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EVALUATION OF SELF-COMPACTABILITY OF FRESH CONCRETE USING THE FUNNEL TEST

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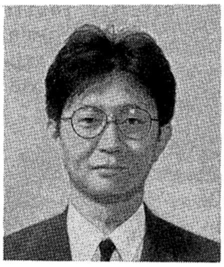
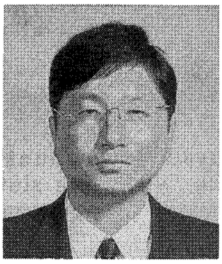
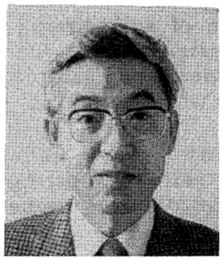

Kazumasa OZAWA　　Noboru SAKATA　　Hajime OKAMURA

The objective of this research is to establish the test method for evaluating self-compactability of fresh concrete, which is inevitable in mix design and manufacturing of self-compacting concrete. A V-type funnel test is proposed for evaluating the flowability through small openings, which is one of the most important properties of self-compacting concrete. It is experimentally verified that self-compactability of fresh concrete placed in the formwork with usual amount of reignforcement can be evaluated by deformability obtained from slump-flow test and flowability through small openings obtained from V-type funnel test.

Keywords; self-compactability, funnel test, fresh concrete

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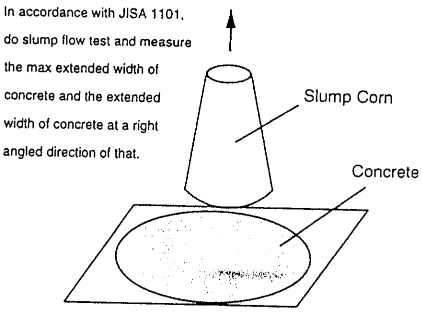
1. INTRODUCTION

The "Self-compacting high performance concrete" developed at the University of Tokyo[1][2] is characterized as follows: At fresh state, it is not only highly deformable but also has sufficient resistance to segregation to allow placement in formwork without a vibrator. At an early age, it generates limited heat due to hydration, and its hardening shrinkage and drying shrinkage are also limited, so few initial defects occur. After hardening, it is highly resistant to such environmental factors as chloride ions and carbon dioxide gas, and has a dense microstructure. Self-compactability without no consolidation at fresh state, which implies the ability to fill all corners of the formwork under its own weight, is one of the most important properties required of high-performance concrete. Whether or not a concrete requires consolidation can be predicted before placing, if this self-compactability can be quantitatively evaluated by simply testing. The evaluation of self-compactability is also crucial in establishing a general method of mix design for self-compacting concrete. This paper reports on an experimental study aimed at developing a test method for estimating how a concrete fills the formwork when placed.

Slump flow testing is widely used for evaluating the flowability of concrete including self-compacting concrete, where the slump is greater than 24cm. It has been reported by a number of researchers, however, that self-compactability cannot be accurately evaluated only through slump flow tests[2]. For this reason, a variety of experiments and theoretical investigations are under way to find an effective method of evaluating the self-compactability of concrete. The authors began by investigating typical methods to see what the results indicate and how the tests perform, thereby evaluating them as methods of determining self-compactability.

1.1 Slump flow test

The slump flow test specified by the Japan Society of Civil Engineers (JSCE) judges the capability of concrete to deform under its own weight against the friction of the surface with no other external restraint present. This is a conventional method widely used for evaluating the flowability of concrete. It is suitable for evaluating the gradient and distance of concrete flow at the time of placing (Fig. 1). It has also been found that slump flow correlates well with the flow gradient and self-compactability of concrete in past experiments in which concrete is placed through a relatively limited number of obstacles (Fig. 2)[3]. This test, however, cannot evaluate a concrete's passage through reinforcing bars because this is determined by deformability under limited external restraint due to the large free surface. Even concretes with the same slump flow can have different behavior when passing through such obstacles as reinforcing bars, depending on their mix proportions[2].



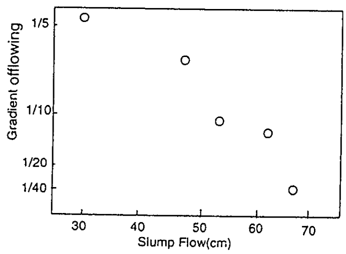
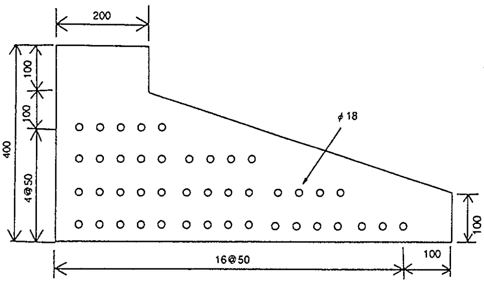


Fig.1 Slump flow test Fig.2 Relation between slump flow and gradient of flowing[3]



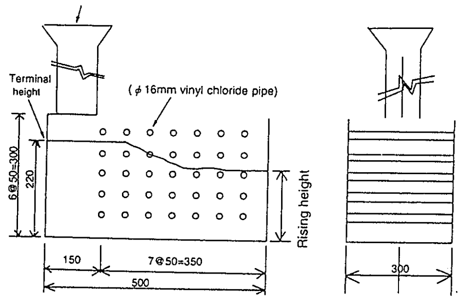


Fig.3 Self-compactability test[4] Fig.4 Self-compactability test[5]
(for development of self-compacting high-performance concrete)

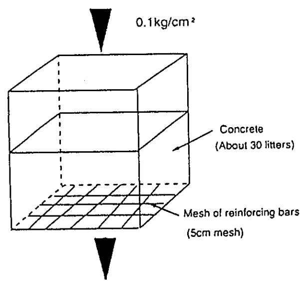


Fig.5
Test of passage through mesh of bars[6]

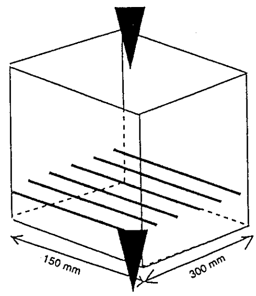


Fig.6
Test of passage through parallel bars

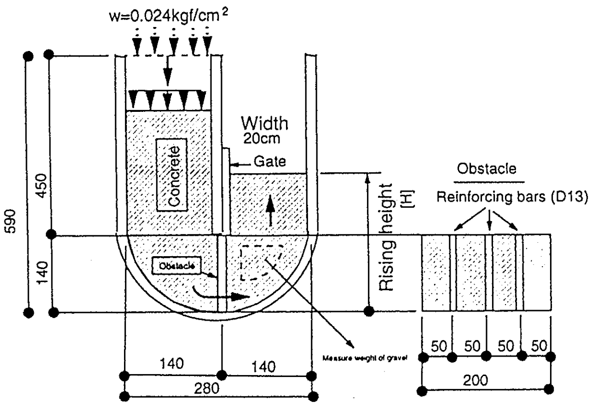


Fig.7 U-type self-compactability test[8]

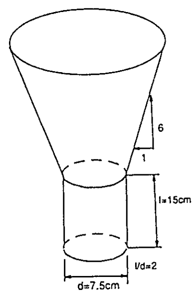


Fig.8 O-funnel test[9]

1.2 Filling test in formwork packed with reinforcing bars

The test shown in Fig.3[4] is one employed during the development stage of self-compacting high-performance concrete. If a concrete is observed to perfectly fill this formwork packed with a lot of reinforcing bars, it is judged to be consolidation-free self-compacting concrete. This method does not give a quantitative evaluation of the self-compactability of concrete.

This test simultaneously evaluates both a concrete's ability to pass through reinforcing bars and its lateral flowability under its own weight. The balance between these two properties changes with the bar spacing and the rate of placement. Since the concrete is placed in small batches, the operators can observe how previously placed concrete moves under pressure from subsequent batches or how it halts and is passed over by subsequently placed concrete. The characteristic of this method is that the behavior of the concrete under conditions approximating actual placement conditions can be observed. The disadvantages are that the pressure acting on the concrete is less than during actual placing and that such tests require a relatively large amount of concrete (approx. 40 liters) and much labor.

An application of this method is shown in Fig.4[5]. This test focuses only on the ability of concrete to pass laterally through reinforcing bars, with the aim of quantitatively evaluating self-compactability in terms of the height of the concrete at the forward edge of the flow.

1.3 Test of passage through small spaces

The test shown in Fig. 5 evaluates the ability of concrete to pass through reinforcing bars under its own weight by dropping it through an arrangement of reinforcing bars[6]. If 100% passes, the degree of self-compactability can be quantitatively evaluated by including the rate of passage in the measurements.

Blocking of concrete between reinforcing bars is caused by insufficient deformability of the mortar in concrete or arching of coarse aggregate particles due to interlocking. Since the balance between these possibilities changes according to the initial height of the concrete, clogging due to insufficient deformability can be limited by increasing the initial height or applying pressure. The amount passing through and the rate of passage depend on the grid spacing and the bar diameter. Self-compactability measurement corresponding to actual construction conditions can therefore be established by appropiately fixing the bar spacing. The disadvantages of this method are that it requires a relatively large amount of concrete (approx. 30 liters) and that measuring the percentage of passing requires much labor.

The test of passage through parallel bars[7] shown in Fig. 6 is an improvement over the test with a steel grid in Fig.5. Given that the actual movement of concrete in a form is mostly two dimensional, parallel bars are acceptable instead of a grid, and the amount of concrete needed is reduced to approximately 20 liters. The results correlate highly with those of the test with a steel grid. It has been experimentally confirmed that parallel bars at a 35 mm spacing correspond closely to a grid with a 50 mm spacing, if bars of the same diameter are used. In this test too, the percentage passed and its rate change depending on the bar spacing and diameter.

The U-type filling test shown in Fig. 7 is another variation of the test shown in Fig. 5.[8] This evaluates self-compactability in terms of the difference in concrete height before and after passing through parallel bars. The difference in pressure across the obstacle is smaller than in the tests shown in Figs. 5 and 6.

The deformation rate of concrete near the obstacle is therefore lower for the same initial height. For this reason, the passability may differ slightly from the tests shown in Figs. 5 and 6, even if the spacing is the same. The advantage of this test is the ease of measurement.

1.4 Funnel test

A funnel with a circular cross-section, as shown in Fig.8, is used in the O-funnel test. This measures some of the properties affecting the self-compactability of concrete by measuring deformation rate where the cross section changes.[9] This is a variation of the J-funnel and P-funnel tests used for the viscosity of fresh paste and mortar, and is probably intended to measure the apparent viscosity of concrete.

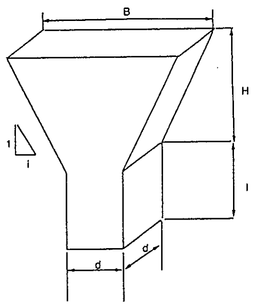


Fig.9 Funnel test equipment

Table 1. Sizes of funnel

No.	i	d	B	H	l
1	0.5	7.5	37.5	30.0	15.0
2	1.0	7.5	52.5	22.5	15.0
3	2.0	7.5	73.5	16.5	15.0
4	1.0	5.0	67.0	31.0	15.0
5	1.0	10.0	43.0	16.5	15.0

2. DEVELOPMENT OF FUNNEL TEST METHODS

The evaluation of a fresh concrete's self-compatibility requires, in addition to deformability measurements represented by the slump flow, evaluation of its ability to pass through obstacles, such as reinforcing bars. As a method of evaluating the self-compactability of concrete, the authors attempted to develop a technique for measuring deformation raste as the concrete flows through a funnel. Whereas conventional funnel tests are used, as mentioned above, to measure the apparent viscosity of paste and grout, the authors intended to use a funnel test as simple means of evaluating the abilily of a concrete to pass through spaces. In other words, the authors assumed that funnel tests measured different relationships between solid particle size and funnel size in the case of concrete when compared with conventional relationships between powder particle size and funnel size.

In developing this new funnel test method we began by trying to grasp the effects of funnel shape on the deformation rate of concrete. We then examined the effects of concrete mix proportion for a fixed funnel shape.

2.1 Effects of funnel shape

Conventional funnels for concrete testing have a circular cross-section through which concrete undergoes a 3-D deformation. In actual formwork, however, concrete deforms two-dimensionally when passing through such obstacles as reinforcing bars. The authors therefore designed the funnel shown in Fig.9 which forces concrete to deform two dimensionally. After filling the funnel with concrete to its top edge the discharge port is opened and the time required for the concrete to flow out (efflux time) measured. The efflux time is defined as the duration between opening the discharge port and when light can be seen through the opening from above. The average velocity is calculated by dividing the volume of concrete by the cross-sectional area of the discharge opening and the efflux time. Tests were conducted using wooden funnels of the five shapes specified in Table 1, with parameters being the funnel slope, i, and the length of a side of the discharge port, d.

The capacity of each funnel was 6 liters. The mix proportions of mortar were fixed to give a mortar flow spread of 260 mm without dropping vibration and an efflux time of 80 sec through a J-funnel. Five different coarse aggregate contents with a maximum size of 20 mm were used to make the concretes of five different mix proportions. The materials used and the mix proportions are given in Appendices 1 and 2. "G/Glim" in the table refers to the ratio of coarse aggregate content by volume relative to the equivalent amount to its solid volume percentage. "S/Slim" refers to the fine aggregate content by volume relative to the equivalent amount to its solid volume percentage. The mixing method is as follws; firstly fine aggregate, powder, water and superolastisizer were mixed for 90 sec. by a pan-type forced mixer with the capacity of 30 litter. Then coarse aggregate and mortar were mixed for 90 sec. by a pug mill forced mixer with the capacity of 50 litter. In Appendix 2, all concretes, excepting the one with the highest coarse aggregate content (G/Glim = 60%) and the mortar, are considered to be self-compacting concrete.

Figure 10 shows that when the discharge port is 7.5 x 7.5 cm, the efflux velocity of all concretes is practically the same and independent of the funnel slope within the range 0.5 to 2.0. However, as the funnel slope becomes steeper, the concrete near the slope tends to be delayed, making it difficult to accurately measure the time it takes for the concrete to flow out. On the other hand, the discharge port size strongly affects the efflux time. As the area of the discharge opening, d^2, increases, the average efflux velocity increases as shown in Fig. 11. It follows that the deformation rate of the mortar and the degree of interference between coarse aggregate particles are affected more by the discharge port size than by friction against the funnel walls.

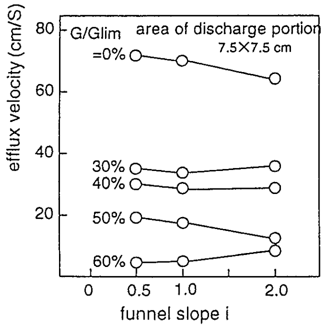


Fig.10 Relation between funnel slope and efflux velocity

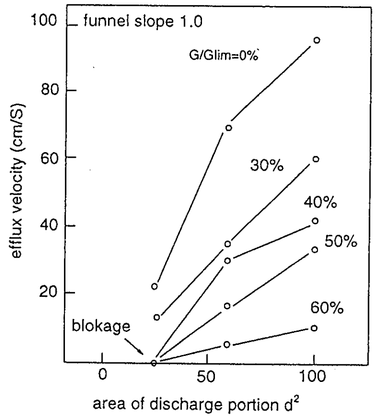


Fig.11 Relation between area of discharge portion and efflux velocity

2.2 Effects of concrete mix proportion

On the basis of the above results on the effects of funnel shape, a funnel test using stainless steel funnels with a slope of 0.5 and a discharge port of size 7.5

cm was studied since it permits easy and quantitative measurements without clogging for a wide range of concrete mixes. In addition, the capacity of the funnel was increased to 10 liters, to reduce measurement error (i = 0.5, d = 7.5 cm, B = 50 cm, H = 42.5 cm, l = 15 cm). We refer to as the "V-funnel test". The proportioning factors that might conceivably affect the average efflux velocity as measured in V-funnel tests are the quality and quantity of mortar and coarse aggregate. The mix proportions of the concretes used in these tests are given in Appendix 3.

Regarding the concretes with constant mortar quality and varying coarse aggregate contents, as G/Glim increased, the slump flow decreased and the efflux velocity through the V-funnel decreased as shown in Fig. 12. This may be because the increase in G/Glim led to a lower mortar content, resulting in reduced slump flow and increased interference among coarse aggregate particles in the funnel.

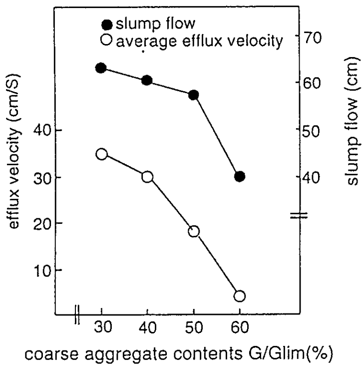


Fig.12 Relation between coarse aggregate content and efflux velocity, slump flow

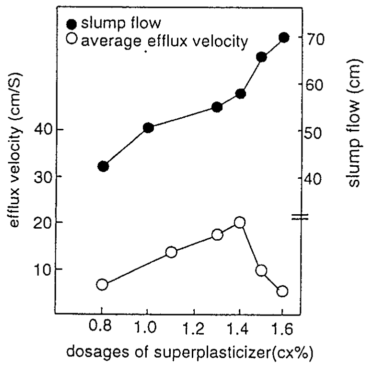


Fig.13 Relation between dosage of SP and efflux velocity, slump flow

Meanwhile, in the case of concretes with fixed coarse aggregate and mortar contents and different dosages of the superplasticizer, the slump flow spread increased as the dosage of the agent increased, as shown in Fig. 13. It was observed, however, that the velocity through the V-funnel peaked at a certain dosage of the superplasticizer. For the concretes used in this test, whereas a slump flow of up to 40 to 60 cm gives an increase in the efflux velocity, a slump flow greater than spread over 60 cm may lead to excessive deformability of the mortar, and thus interference due to contact among coarse aggregate particles may become prevalent resulting in reduced efflux velocity.

The results of both tests are plotted in Fig. 14 with the slump flow on the horizontal axis and the efflux velocity on the vertical axis. This confirms that concretes whose slump flow is adjusted to 60 cm or greater by changing G/Glim have good self-compactability, while those with a slump flow adjusted to 65 cm or greater by changing the dosage of superplasticizer have poor self-compactability. This figure clearly demonstrates that this difference can be evaluated from the efflux velocity in the funnel test.

Figure 15 shows that when the slump flow is adjusted to a constant value of 60 ± 3 cm by changing the dosage of the superplasticizer. The efflux velocity increases as the water-powder ratio increases in the range of the water-powder ratio by volume of 80 to 120%. This behavior becomes more obvious as the coarse aggregate content decreases. Such great changes in velocity relative to changes in water powder ratio are due to the fact that the efflux velocity of a concrete with a lower coarse aggregate content is more sensitive to the properties of the mortar. On the other hand, the efflux velocity of concretes with a high coarse aggregate content exhibit only limited increases as the water-powder ratio increases, because the effects of interference among coarse aggregate particles also increase.

Thus the efflux velocity through a V-funnel increases when the coarse aggregate content is low and/or the deformation rate of the mortar is high. An excessively high deformation rate leads to greater interference among coarse aggregate particles, and can reduce the efflux velocity. Consequently concrete with a relatively high velocity can be considered as having good ability to pass through small spaces. Concretes with the same slump flow can have different velocities through a V-funnel, depending on the mix proportion. In such cases, not only the properties of mortar but also the degree of interference among coarse aggregate particles can be evaluated by measuring the efflux velocity. This can be considered an effective method of evaluating the self-compactability of fresh concrete.

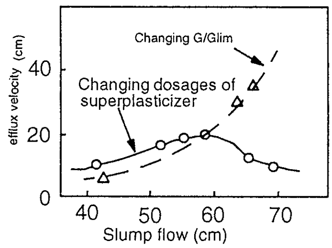


Fig.14 Relation between slump flow and efflux velocity

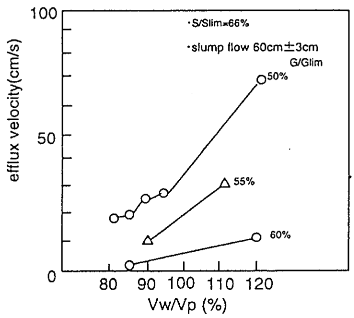


Fig.15 Relation between water to powder ratio by volume and efflux velocity

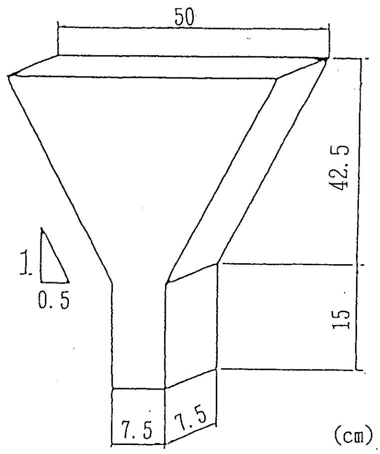


Fig.16 Shape and size of V-type funnel

2.3 Proposal for V-funnel testing

On the basis of the above examination, the authors propose a test using the V-funnel shown in Fig. 16 as a method of evaluating a concrete's ability to pass through small spaces. For a more accurate evaluation of self-compactability, the funnels slope and discharge port size should be changed depending on the portion to be placed. However, a standaed slope and discharge port size were established as 0.5 and 7.5 cm, respectively, in consideration of ease of quantitative measurement and applicability to a wide variety of concretes without blocking; these values are suitable for the general evaluation of self-compactability. The evaluation of test values was carried out on the average of three consecutive tests on samples from the same batch of concrete.

3. EVALUATION OF SELF-COMPACTABILITY BY FUNNEL TESTS

In order to verify the validity of self-compactability evaluations from the slump flow and efflux velocity measured in funnel testing, the self-compactability of concrete should be confirmed by some other means. For this reason, passage tests through parallel bars and filling tests in congested formwork were conducted along with the V-funnel test.

Here the slump flow spread and the efflux velocity nondimensionalized respectively by a slump flow spread of 60 cm and an efflux velocity of 5 seconds, were used. The relative flow area, Af, and relative efflux velocity, R, are expressed as follows;
$Af = (SF/60)^2$, where SF is slump flow value of concrete under evaluation (cm).
$R = 5/V$, where V is efflux velocity of concrete under evaluation (seconds).

3.1 Relationship between V-funnel test and passage test through bars

If a concrete's ability to pass through spaces can be evaluated from the efflux velocity in V-funnel testing, it is necessary to confirm the corresponding spacing in passage tests through parallel bars. Concrete was charged in the container shown in Fig. 6 up to a height of 60 cm. It was then allowed to flow down by opening the bottom, and the efflux time was measured. The results with bar spacings of 81, 56, and 41 mm and a bar diameter of 19 mm were compared with those of the V-funnel tests.

These evaluations were made in terms of relative spacing (see Fig. 17). Relative spacing, L, is expressed as the product of net bar spacing, L_0, and ratio of net bar spacing to distance between bar centers, $L_0/(L_0+\phi)$, thus taking into account the effects of bar diameter. The relative spacings of the 19 mm bars at net spacings of 81, 56, and 41 mm are 65.6, 41.8, and 28.0 mm, respectively.

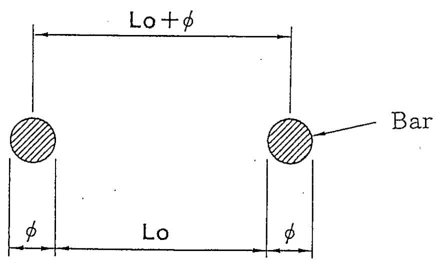
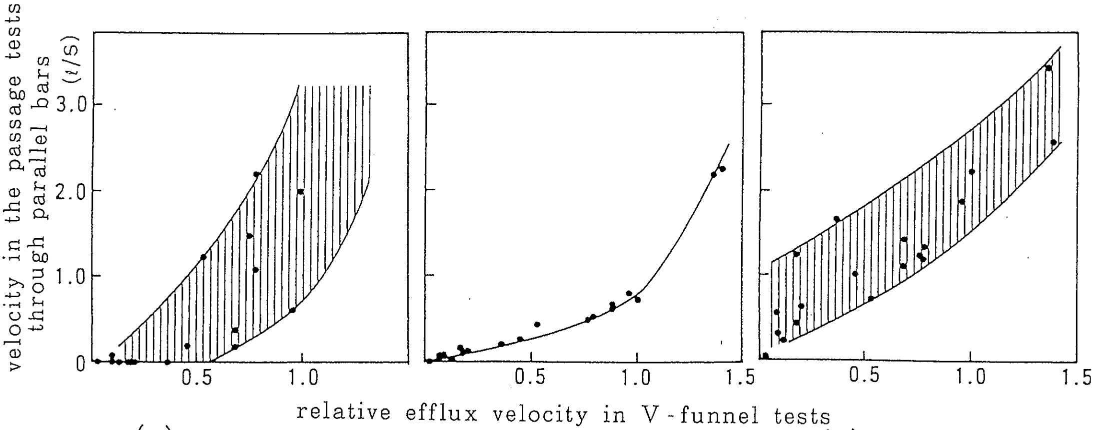


Fig.17 Bars and bar spacing

$L = L_0^2/(L_0 + \phi)$,
where L is relative spacing, L_0 is net bar spacing and ϕ is bar diameter.

The materials used and their physical properties are given in Appendix 1. The established ranges were: Vw/Vp = 72.5 to 180%, G/Glim = 50 to 60%, and S/Slim = 50 to 75% (19 mix proportions), allowing for evaluation tests on a relatively wide range of mix proportions. Tests were conducted on antiwashout underwater concrete as well. The slump flow of the tested concretes ranged from 38.5 to 71.5 cm. The mix proportions of the concretes tested are given in Appendix 4.

The relationships between relative efflux velocity in V-funnel tests and efflux velocity in the passage tests through parallel bars are shown in Fig.18. This figure reveals that the efflux velocity in the passage test increases as the relative efflux velocity in the V-funnel test increases for all relative spacings; 65.6, 41.8, and 28.0 mm. With relative spacings of 65.6 mm and 28.0 mm, the relationships between efflux velocities in the two both tests have a certain spread and cannot be expressed as one-to-one relationships. On the other hand, the relative efflux velocity in the V-funnel test and the passage test has a one-to-one relationship expressible by a singly line when the relative spacing is 41.8 mm. This suggests that the V-funnel test quantitatively evaluates a concrete's ability to pass through a relative spacing of approximately 40 mm in the passage test. It also implies, however, that concretes of the same efflux velocity in a V-funnel can show different efflux velocities through parallel bars with spacings other than this.



(a) L=65.6mm (b) L=41.8mm (c) L=28.0mm

Fig.18 Relation between relative efflux velocity in V-funnel tests and efflux velocity in the passage tests through parallel bars

3.2 Verification by placing tests in congested formwork

The evaluation of concrete by the V-funnel tests was verified by placement in test formwork congested with reinforcing bars. This test evaluates the ability of concrete to pass through the narrow spaces between bars vertically and horizontally and to flow laterally at the same time. Thus it represents somewhat more conjested conditions than found in a general structure.

PVC pipes 18 mm in diameter are arranged in the test equipment at 32 mm centers as shown in Fig. 3. Concrete is placed in the equipment using a cup-shaped 3-liter container at a rate of approximately 0.5 liters/sec., and the flow of concrete during placing and the state of concrete around the bars after placement is observed. The 32 mm spacing and 18 mm bar diameter correspond to a relative spacing of 20.5 mm.

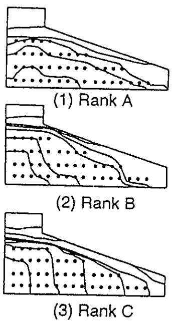
The flow and filling of the concrete is recorded on video tape. The self-compactability of each concrete is rated as one of three levels, A, B, or C, according to the visual evidence. Concretes with the lowest level of selfcompatibilty are rated C. "A" is for the highest level of self-compactability. This rating is made according to the criteria given below. Typical flow patterns for each level are shown in Fig.19.

A: Concrete flows sequentially with the pressure being conveyed to the entire concrete. All corners are filed.

B: Concrete partially flows over the surface of the preceding batch, but the gradient of the flow is small. Little free fall as shown in Fig. 20 is observed at reinforcing bars. Concrete fills almost everywhere without voids, but small voids up to approximately 5 cm^3 may be present.

C: Concrete flows over the surface of the preceding portion. Free fall of concrete as shown in Fig. 20 is observed. Concrete nearly fills the form but voids of approximately 20 cm^3 are observed, especially at the top of the flow.

The 49 cases of concrete mix proportions used included Vw/Vp = 75 to 120%, G/Glim = 40 to 60%, and S/Slim = 55 to 74%. The mix proportions are given in Appendix 5.



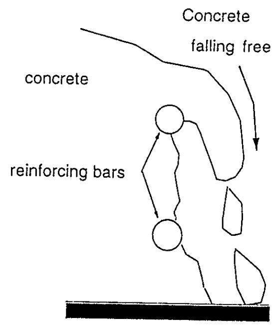


Fig.19 Level of self-compactability in the test through conjested reinforcing bars

Fig.20 Situation of free fall of concrete

The relationships between relative flow area and relative efflux velocity are shown in Fig. 21, along with the ratings of self-compactability in congested formwork. This figure reveals that a large relative flow area and high relative efflux velocity generally lead to a high rating of self-compactability, while a small relative flow area and low relative efflux velocity lead to a low rating. The plots can be roughly divided into three zones according to rating group. Self-compactability cannot be evaluated using either relative flow area or relative efflux velocity alone. In a zone of the same self-compactability, the larger the slump flow the lower the efflux velocity tends to be, and vice versa.

The "A" zone also includes some concretes rated "B", suggesting that the relative flow area and relative efflux velocity are in some cases not sufficient for accurately evaluating self-compactability as represented by filling tests in congested formwork. Since the relative spacing of PVC pipes in these filling tests is as little as 20.5 mm, the passage of concrete through bars of such a small spacing may vary depending on mix proportion, even if the relative efflux velocity is the same in the V-funnel test.

When the maximum size of coarse aggregate is 20 mm, the maximum value obtained in slump flow testing is around 70 cm (relative flow area: 1.36), and the minimum efflux time in the V-funnel test is around 3 sec. (relative efflux velocity: 1.67). The efflux time of water is around 0.2 sec. Concretes with high relative efflux velocities in the V-funnel test include those with low self-compactablity, but concretes with high self-compactabiliy have relatively large slump flow and high relative efflux velociy within the ranges of the limit values.

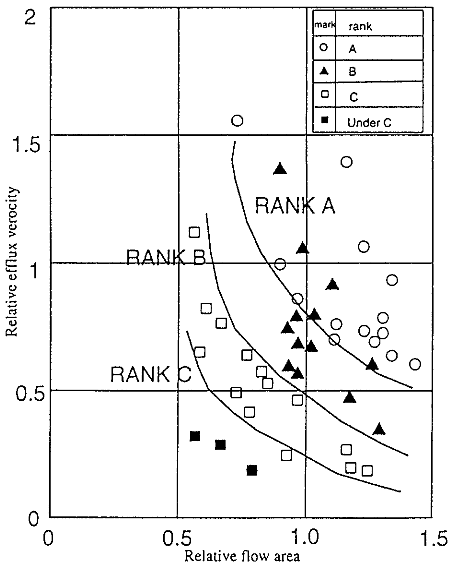


Fig.21 Relation between relative flow area and relative efflux velocity

A comparison is made in Fig. 22 among the results of filling tests through congested bars with three types of concrete whose relative flow area and relative efflux velocity are adjusted to be similar, in the ranges 1.19 to 1.30 and 0.86 to 0.98, respectively. In these concretes, the quality and unit content of fine and coarse aggregates are fixed, while the type of powder, water-powder ratio, and superplasticizer dosage are different. Three types of powder were used: normal portland cement (NP), 95:5 moderate-heat portland cement and limestone powder (MS-100), and 30:30:40 normal portland cement, ground granulated blast-furnace slag, and fly ash. As shown in the figure, the self-compactability of the three types was practically the same. This indicates that the self-compactability of concretes containing aggregates of the same quality and unit content and different types of powder are the same if the slump flow spread and the efflux velocity through a V-funnel are equalized by adjusting the volumetric water-powder ratio and admixture dosage.

The results of filling tests through congested bars were compared regarding concretes with the same relative flow area and relative efflux velocity, but with different coarse aggregate contents. A concrete with a coarse aggregate content, G/Glim, of 50% showed better self-compactability than one with a G/Glim of 55%, revealing that the same relative flow area and relative efflux velocity can lead to different self-compactabilities. A medium-scale flow experiment[7] was conducted on these two concretes as shown in Fig. 23. As seen from the figure, the flow distances and flow gradients differed, resulting in different final filling states due to the different self-compactabilities. As in the filling test through congested bars, the concrete with a G/Glim of 50% showed better self-compactability that with a G/Glim of 55%. On the other hand, the same self-compactability as in the congested formwork test was observed in the middle-scale flow experiment when comparing concretes containing aggregates of the same quality and contents but with different types of powder and volumetric water-powder ratios to maintain the same relative flow area, relative efflux velocity, and self-compactability.

Consequently, it is concluded that the self-compactability of concrete in actual construction as evaluated by the medium-scale flow experiment can be roughly evaluated by the filling test shown in Fig. 3, and that the coarse aggregate content strongly affects the self-compactability. Different coarse aggregate contents can therefore lead to different self-compactabilities, even if the relative flow areas and relative efflux velocities are the same.

It has been shown that tests using a V-funnel with a discharge port 7.5 x 7.5 cm allows evaluation of ability to pass through spaces of 40 mm relative spacing. It is difficult, however, for these tests to evaluate passage through smaller spaces, particularly when the coarse aggregate content is different. To solve this problem, a V-funnel test with a different size of opening may be conducted along with a normal V-funnel test.

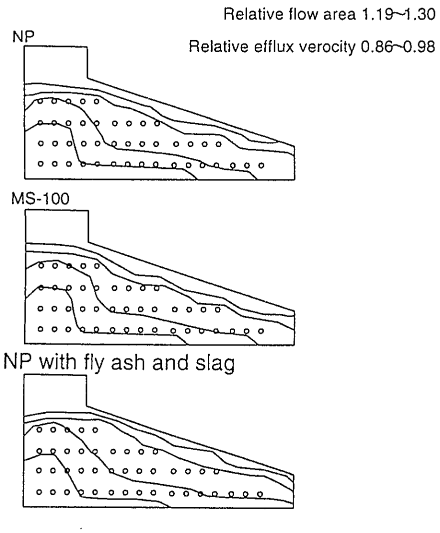


Fig.22 Self-compactability of concrete with different types of powder

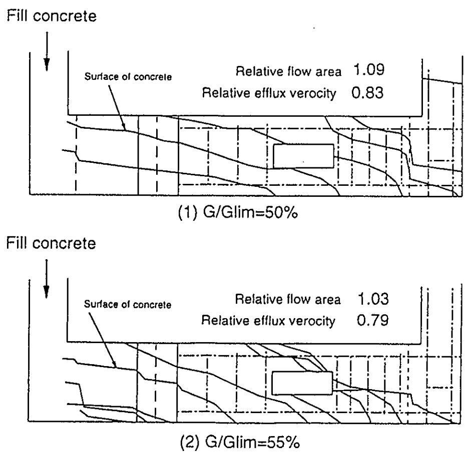


Fig.23 Situation of flow in a medium-scale self-compactability test

4. CONCLUSIONS

(1) The authors propose a funnel test method (V-funnel test) in which concrete undergoes a two-diensional deformation as a way to evaluate a concrete's ability to pass through narrow spaces. The shape and dimensions of the funnel are: slope is 0.5; length of one side of the discharge port is 7.5 cm; and concrete capacity is 10 liters. This device permits easy and quantitative measurement of a wide range of concrete types without blocking. The proposed method is for concrete with a maximum coarse aggregate size of 20 mm.

(2) The efflux velocity of concrete in the V-funnel test is used to evaluate the ability to pass through spaces of a relative spacing of approximately 40 mm. This corresponds to bars 19 mm in diameter with a net spacing of 56 mm. Concrete with good self-compactability has a high efflux velocity through the V-funnel.
(3) When evaluating the deformability of concrete by slump flow and its ability to pass through narrow spaces using the efflux velocity through a V-funnel, it is found that the self-compactability of the concrete can be roughly evaluated by both. It is difficult, however, to accurately evaluate using these methods whether the concrete will adequately fill congested formwork where the relative bar spacing is less than 30 mm. Self-compactability in tight spacing conditions may be evaluated by funnel tests in which the discharge port size is suitably selected.

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Appendix - Table 1 (1) Physical properties of aggregates

	mark	kinds	maximum size of aggregate (mm)	district	specific gravity under saturated surface-dry	absorption (%)	percentage of solid volume (%)	fineness modulus
fine aggregate	S1	river sand	-	River Fuji	2.59	1.91	70	3.29
	S2	river sand	-	River Fuji	2.62	2.2	66.8	3.01
coarse aggregate	G1	crushed rock	20	Oume	2.71	0.6	61	6.69
	G2	crushed rock	20	Kuzuo	2.66	0.4	61.5	6.7

Appendix - Table 1 (2) Physical properties of powders

kinds	mark	manufacturer	specific gravity	specific surface area (cm2/g)
Ordinary portland cement	NP	Sumitomo cement	3.16	3360
Moderate heat portland cement	MP	Nippon cement	3.2	3240
Fly ash	F	Denpatu coaltech	2.2	3280
Blast-furnace slag	S	Nippon Steel chemical	2.91	6020
Limestone powder	L18	Toyo fine chemical	2.68	18000
	L4	Calcede	2.67	4000

MS100 :mixed MP and L18 with 95:5 by volume specific
OBF1:mixed NP and S and F with 30:30:40 by volume specific
OBF2:mixed NP and S and F with 30:30:40 by weight specific
MS60S40:mixed MS100 and S with 60:40 by volume specific
MS60L40:mixed MS100 and L4 with 60:40 by volume specific
MS40S60:mixed MS100 and L4 with 40:60 by volume specific

Appendix - Table 1 (3) Properties of admixtures

kinds	mark	principal ingredient
Superplasticizer	SP1	Modified lignin. Alkylarylsulfonate and Action derivative polymer.specific gravity 1.16-1.20
	SP2	Polycarboxylate ether and cross-linked polymer specific gravity 1.04-1.06
	SP3	Poly-condensed triazine compound specific gravity 1.12-1.14
Viscosity agent	V1	Methyl-cellulose type water-soluble polymer

Appendix - Table 2 Mix proportions of concrete used for development of funnel test 1.

No.	kinds of coarse aggregate	kinds of fine aggregate	kinds of admixture	kinds of powder	Vw/Vp (%)	G/Glim (%)	S/Slim (%)	unit content (kg/m3)				
								water W	powder P	fine aggregate S	coarse aggregate G	admixture
1	G1	S1	SP1	OBF1	85	0	68	230	733	1231	0	10.26
2	G1	S1	SP1	OBF1	85	30	68	188	599	1007	494	8.39
3	G1	S1	SP1	OBF1	85	40	68	174	555	932	659	7.77
4	G1	S1	SP1	OBF1	85	50	68	160	510	857	824	7.14
5	G1	S1	SP1	OBF1	85	60	68	146	466	782	989	6.52

Appendix - Table 3 Mix proportions of concrete used for development of funnel test 2.

No.	kinds of coarse aggregate	kinds of fine aggregate	kinds of admixture	kinds of powder	Vw/Vp (%)	G/Glim (%)	S/Slim (%)	unit content (kg/m3)				
								water W	powder P	fine aggregate S	coarse aggregate G	admixture
1	G1	S1	SP1	OBF1	85	50	68	160	510	857	824	4.08
2	G1	S1	SP1	OBF1	85	50	68	160	510	857	824	5.61
3	G1	S1	SP1	OBF1	85	50	68	160	510	857	824	6.63
4	G1	S1	SP1	OBF1	85	50	68	160	510	857	824	7.14
5	G1	S1	SP1	OBF1	85	50	68	160	510	857	824	7.65
6	G2	S2	SP2	MS100	85	50	66	171	631	799	819	13.25
7	G2	S2	SP2	MS100	90	50	66	176	616	799	819	11.67
8	G2	S2	SP2	MS100	95	50	66	182	603	799	819	10.25
9	G2	S2	SP2	MS100	120	50	66	203	531	799	819	6.9
10	G2	S2	SP2	MS100	90	55	66	168	587	765	899	11.74
11	G2	S2	SP2	MS100	110	55	66	186	531	765	899	7.25
12	G2	S2	SP2	MS100	85	60	66	155	574	728	982	11.48
13	G2	S2	SP2	MS100	120	60	66	184	484	728	982	5.31

Appendix - Table 4 Mix proportions of concrete used for the test of passage through parallel bars

No.	kinds of admiture	kinds of powder	Vw/Vp(%)	G/Glim(%)	S/Slim(%)	Unit content (kg/m3)						slump flow(cm)	V-type funnel time (s)
						water W	powder P	fine aggregate S	coarse aggregate G	admixture	viscosity agent		
1	SP2	MS100	85	60	66	155	573	728	982	10.89	-	54	40.6
2	SP2	MS100	120	60	66	184	483	728	982	5.31	-	45.5	29.8
3	SP2	MS100	82.5	50	66	168	640	799	819	12.8	-	63	9.5
4	SP2	MS100	82.5	55	62	169	642	718	899	12.84	-	71.3	11.2
5	SP2	MS100	110	55	62	195	558	718	899	7.25	-	63.7	5.2
6	SP2	MS100	120	60	66	184	483	728	982	6.28	-	61.3	13.7
7	SP2	MS100	92.5	50	66	179	607	799	819	10.32	0.006	64.5	6.6
8	SP2	MS100	180	60	62	219	380	684	982	19.1	2.5	57.5	276.3
9	SP2	MS100	120	50	66	203	531	799	819	21.24	1.5	60.5	58
10	SP2	OBF2	79.3	50	66	181	600	799	819	9.6	-	61.3	5
11	SP2	OBF2	85	49.6	63.7	195	594	775	811	9.5	-	71	3.7
12	SP2	OBF2	72.5	50.6	68.2	167	606	822	827	9.69	-	38.5	25.2
13	SP2	OBF2	90	50	74	159	464	896	819	5.8	-	50	6.4
14	SP2	OBF2	90	50	66	176	517	799	819	5.69	-	65.5	3.6
15	SP2	OBF2	72.5	50	66	156	570	799	819	7.98	-	64.8	6.4
16	SP2	OBF2	72.5	50	66	156	570	799	819	7.98	-	64	7.3
17	SP2	MS100	110	60	70	168	481	773	982	6.73	-	45.3	28.1
18	SP2	MS100	92.5	50	66	179	607	799	819	10.32	-	53.5	7.2
19	SP3	MS100	160	55	75	179	350	870	899	7	0.538	61.3	56.9

coarse aggregate :G2 fine aggregate :S2

Appendix - Table 5 Mix proportions of concrete used for self - compactability test of passage through conjested reinforcing bars

No.	kinds of coarse aggregate	kinds of fine aggregate	kinds of powder	Vw/Vp (%)	G/Glim (%)	S/Slim (%)	unit content (kg/m3)					slump flow (cm)	V-type funnel time (cm)
							water W	powder P	fine aggregate S	coarse aggregate G	admixture		
1	G1	S1	MS100	95	50	63	182	603	791	827	10.25	68.5	5.1
2	G1	S1	OBF2	85	50	63	172	533	791	827	8	67	5.8
3	G1	S1	NP	103	50	63	190	581	791	827	9.88	65.5	5.8
4	G1	S2	MS100	100	50	66	187	587	809	827	9.98	68.5	7.7
5	G1	S2	MS100	102.5	49.8	65	191	585	792	824	9.95	67.8	8
6	G1	S2	MS100	95.8	50.3	67.1	180	588	815	832	10	51.3	10.1
7	G1	S2	MS100	95.8	50.3	67.1	180	588	815	832	10	58.8	8.1
8	G1	S2	MS100	100	50	66	187	587	802	827	9.98	66.3	6.5
9	G1	S2	MS100	100	50	66	187	587	802	827	9.98	66.8	6.3
10	G1	S2	MS100	93.6	50.4	67.1	176	591	820	833	9.98	55.9	9.3
11	G1	S2	MS100	100	55	62	187	587	721	911	8.8	67.1	13.4
12	G1	S2	MS100	95	55	62	182	603	721	911	9.05	56.3	8.4
13	G1	S2	MS100	95	55	62	182	603	721	911	10.25	61.9	10.6
14	G1	S2	MS100	90	60	58	177	616	645	992	10.65	65.4	27.7
15	G1	S2	MS100	120	60	58	204	532	645	992	10.61	61	26.6
16	G1	S2	MS100	95	40	66	199	657	872	661	9.86	57.1	5
17	G1	S2	MS100	100	50	66	187	587	802	827	9.98	62.8	6.1
18	G2	S2	MS100	95	55	62	182	603	718	899	9.02	52.1	11.3
19	G2	S2	MS100	120	60	70	175	458	773	982	9.16	52	24.6
20	G2	S2	MS100	120	60	70	175	458	773	982	6.87	45.8	19
21	G2	S2	MS100	110	60	70	168	481	773	982	7.7	47.6	20
22	G2	S2	OBF2	85	50	66	171	530	799	819	5.83	64	3.9
23	G2	S2	OBF2	80	50	66	165	546	799	819	6.45	68.5	5.7
24	G2	S2	OBF2	80	50	66	165	546	799	819	5.46	62.5	6
25	G2	S2	MS100	90	50	66	176	616	799	819	11.67	65.8	6.4
26	G2	S2	MS100	85	50	66	171	631	799	819	13.25	71	7.8
27	G2	S2	MS100	120	50	66	203	531	799	819	6.9	63	2.5
28	G2	S2	MS100	110	50	62	195	559	718	819	8.37	64.5	4.5
29	G2	S2	OBF2	95	50	72	168	464	886	819	4.18	46.5	4.4
30	G2	S2	OBF2	90	50	74	159	464	896	819	5.57	49.5	6
31	G2	S2	OBF2	90	50	74	159	464	896	819	6.5	54.5	7.5
32	G2	S2	OBF2	90	50	74	159	464	896	819	7.42	59.8	5.5
33	G2	S2	OBF2	85	50	74	154	477	896	819	8.59	63.8	6.6
34	G2	S2	OBF2	90	50	74	159	464	896	819	6.5	57.8	6.5
35	G2	S2	OBF2	90	50	74	159	464	896	819	5.57	44.5	6.8
36	G2	S2	OBF2	90	50	74	159	464	896	819	5.8	50.8	6.4
37	G2	S2	OBF2	80	50	58	165	546	639	819	6.01	59	10.4
38	G2	S2	OBF2	75	60	55	165	577	608	982	6.35	57	19.1
39	G2	S2	OBF2	80	60	58	165	546	639	982	6.83	63.3	19.8
40	G2	S2	MS100	92.5	55	62	179	608	718	900	10.34	68	6.1
41	G2	S2	MS100	95	55	62	182	603	718	900	9.12	59.3	6.6
42	G2	S2	MS100	92.5	55	62	179	608	718	899	9.73	60.8	6.3
43	G2	S2	MS100	92.5	50	66	179	607	799	819	10.32	62.5	5.8
44	G1	S1	MS100	100	50	65	172	541	819	827	8.12	59.3	6.9
45	G1	S1	MS100	110	50	65	180	515	819	827	7.73	62.8	5.4
46	G1	S1	MS60L40	100	50	65	172	509	819	827	7.64	60	4.9
47	G1	S1	MS60S40	100	50	65	172	525	819	827	7.88	58.5	6.1
48	G1	S1	MS60S40	110	50	65	180	500	819	827	7.5	60.8	6.1
49	G1	S1	MS40L60	100	50	65	172	492	819	827	7.38	56.8	3.8

admixture: SP2