Study on Improvement of Vibration Compaction Performance of Fresh Mortar

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***Abstract*—An influence of the difference in the particle size distribution of fine aggregate in mortar on plastic viscosity and packing properties under shaking was investigated. Furthermore, these effects on bleeding rate and liquefaction of fine aggregate with moisture by vibration were also investigated. As a result, if there is no significant difference in the shape and surface texture of the fine aggregate, the influence of fine aggregate type on the plastic viscosity under the vibration was relatively small, and the influence of particle size distribution on the filling property of mortar was also small. The mortar having a large plastic viscosity under vibration in each particle size distribution has a small bleeding amount. Bleeding also showed a close relationship with the time until liquefaction occurred when vibrating fine aggregate containing water.**

***Index Terms*—Mortar, Size distribution of fine aggregate, vibration, plastic viscosity, filling property, bleeding, liquefaction phenomenon**

I. Introduction

There is an increasing demand for higher quality and longer life cycle time of concrete structures. In order to improve the quality of concrete structures, it is important to evaluate the construction performance of fresh concrete. Construction performance is an index determined from the fluidity of fresh concrete and segregation resistance, new concept that can evaluate fluidity by slump and the segregation resistance by powder amount on blending has been proposed by Japan Society of Civil Engineers [1]. On the other hand, even concrete having the same slump has also been pointed out in recent years that behavior of filling properties under vibration by the internal vibrator, the ability to pass gaps between the reinforcing bars, filling performance within the mold, etc. are different [2]. Also, it has been reported that high-density reinforcing structures may causes various troubles such as poor filling, honeycomb and the deterioration of surface quality of concrete, depending on the method of vibration compaction [3]. Furthermore, it has been reported that bleeding, which is one of indices closely related to the quality of concrete structures, has completely different properties under static conditions and those subjected to vibration work [4]. As described above, in many cases, it is not possible to properly evaluate the construction performance by merely using the amount of powder in slump and blending. For adequate construction and improvement of quality, it is important to evaluate the deformability, fluidity, segregation resistance of fresh concrete in a vibration environment close to the actual construction situation. As a test to evaluate the performance of fresh concrete that can't be evaluated by slumps, tamping test and vibrating box filling test have been proposed [2]. In addition, cases of examining the compaction performance of fresh concrete under vibration have also been reported [5], [6]. However, these methods have problems regarding the relevance to actual construction conditions and the applicability to arbitrary concrete. In addition, the mechanism of filling performance of concrete under vibration and the optimization of vibration compaction method etc. can't be considered sufficiently [7], [8]. On the other hand, rheological properties such as plastic viscosity and yield value are mentioned as fundamental physical properties that govern the fluidity of fresh concrete [9]. In the numerical analysis for evaluating the fluidity of fresh concrete and mortar, the evaluation of these rheological properties is very important [10]-[12]. However, there are many reports on rheological properties under static conditions, but there are few studies on rheological properties under vibration [13], [14].

Therefore, in this study, for the purpose of improving the compaction performance of concrete under vibration, the influence of the difference in the particle size distribution of fine aggregate in mortar on plastic viscosity and filling property under vibration was investigated. Furthermore, these effects on bleeding rate

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and liquefaction of fine aggregate with moisture by vibration were also investigated.

II. Experiment Summary

A. Materials Used and Mix Proportions of Mortar

The materials used and the Mix Proportions of mortar are shown in Table Ⅰ and Table Ⅱ respectively. The particle size distribution and the physical properties of the fine aggregate are shown in Fig.1 and Table Ⅲ respectively. Using PCE based high-performance AE water reducing agent, mortar flow by 15 tamping was adjusted so as to be three kinds of fluidity (160 mm, 180 mm, 200 mm) within the range of 150 mm to 230 mm for each compounding.

TABLE I. Materials Used

Material	Properties	Density (g/cm^3)
Cement	Ordinary Portland cement	3.15
Fine aggregate	Crushed sand from Sakuragawa Ibaraki	2.61
	Natural sand from Oikawa Shizuoka	2.58
Chemical admixture	High-performance AE reducing agent	-

TABLE II. Mix Proportions

Fine aggregate	Size distribution of fine aggregate	W/C (%)	S/C	Ad/C (%)
Crushed sand	Fine	50	2.8	0~2.3
	Middle			
	Coarse			
Natural sand	Fine	50	2.8	0~2.5
	Middle			
	Coarse			

TABLE III. Physical Properties of Fine Aggregate

Fine aggregate	Size distribution of fine aggregate	Water absorption rate (%)	Solid Content (%)
Crushed sand	Fine	1.35	63.1
	Middle		63.3
	Coarse		62.8
Natural sand	Fine	1.95	62.8
	Middle	1.70	65.8
	Coarse	1.20	64.7

B. Mortar Mixing Method

A Hobart type mixer with a maximum capacity of 20 liters was used. After adding cement and fine aggregate, mixing was carried out at low speed (110 rpm) for 30 seconds, immediately thereafter, admixture and water were added and mixed at low speed (110 rpm) for 60 seconds. Finally, mortar was mixed at high speed (230 rpm) for 30 seconds and was discharged.

C. Test Item and Test Method

1) Mortar Flow Test

Influence of various type of materials and change amount of chemical admixture into the primitive performance i.e. the flow value of fresh mortar was investigated (in accordance with JIS A 5201) in this experiment.

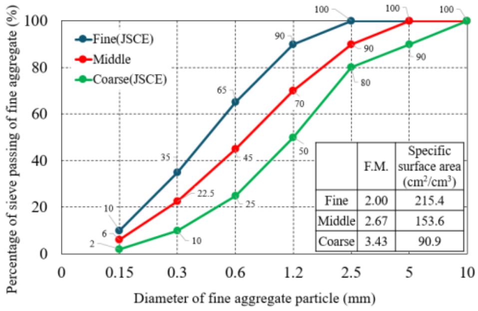

Figure 1: Particle size distribution of Fine aggregate

2) Rheology Test

Fig.2 shows the outline of a viscometer of which was used in this experiment [15]. A steel rod which has 3 thin steel blade subsiding into the fresh mortar by weight of itself and apparent plasticity viscosity can be calculated from the relation between shearing velocity and total shearing stress. The calibration curve for modifying from apparent plasticity viscosity to plasticity viscosity have been verified in previous study [15]. Fig.3 shows behavior of the Bingham fluid. Fresh mortar is being considered as a Bingham fluid. Measuring the shearing velocity is supposed to be conducted 4 to 5 times with different levels of weight for accuracy. In addition, surface of the all blades should be put into the shallow part of fresh mortar before it starts subsiding down to get equivalent effect of blade's surface area. A table vibrator (acceleration 42.0 m/s^2, frequency 40Hz) was used when the measurement under vibration.

3) Mortar Box Filling test

Fig.4 shows schematic of box test apparatus which was used to evaluate the fluidity of fresh mortar under vibration. This refers test apparatus for self-compacting concrete(JSCE-F511) reduced in scale of 1/2. Photo 1 shows that the outline of equipment. Each device was fixed on the table vibrator stiffly.

There are three vertical obstacle bars which have 6mm of diameter between side A and side B at even intervals to prevent mortar flowing before it receives vibration. Fresh mortar was poured into side A divided by 3 layers using tamping rod consequently and settled for a minute into side A. Then shutter was opened fully and the table vibrator was actuated immediately. Time which surface level of mortar reaches to 95 mm and 150 mm from the bottom of device in side B, after the table vibrator was operated, was measured. Time to reach 150mm was defined as 150mm filling time(s) and rising velocity of surface of mortar between 95 to 150mm was calculated and defined as V-pass(mm/s).

4) Mortar Bleeding Test

Measurement of the bleeding amount was carried out in two ways: when no vibration is applied (hereinafter referred to as "no vibration") and when vibration is applied (hereinafter referred to as "vibration"). For the test, natural sand was used and a mortar bleeding vessel with a capacity of 2 L was used. The test was carried out under a constant environment at a temperature of 20 °C. and a humidity of 60%. The mortar sample is divided into two layers, and in the case of no vibration, after thrusting each layer 15 times with a rammer, in the case of vibration, after giving vibration to each layer for 15 seconds with a table vibrator, the surface was finished, afterwards, collection of bleeding water was conducted. The frequency was set to 40 Hz which is the same as that of the feather penetration type viscosity measurement test. The sampling time of bleeding water was set every 10 minutes from 0 to 60 minutes and every 30 minutes after 60 minutes. The test was terminated when the collected volume reached 0 ml twice in succession.

5) Pore Water Pressure Measurement

By measuring the pore water pressure of fine aggregate (Natural Sand) containing water, the time to liquefy at the time of vibration was investigated.

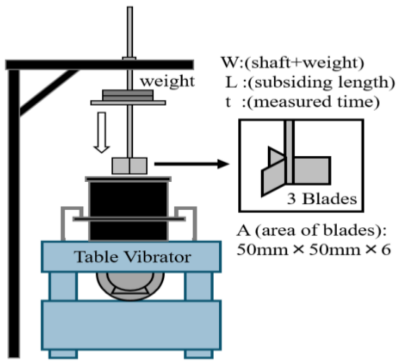

Figure 2. Schematic of Blades Viscometer

Fig. 5 shows the outline of the pore water pressure test apparatus. Natural Sand was used for the test. The cylindrical container was fixed on a table vibrator, and a piezometer was attached to three positions of a position of 200 mm from the bottom of the cylindrical container center (below, upper side), a position of 125 mm (center) and a position of 50 mm (below, below) It was. The sand was packed in two layers, the table vibrator was operated at 40 Hz, vibration was applied to each layer for 15 seconds, and it was compacted. The compaction height was 250 mm from the bottom of the cylindrical container. Thereafter, a certain amount of water was placed in the compacted fine aggregate, and the pore water pressure was adjusted to 0 point, then the table vibrator was operated, and the pore water pressure was measured.

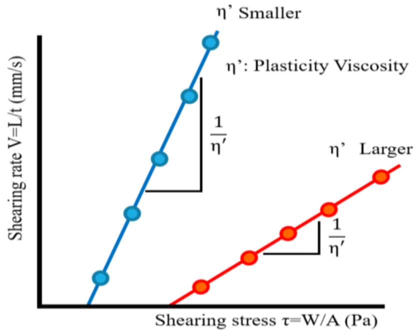

Figure 3. Rheological Property of the Bingham Fluid

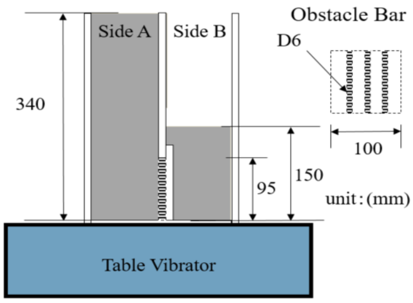

Figure 4. Schematic of apparatus for Mortar Box filling test

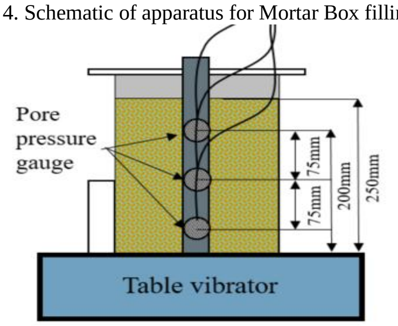

Figure 5. Outline of pore water pressure test apparatus

III. Results And Discussion

A. Relationship between Type and Particle Size Distribution of Fine Aggregate and Excavating Plastic Viscosity.

Fig. 6 and Fig. 7 show relationship between the 15-shot flow of crushed sand and Natural Sand and the plastic viscosity at the time of vibration. It has been reported that if the type of fine aggregate, water absorption rate, shape, etc. are different, the workability will be affected [16]. However, as shown in Fig.6 and Fig. 7, even if the type and the water absorption ratio of the fine aggregate are different, the influence on the plastic viscosity at the time of vibration in the same particle size distribution tends to be small. Therefore, as shown in Fig. 8, the particle sizes of crushed sand and Natural Sand of 1.2 mm, 0.6 mm, 0.15 mm or less were observed with a microscope. As a result, even when the type and the particle size of the fine aggregate differed, I could hardly see any difference. The solid content of Crushed sand(1.2 mm: 55.7%, 0.6 mm: 54.9%, 0.15 mm or less: 55.6%) and the solid content of Natural sand (1.2 mm: 57.2%, 0.6 mm: 56.5%, 0.15 mm or less: 56.9 %) Also showed no significant difference. In other words, if the shape and surface properties are similar, it can be said that there is little influence on the plastic viscosity at the time of vibration. Since the results may be different if fine aggregates with different shapes and surface textures are used, these points will be examined in the future.

B. Filling Properties and Plastic Viscosity under Vibration

Fig. 9 shows the relationship between the plastic viscosity at the time of vibration and 150 mm reaching time. From Fig.9 as can be seen from the particle size distribution, if the plastic viscosity at the time of vibration increases, the filling time of 150 mm will be delayed. Also, irrespective of the particle size distribution, as long as the plastic viscosity at the time of vibration increases, the filling time of 150 mm is delayed. Specific surface area has a large specific surface area and restrains much of the mixing water, so the plastic viscosity becomes large and the filling time of 150 mm is delayed. That is, it is considered that the filling property decreases.

C. Bleeding and Plasticity Viscosity under Vibration

Figure 10 shows the relationship between the amount of bleeding with vibration and the plastic viscosity at the time of vibration. Although it tends to be gathered according to the particle size distribution, as a whole, it was confirmed that as the bleeding amount was increased, the plastic viscosity at the time of vibration became smaller in the order of fine, medium and coarse. Even in the case of no vibration, the same result was obtained. The details with large plastic viscosity are considered to have a small bleeding amount because the specific surface area is large and it is easy to constrain the free water. From these results, it was found that the bleeding amount tends to be small in the mortar having large plastic viscosity at the time of vibration in each particle size distribution.

D. Bleeding and Filling of Mortar

Fig. 11 shows the relationship between the bleeding amount with vibration and the filling time of 150 mm. The item with the smallest amount of bleeding required the longest time to reach 150 mm. From Fig. 11 irrespective of the particle size distribution, when the bleeding amount exceeds about 0.1 cm^3/cm^2, 150 mm filling time tends to be faster, and one correlation is seen throughout. Even in the case of no vibration, the same result was obtained.

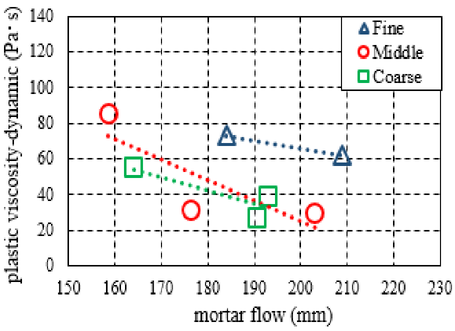

Figure 6. Flow vs viscosity-dynamic (Crushed sand)

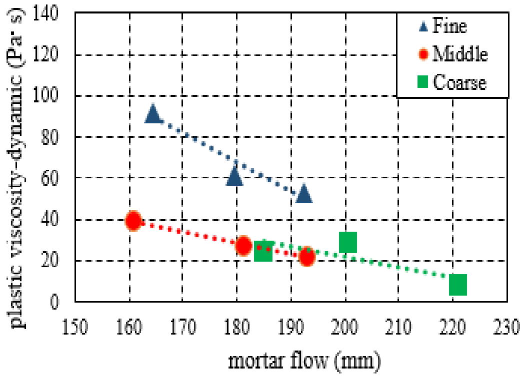

Figure 7. Flow vs viscosity-dynamic (Natural sand)

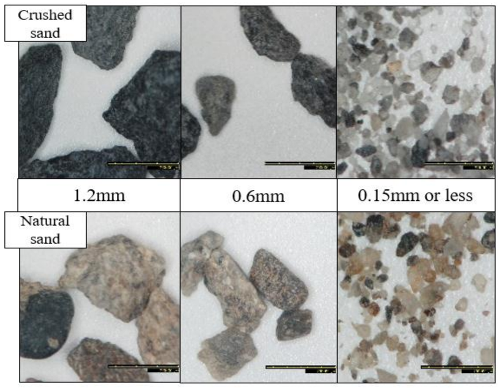

Figure 8. Photo by grain size of Crushed sand and Natural Sand

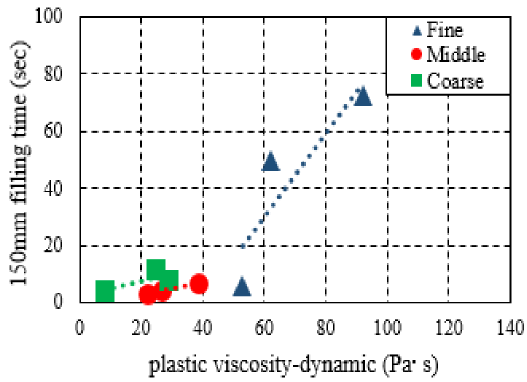

Figure 9. Viscosity-dynamic vs 150mm filling time (Natural Sand)

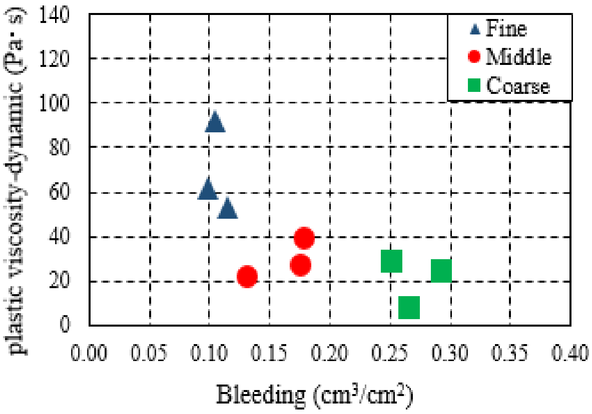

Figure 10. Bleeding vs viscosity-dynamic (Natural Sand)

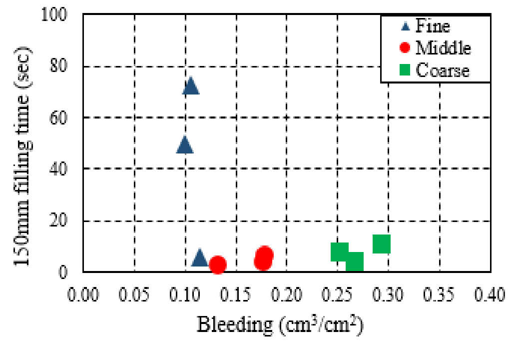

Figure 11. Bleeding vs 150mm filling time (Natural Sand)

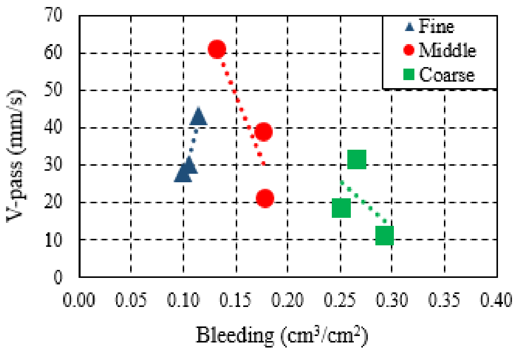

Figure 12. Bleeding vs V-pass (Natural Sand)

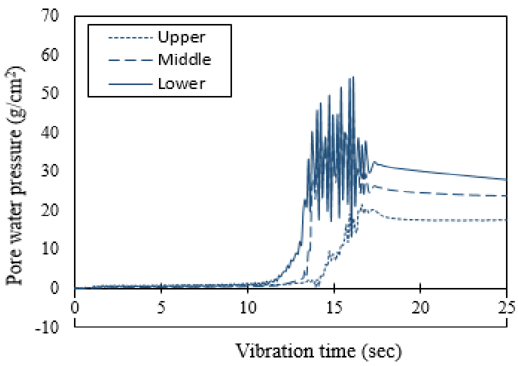

Figure 13.Vibration time vs Pore water pressure (Fine-Natural Sand)

As shown in Fig.10 and Fig. 11, when the fine aggregate has a particle size distribution close to the middle grain, the plastic viscosity at the time of vibration is about 50 Pa ·s or less, and the bleeding amount is about 0.1 to 0.2 cm^3/cm^2. There was a tendency that filling property was good, but the elucidation of the mechanism is to be solved in the future.

Fig. 12 shows the relationship between the bleeding amount with vibration and V-pass. The smaller the bleeding amount, the more the V-pass tends to be faster for each particle size distribution, but there is no correlation like the filling time of 150 mm as seen throughout.

E. Bleeding and Liquefaction

Fig. 13 to Fig. 15 shows the relationship between vibration time and pore water pressure. In this experiment, attention was paid to the time from the start of application of vibration to the occurrence of liquefaction phenomenon.

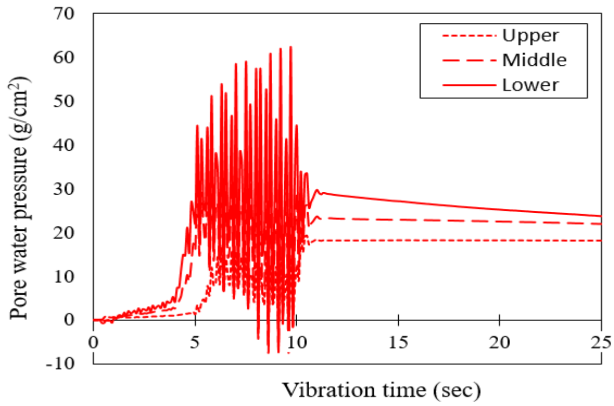

Figure 14. Vibration time vs Pore water pressure (Middle-Natural Sand)

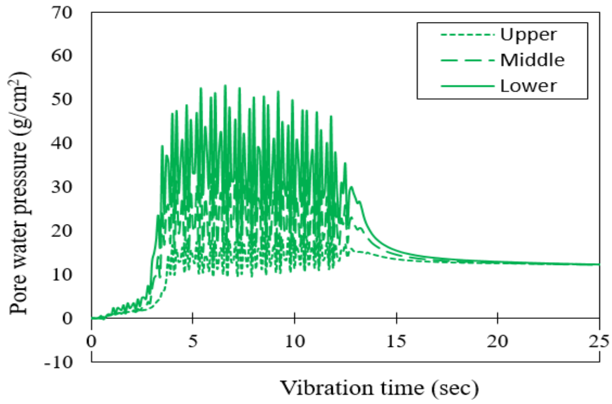

Figure 15. Vibration time vs Pore water pressure (Coarse-Natural Sand)

As for the details, pore water pressure begins to rise in about 12 to 14 seconds, and occurrence of liquefaction can be confirmed. In the middle eyes, occurrence of liquefaction can be confirmed in about 5 seconds after the start of vibration. The occurrence of liquefaction can be confirmed in about 2 seconds to 3 seconds after the start of vibration.

Here, the details are considered to have taken a long time to liquefy because the specific surface area is large, and the amount of water constrained by the fine aggregate, so-called constrained water, increases. On the other hand, since coarse particles have a small specific surface area, restricted water is reduced and free water is increased. Therefore, it is considered that the time until liquefaction occurs is earlier.

From the above, it is found that the time until liquefaction occurs when the fine aggregate containing water is vibrated greatly affects the difference in bleeding amount at the earlier stage in each particle size distribution It was.

IV. Conclusion

As a result of experiments on the relationship between the type and particle size distribution of fine aggregate in mortar on the plastic viscosity under vibration and the filling property and the relationship between bleeding amount and liquefaction phenomenon, I found out.

1) The reason that the difference in the type of fine aggregate had less influence on the plastic viscosity

under vibration was thought to be because the crushed sand and Natural Sand used this time had similar particle shapes and surface properties.

2) Regardless of the difference in particle size distribution, the mortar having a large plastic viscosity under vibration tends to have a small bleeding amount.

3) When the particle size distribution of the fine aggregate is close to middle grain, the plastic viscosity under vibration was about 50 Pa・s or less, and the bleeding was about 0.1 to 0.2 cm^3/cm^2 and the filling property was also favorable.

4) From the relationship between the bleeding and the filling time of 150 mm, irrespective of the particle size distribution, when the bleeding exceeds about 0.1 cm^3/cm^2, the filling time of 150 mm becomes faster.

5) Bleeding shows that it is closely related to the time until liquefaction occurs when vibrating fine aggregate containing water.

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REFERENCES

[1] Japan Society of Civil Engineers: Formulation Specification for Concrete Established in 2012 [Construction Edition], 2012
[2] Civil Engineering Society: Concrete Technology Series 102, Inspection and Inspection System for Concrete Construction Performance Report Subcommittee Second Phase Committee Report, 2013.11
[3] K. Hayakawa, Y. Kato: Experimental Study on Filling Behavior and Quality Fluctuation of Fogging Concrete by Vibration Compaction, Concrete Engineering Annual Papers Collection, Vol. 32, No. 1, pp. 1325 - 1330, 2010
[4] S. Date, Y. Ito, S. Hasegawa, Y. Tsuji, "Effects of partitioning and mixing on freshness under mortar vibration," *Concrete Engineering Annual Proceedings*, vol. 28, no. 1, pp. 1091-1096, 2006.6
[5] T. Nishikawa, C. Hashimoto, Y. Koji, H. Mizuguchi, "Development of a consistency evaluation test method for fresh concrete using a vibrating apparatus," *Annual Concrete Engineering Work*, vol. 22, no. 2, pp.397-401, 2000.7
[6] Liangshun, K. Kokufu, K. Uji, A. Ueno, "Study on the compaction property test method of fresh concrete," *Papers of the Japan Society of Civil Engineers E*, vol. 62 no. 2, pp. 416-427, 2006.6
[7] T. Saito, M. Ogaki, Y. Fujikura, S. Date, "Basic study on rheological properties and filling performance of mortar under different frequency vibration," *Concrete Engineering Annual Papers Collection*, vol. 38, no. 1, pp.1353-1358, 2016
[8] P. F. G Banfill, etc, "Rheology and vibration of fresh concrete: Predicting the radius of action of poker vibrators from wave propagation," *Cem Concr Res*, vol. 41, No.9, pp.932-941, Sep 2011
[9] Y. Fujikura, "Fundamental study on the influence of rheological characteristics on stillness and vibration of concrete on filling performance," *Fujita Technical Research Report* No.51, pp.21-26, 2015
[10] H. Mori, Y. Tanigawa, "Flow analysis method of fresh concrete subjected to vibration force," *Report of the Structural Review Paper of the Japanese Architectural Institute*, 388, pp. 18-26, 1988.6
[11] F. Flora, etc, "Rheology of fresh concretes with recycled aggregates," *Const Build Master*, vol. 73, pp.407-416, Dec 2014
[12] M. A. Noor, T. Uomoto, "Rheology of high flowing mortar and concrete," *Mater Struct*, vol. 37, pp.513-512, Oct 2004
[13] T. Saito, Y. Fujikura, S. Hashimoto, S. Date, "Basic research on rheological properties under static and vibration of mortar," *Concrete Engineering Annual Paper*, vol. 37, no. 1, pp. 1099-1104, 2015.
[14] T. Saito, Y. Fujikura, S. Hashimoto, and S. Date, "Study on the rheological properties of fresh mortar under vibration," *International Journal of Structural and Civil Engineering Research*, vol. 4，no. 3，pp. 291-295，2015.8
[15] Y. Muroga, S. Date, T. Osuga, "Development of a viscousness evaluation test apparatus for mortar," *Annual Conference on Civil Engineering Society*, vol. 55, Department 5, V-406, 2000.9
[16] Civil Engineering Society: Concrete compound design and construction guidelines based on construction performance [2016 version]

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