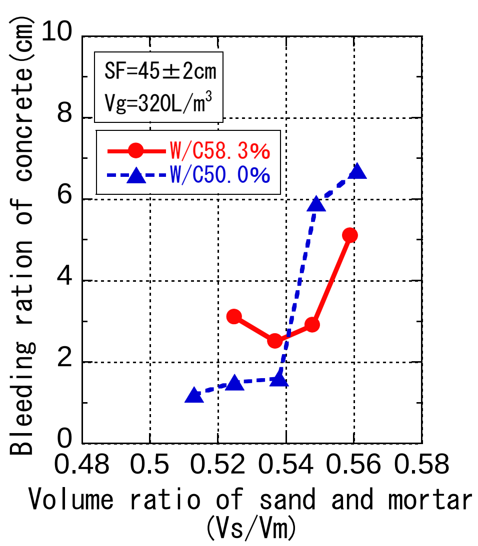


Figure 7. Sand-mortar volume ratio and bleeding ratio of concrete

Performance of Consolidation. The relation between the Vs/Vm and the filling height of concrete (JSCE-F511) is shown in Figure 8. The filling height of concrete is the highest when the Vs/Vm is around 0.54, and abruptly decreases when the Vs/Vm exceeds 0.54. This shows that the performance of consolidation can be improved by using flowable concrete that demonstrates higher segregation resistance and a smaller amount of bleeding water than other concretes of similar slump flow values.

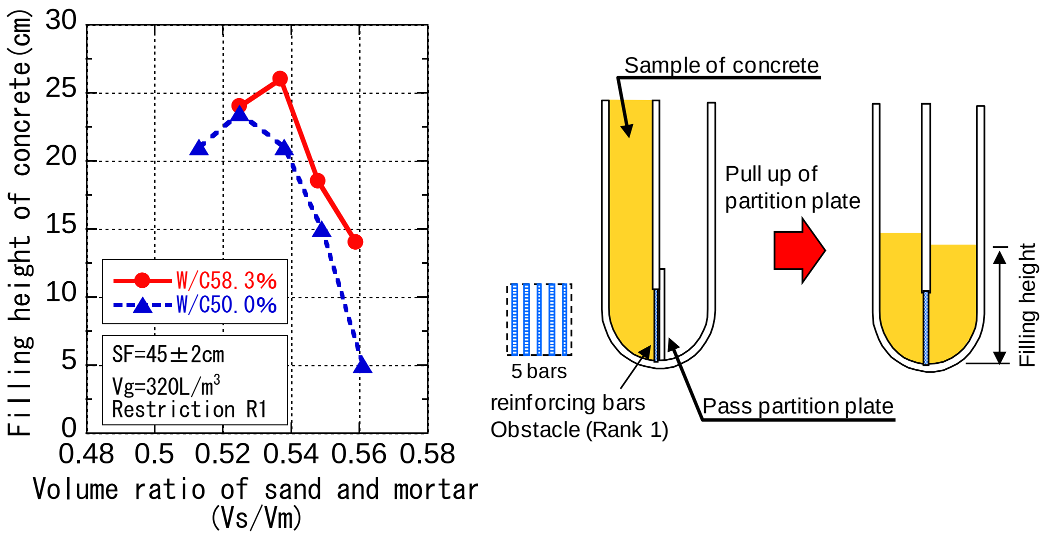


Figure 8. Sand-mortar volume ratio and filling height of concrete

4. CONCLUSIONS

Through experiments and analysis concerning the influence of mix proportions on the quality of flowable concrete, the following were found.

(1) The funnel flow time of mortar is a useful index to the combined effect of both viscosity of cement paste expressed by water-cement ratio (W/C) and interlocking of sand expressed by sand-mortar volume ratio (Vs/Vm).

(2) The bleeding ratio of mortar can serve as an index to ensure flowable concrete without segregation. The Vs/Vm was found to be a key parameter for minimizing the bleeding ratio.

(3) When mortar is proportioned to minimize bleeding, flowable concrete made using such mortar also shows little bleeding and good consolidation performance.

REFERENCES

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