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STUDY ON VISUALIZATION TECHNIQUE FOR BLOCKING OF FRESH CONCRETE FLOWING IN PIPE

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SYNOPSIS

In order to see how fresh concrete was blocked in pipes, a visualization technique was invented using transparent material for mortar and cokes for aggregates. Although the concrete in this study was not the same as actual concrete, the static resistance against segregation in model concrete was made equivalent to that in actual concrete by controlling the specific gravities of mortar and aggregate materials. Using the proposed technique, the process of blocking and the arched shape of blocked gravels were clearly observed.

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1. INTRODUCTION

"Visualization of flow" represents a special technique to see the flow which may not be perceived directly. It has been developed in the field of fluid mechanics and in the fields concerned with fluid mechanics [1]. As is shown in the proverb that seeing is believing, to see what happens is the best way for understanding the mechanism of flow.

This paper dealt with how the visualization technique was developed in the field of pumpability of fresh concrete. For recording the visualized results in this system, video tapes were used instead of movie films. Although the displayed movements of aggregates and mortar flow on screen were clear enough for analytical treatments, photographs should be taken sequentially for the presentation requirements of papers. Photo 1 shows the concrete flow in a tapered pipe. Due to the visualization technique, aggregates can be seen directly. The mortar flow can also be observed by tracer particles. Fig.1 shows the schematic view of what is taken in Photo 1.

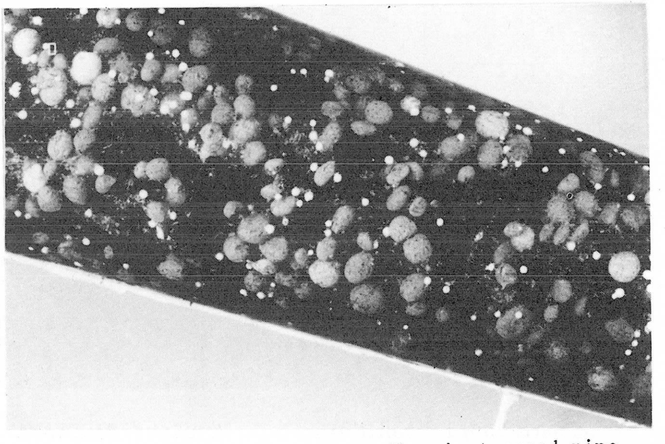

Photo.1 Visualized concrete flow in tapered pipe

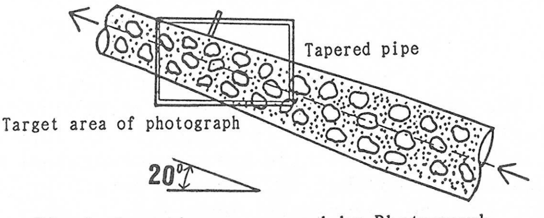

Fig.1 Location expressed by Photograph

Concrete pumping has been widely used in the construction sites since 1965 in Japan, and has produced a lot of economical profits by reducing man power and construction time. For better concrete pumping, the recommended practice has already been published by both Japan Society of Civil Engineers (JSCE) and Architectural Institute of Japan (AIJ), separately. However, it is not satisfactorily established how to evaluate the pumpability of fresh concrete quantitatively. For example, there is no safety standard against blocking in bent pipes, tapered pipes and bifurcated pipes. The easy countermeasure against blocking is to increase water content or to increase sand percentage (s/a). But, unsuitable treatments must result in poor durability of hardened concrete.

The research on pumpability of fresh concrete so far focused on the field tests using actual pumps and pipes. The objective was mainly to examine whether the blocking happened or not under the given pump and pipe arrangement. The pressure losses through the pipes were additionally measured just for assuring the possible conveying distance. The application of the obtained information was usually limited to the specified conditions so that the mechanism of blocking was not clearly understood in a general manner.

Recently the scale model of concrete pump has been developed for simulating the concrete flow in pipes at the laboratory [8,9,10]. It made the experimental study easy to conduct repeatedly with various designs of mix proportion and different conveying speed which were difficult to do with at the field tests. The development of scale model turned the research interest on pumping to the deformability of fresh concrete [8,9,10]. However, the obtained results by the scale model test were not different in quality from those by the field tests. They showed the properties of concrete just before and after pumping, not during pumping. In addition, the possible measurement was limited to the variation of pressure in pipes. It was still veiled how concrete flowed in the pipe. The information from the test, then, proved only the indirect clue for the deformability of fresh concrete and for the mechanism of blocking. The mechanical behavior of fresh concrete may not be cleared by this approach. Furthermore, the scale model always involves scale effect problems.

Based on the above review, we introduced the multi-phase flow concept instead of the traditional "material" concept for treating the behavior of fresh concrete in pipes. The concrete flow is a three-phase mixture flow consisting of solid, liquid and gas portion. In this sense, the debris flow [11] and the liquid-solid two phase flow [12] can be references to our problems even though there exist some differences in particle grading distribution and flow speed. As far as the flow problem is concerned, the best approach is to see and record the flow. Accordingly, the most effective way to study the mechanical behavior of fresh concrete is to develop the visualization technique for concrete flowing in pipes.

The objective of this study is to develop the concrete model which allows the behaviors of concrete components be observed and recorded directly. The model should have the similar properties to the actual concrete in terms of segregation resistance between mortar and aggregate.

2. PROBLEMS IN VISUALIZATION OF CONCRETE FLOW

Fresh concrete flowing in pipes consists of various size of particles, such as air, water, cement, fine and coarse aggregates. On the other hand, the flow in the fluid mechanics is generally mono-phase flow of water or air, and is easily visualized by various techniques, such as the trace method, the taft method, the injected tracer method and optical methods. Those methods might be good for water or air flow which is transparent, but not applicable to concrete flow directly. In fact, when concrete is poured in a transparent glass bowl, what can be seen is only the surface of concrete on the glass wall, but not the inside of concrete.

In order to see the inside of concrete, the components of concrete should be replaced by transparent materials. In choosing such materials, a special attention should be paid to which components are essential and to be visualized for studying the deformability of fresh concrete and the blocking mechanism. In addition, consideration should be extended to the easiness of obtaining the materials, and to the observation and recording system of the flow.

In this paper we focused on the mortar flow and the movements of coarse aggregate. Fresh concrete was, then, modeled as two-phase composite material consisting of a continuous phase (mortar) and a dispersion phase (coarse aggregate). The two phase model of fresh concrete may be justified by the previous test results which tell that the volumetric ratio of coarse aggregate to mortar (Vg/Vm) is the most influential factor on the deformability of fresh concrete [9,10], and that the arching of coarse aggregates is the trigger of blocking in pipes [8]. The experience of visualization technique in the fluid mechanics might support the two phase model by saying that less number and larger size of the target makes visualization of flow clear and accurate.

3. VISUALIZATION MODEL FOR FRESH CONCRETE

3.1 Requisite properties for model concrete

When the actual fresh concrete is replaced by the two phase model concrete, the proper materials should be chosen for both the mortar phase and coarse aggregate phase of model concrete. As the requisite properties for the materials, the following three conditions should be satisfied:

(a) Model mortar is transparent enough to observe the behavior of model coarse aggregates during flowing in pipes.
(b) Segregation resistance between mortar and coarse aggregate of model concrete is equivalent to that of actual concrete.
(c) Critical volumetric ratio of mortar to coarse aggregate (Vg/Vm) at blocking in deformed pipes is specified as a similar value between actual concrete and model concrete.

Material segregation of concrete happens at casting and after placement of concrete. The segregation at casting is mainly the separation of mortar from coarse aggregate. On the other hand, the segregation after placement of concrete is well known as the bleeding which represents the separation of water from concrete due to the settlement of solid particles. Here in this paper, we neglected the latter segregation because the fresh concrete was expressed as the two phase model consisting of mortar and coarse aggregate, and because we focussed on the behavior of concrete during pumping.

In order to consider the segregation resistance of concrete, the equilibrium equation was reviewed under the condition of one stone dropping down in fresh concrete with relative velocity of V (cm/sec). The forces acting on the stone were the dragging force due to viscosity of concrete, the buoyancy of concrete and the self weight of the stone. Here, the stokes' law was applied to express the dragging force [13]. The equation is derived as follows:

$$\frac{4}{3}\pi r^3 \rho \frac{dv}{dx} = \frac{4}{3}\pi r^3 \rho g - 6\pi r \eta v - \frac{4}{3}\pi r^3 \rho_c g \qquad (1)$$

where, r : radius of stone (cm)
ρ : mass density of stone (g/cm^3)
ρ_c : density of concrete (g/cm^3)
η : coefficient of viscosity (dyne·sec/cm^2)
g : acceleration of gravity (cm/sec^2)

When the relative velocity reached finally to V, the above equation is simplified as the following form taking dv/dt = 0.

$$V = \frac{2 r^3 g (\rho - \rho_c)}{9\eta} \qquad (2)$$

The equation (2) tells that the final relative velocity (V) is determined by the radius of the stone, the difference of density between the stone and concrete, and the viscosity of concrete. Accordingly, the following considerations are necessary in model concrete for simulating the segregation resistance of actual concrete.

(b-1) To choose the size of model coarse aggregate similar to that of actual coarse aggregate. In other words, the distribution of particle size and the maximum size of actual coarse aggregate should be simulated.

(b-2) To make the density difference between coarse aggregate and concrete of model concrete equivalent to that of actual concrete. The density of a material is defined as the product of the pure water density at 4 °C and the specific gravity of the material. When the temperature of model concrete is the same as that of actual concrete, the density difference is equivalent to the difference in specific gravity. Accordingly, the model concrete should be designed to have the same temperature and the same difference of specific gravity between coarse aggregate and concrete as the actual concrete.

(b-3) To make the viscosity of model concrete similar to that of actual concrete. Since the previous studies tell that the volumetric ratio of coarse aggregate to mortar (Vg/Vm) is the most dominant factor for blocking of concrete in pipes, it is necessary to choose the grading distribution, the shape and the maximum size of coarse aggregate so that the critical volumetric ratio (Vg/Vm) at blocking should be similar between the model and the actual concrete.

3.2 Model mortar

The model mortar was made of super absobent polymer named starch-polyacrylate. This polymer was white powdered. Mixing with a small amount of powder, the drinking water was transformed into viscous liquid with high transparency.

Although there exist many materials which possess high transparency and viscosity, this polymer has the advantage in stability against temperature and humidity, and in time-independency. In addition, the material is easy to obtain in the market, and easy to handle.

Beside this polymer, organic materials such as gelatin are considered to use. However, they are not easy to handle because the viscosity and the transparency change due to the environmental conditions and the lapse of time. In addition, gelatin requires special treatments for disposal after test. As far as the large scale experimental tests are concerned, the stability and the time-independent property of material are the most requisite properties for reducing the cost of materials by repetitive use. Since the proposed polymer is harmless to animals and plants, it is disposable by water washing. The model coarse aggregate can, then, be used again after washing the polymer out. Reuse of the model aggregates gives the advantage to the model concrete by reducing the preparation work and by limiting the variation of materials.

By these reasons the proposed model concrete may be superior to the actual concrete even for the study on rheological behavior of fresh concrete. The physical properties of the super absobent polymer are shown in Table 1.

The viscosity of model mortar was evaluated by the consistency test method specified in JSCE Standard Specification. Fig.2 shows the relationship between the value of flow of model mortar and the content of super absobent polymer in one liter water. It is easy to adjust the viscosity of mortar by arranging the additive amount of polymer.

As stated in the previous page, the similarity in viscosity of concrete is one of the three requisite properties for the model (b-3). Since the viscosity of concrete depends greatly upon the viscosity of mortar, the fulfillment of viscosity condition on mortar may be a substitute for that on concrete.

Through the above discussion, the proposed model mortar can represent any type of actual mortar in fresh concrete which has various segregation resistance between mortar and aggregate. The advantage of the model mortar lies in the insensitivity of viscosity to temperature. Using the same water as for the actual concrete, the temperature of the model mortar can easily be matched with that of the actual mortar without change of viscosity. Consequently, the second condition for model concrete (b-2) requires only the similarity in the difference of specific gravity between mortar and aggregate.

Table 1 Properties of super absorbent polymer

Water absorptivity (g/g)	Deionized water	700
	Physiologocal salt solution	65
	Salt solution (1.6%)	50
	Blood of sheep	70
pH		Neutrality
Apparent density (g/ml)		0.4
Percentage of moisture content		≦ 7
Grading (%, weight)	≧ 20 mesh	1
	20~145 mesh	89
	≦145 mesh	10

3.3 Model aggregate

The specific gravity of aggregate for actual concrete is usually 2.6. Since the model mortar has the specific gravity of 1.0, the normal aggregate can not be used because of too large difference of specific gravity. Even if the viscosity of model mortar is increased, the material segregation may not be avoided.

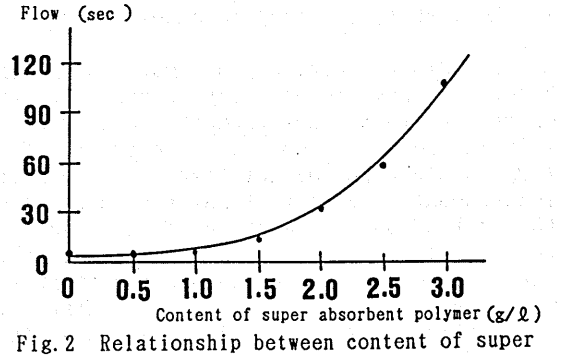

Fig. 2 Relationship between content of super absorbent polymer and flow

In actual concrete, the specific gravity of aggregate is about 0.3 greater than that of mortar. This may be the key value for the model concrete. Since the specific gravity of the model mortar is 1.0, the value of 1.3 may be appropriate for the specific gravity of model aggregate. Then, the artificial lightweight aggregate is proposed as the model aggregate. Although there exist other materials which satisfy the required conditions of specific gravity and shape, the artificial lightweight aggregate may be the best for use at this moment due to its easiness and cheapness to obtain. The only defect is the small range of available grading size. The manufactured grading is 5 - 15 mm. For modeling a large size of aggregate, another material should be sought.

Table 2 Properties of proposed model coarse aggregate

Type of model	Grading (mm)	Specific gravity	Absorption (%) (after 24hour)	Fineness modulus	Solid volume percentage
Artificial light-weight aggregate	15 ~ 5	1.42	8.45	6.47	67.5
Cokes coated with asphalt	25 ~ 15	1.23	0.00	7.41	55.3

Considering the required properties and the easiness to obtain, we decide to use cokes as a large size of aggregate. Cokes, however, can not be used as they are. They are so porous as to absorb water, and are so weak in strength as to get crushed easily during pumping. Crushed cokes make the model mortar dirty and less transparent. In order to improve the defects of the cokes, asphalt is used to coat the cokes. Asphalt coating fills up the voids of cokes, and increases the strength. As the specific gravity of coated coke is about 1.3, the material segregation resistance may not be severe when the coated cokes are mixed with model mortar.

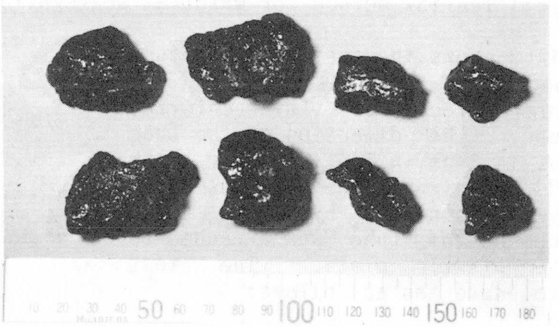

Photo. 2 Model coarse aggregate (15~20 mm)

For simulating the actual aggregate used in the pumping tests, the maximum size of the model aggregate is arranged as 25 mm, and the grading is in the range of 15 - 25 mm. Photo 2 shows the coated cokes. The physical properties of model aggregate are shown in Table 2. Varying the volumetric ratio of artificial lightweight aggregate to coated coke, the grading of model aggregate was adjusted to satisfy the requisite conditions (b-1) and (c) as stated before.

4. COMPARATIVE STUDY OF MODEL CONCRETE WITH ACTUAL CONCRETE

4.1 Segregation

The materials for the model concrete were chosen so as to simulate the segregation resistance of the actual concrete. The consideration was mainly paid to the factors which influenced the final velocity (V) in the equation (2). The equation (2) represents the motion of one gravel dropping down in fresh concrete. The segregation in the actual concrete, however, may be caused by the movement of grouped coarse aggregate in the cement paste or in the mortar. Then, the consideration should be extended to the movement of aggregate as a group.

It is discussed in this section how to evaluate the segregation resistance of the model concrete consisting of a group of coarse aggregate and mortar.

4.2 Test program

In order to evaluate the segregation resistance of concrete, the consideration was focussed on the variation of volumetric ratio of coarse aggregate to mortar in the lapse of time. When concrete was poured in a cylinder mold, the coarse aggregate settled a little due to the difference of specific gravity between the coarse aggregate and the mortar. After settlement the volumetric ratio (Vg/Vm) differed at the upper and the lower part of concrete from the initial value. The settlement of coarse aggregate represents a kind of segregation in concrete. Accordingly, the variation of the ratio (Vg/Vm) in the vertical direction of the cylinder mold may be the good index to compare the model concrete with the actual one in terms of segregation resistance.

4.2.1 Testing method for material segregation

Fig.3 shows the testing apparatus. The test cylinder consisted of three pieces of vinyl chloride tube. The dimension of the tube was 14.8 cm inside diameter with 10 cm height. The tube was piled up and connected by vinyl tape. The bottom tube was attached to the plastic plate. The test procedure was as follows:

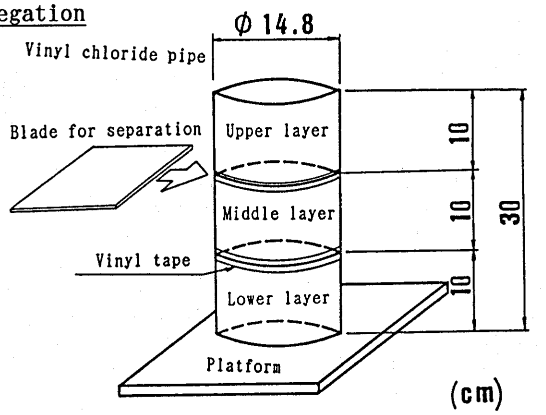

Fig. 3 Apparatus for static segregation test

1) With use of hand scoop, pour concrete in the cylinder statically up to the top. Then, consolidate concrete by the trowel until air bubbles are removed.
2) After the lapse of time (15 or 30 or 60 min.), strip the vinyl tape and insert the plastic blades carefully in between each tube to separate the concrete into three layers.
3) Screen the concrete of each layer by the sieve of 5 mm mesh. Determine the volume of coarse aggregate and the volumetric ratio of coarse aggregate to mortar (Vg/Vm) at each layer. In order to reduce the measurement error, the test results was cancelled when the average volumetric ratio of the three layers deviated more than 3 % from the initial set value. In this test program, the identical test was repeated three times on the other days.

4.2.2 Mix proportion

(1) Fresh Concrete:
Normal portland cement was used with specific gravity of 3.12. Fine and coarse aggregate were river sand and river gravel. The physical properties are shown in Table 3. As the admixture, the standard type of AE water reducing agency was used. Table 4 shows the mix proportion. Two different values of slump were objected with the values of W/C and Vg/Vm being kept constant as 55 % and 75 %, respectively. The air content was in the range of 4 % to 6 %. The concrete temperature was held constant at 17±1 °C during the test period.

Table 3 Properties of aggregate

Type of aggregate	Grading (mm)	Specific gravity	Absorption (%) (after 24hour)	Fineness modulus	Solid volume percentag
Fine aggregate: Natural Sinano-Gawa river sand	5 ~ 0	2. 6 1	1. 3 7	2. 4 1	———
Coarse aggregate:Natural Sinano-Gawa river gravel	2 5 ~ 5	2. 7 0	0. 9 0	7. 2 0	6 5. 2

Table 4 Mix proportions of concrete

Mix. No.	M. S. (mm)	Slump (cm)	Air (%)	W/C (%)	Vg/Vm (%)	S/C	s/a (%)	Unit weight (kg/m^3)			
								W	C	S	G
F C 1	2 5	1 2 ± 1	5 ± 1	5 5	7 5	2. 7	4 0	151	274	740	1155
F C 2	2 5	2 1 ± 1	5 ± 1	5 5	7 5	2. 1	3 7	171	311	653	1159

Vg/Vm : Volumetric ratio of Aggregate to mortar

(2) Model Concrete:
The materials for the model concrete were exactly the same as the proposed ones in this project. By mixing the artificial lightweight aggregate with the coated cokes at the even volume, the grading of aggregate was arranged to satisfy the JSCE code specification. Table 5 shows the mix proportion of the model concrete. As well as the fresh concrete, two different proportions were prepared. The difference was just made by varying the additive amount of super absobent polymer. The air content was neglected because it had little influence on the viscosity of the model concrete.

Table 5 Mix proportions of proposed visual model concrete

Mix. No.	Content of super absorbent polymer (g/liter)	Vg/Vm (%)	Vgl /Vgc (%)	Unit weight (kg/m^3)			
				W	P	G l	G c
V M 1	3. 0	7 5	1 0 0	571	1.71	303	264
V M 2	1. 8	7 5	1 0 0	571	1.03	303	264

P :Super absorbent polymer, G l :Artificial light-weight aggregate
G c :Cokes coated with asphalt

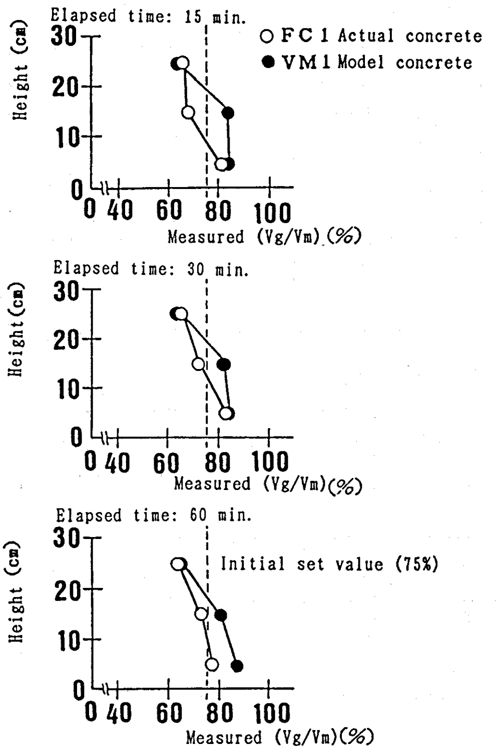

Fig. 4 Variation of (Vg/Vm)
(Comparison FC1 with VM1)

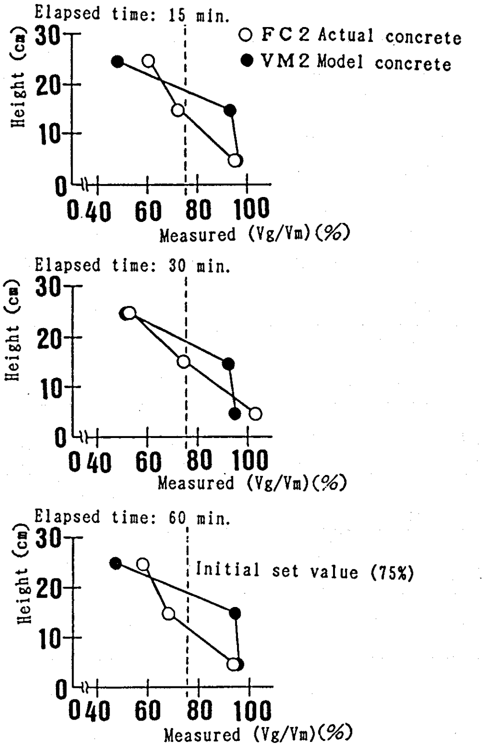

Fig. 5 Variation of (Vg/Vm)
(Comparison FC2 with VM2)

4.3.3 Test results and discussion

Figs.4 and 5 show the variation of the volumetric ratio (Vg/Vm) in the vertical direction in the lapse of certain time after casting. Despite the difference of the lapsed time after casting, there existed the tendency in both the model and the actual concrete such that the deviation of (Vg/Vm) from the initial set value increased with decrease of viscosity. In addition, the lapsed time after casting did not influence the variation of (Vg/Vm) so much. This meant that the segregation might come to an end in 15 min. after casting.

Judging from the results, it was concluded that 1.8 g/l and 3.0 g/l of the additive amount of super absobent polymer could make the model concrete comparative to the actual concrete having the slump of 21 cm and 12 cm, respectively.

5. EVALUATION OF VISUALIZATION MODEL FOR CONCRETE FLOW IN PIPES

5.1 Objectives

In the previous section the model concrete was examined in view of static material segregation resistance. It is also necessary to examine the model under the condition of flowing in pipes.

In order to evaluate the similarity of the model concrete to the actual one, we considered it an index whether the blocking of concrete happened in the tapered pipe or not. Since the volumetric ratio (Vg/Vm) was recognized as the most dominant factor for blockage, the critical value of (Vg/Vm) at blocking might be a good reference value to the segregation resistance of flowing concrete. By this reason, the grading and shape of model coarse aggregate were so arranged as to cause blocking at the similar ratio of (Vg/Vm) to that of the actual concrete at blocking in the tapered pipe.

In comparison with continuously taken photo pictures, the video photographing may be the bast way to monitor and record the flow of model concrete. The motion displayed on the screen of the video system could be reviewed continuously and repeatedly. Even the delicate movement of aggregate could be observed clearly and in detail. The video system can reproduce much more information from one operation of the pumping test than the photo pictures. However, as far as the presentation in the paper is concerned, the photo pictures must be used.

5.2 Testing method and mix proportion

The concrete pumping system for this project was similar in size to that used in the previous studies on the deformability of fresh concrete [8-10]. Fig. 6 shows the system. It consisted of the oil pressure generator, the piston cylinder of 1 m length, and the straight steel pipe having 15.5 cm inside diameter and 1 m length.

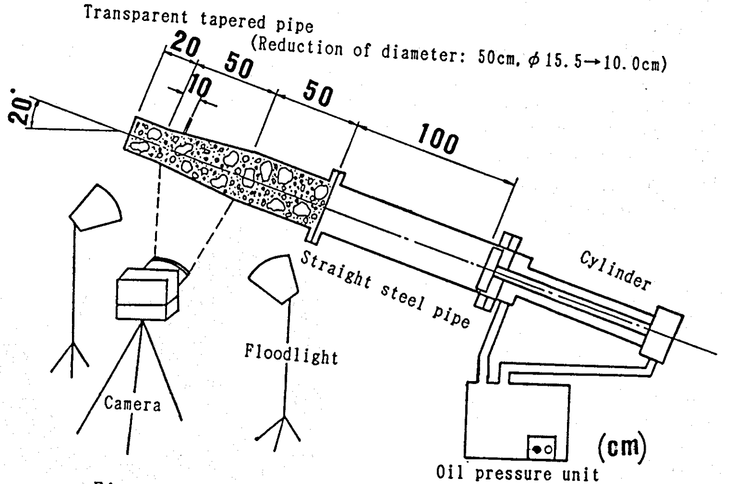

Fig. 6 Apparatus for concrete pumping test

The transparent tapered pipe was connected to the end of the straight steel pipe. The 50 cm length of the transparent pipe was straight having 15.5 cm inside diameter, and the pipe diameter was reduced linearly from 15.5 cm to 10 cm within 50 cm length. For the straight portion of 50 cm length, the transparent acrylic pipe was used. The pipe was commercially supplied. But the tapered portion was manufactured in the laboratory using the transparent vinyl chloride plate.

The test procedure for pumping of model concrete was as follows:
1) Set the pumping apparatus at 20 degree of angle from the horizontal level.
2) Draw the piston back to an end in the piston cylinder.
3) Pour the model concrete fully in the steel straight pipe portion.
4) Connect the transparent pipe to the end of the steel pipe, and pour the additional concrete carefully in the pipe without disturbing the original volumetric ratio (Vg/Vm). Large air voids should be cleared out.

The pumping speed was set constant at 6 cm/sec.

The coarse aggregates, such as artificial lightweight aggregate and coated cokes, might be easy to observe and trace on the displayed screen, but not the transparent mortar. Then, small particles of foamed styrol (particle size:3 mm) were added in the mortar for making the mortar flow easy to trace. The motions of tracers (artificial lightweight aggregate, coated coke and styrol particle) were recorded by photo pictures taken continuously using a Nikon F3 camera and Kodak Tri-X film. The motor drive equipment was set to the camera for automatically shuttering and rolling up of film. The photo conditions were as follows:

Lens, 100 mm F4 ; Film, black and white ASA400 ; Exposure, 1/125 sec. ;
Diaphragm, F4 ; Speed of motor drive, 6 frames/sec.

The mix proportion of the model concrete is shown in Table 6. Within the allowable range of grading specified in the JSCE standard, the grading of aggregate was adjusted by varying the contents of artificial lightweight aggregate and coated coke so as to cause blocking at the similar volumetric ratio (Vg/Vm) of actual concrete. Based on the previous studies [9,10], the critical ratio at blocking for the tapered pipe in this study was estimated as between 80 and 90 %. Then, 85 % was taken as the design value for the model concrete.

Table 6 Mix proportions of proposed visual model concrete

Mix. No.	Content of super absorbent polymer (g/liter)	Vg/Vm (%)	Vgl /Vgc (%)	Unit weight (kg/m^3)			
				W	P	G l	G c
VM3	3.0	85	50	541	1.62	217	378

5.3 Test results and discussion

Photos 3 and 4 show the concrete flow, just before and after blockage, respectively. To make the arching of aggregate clear in the picture, the concrete forward the arch was removed.

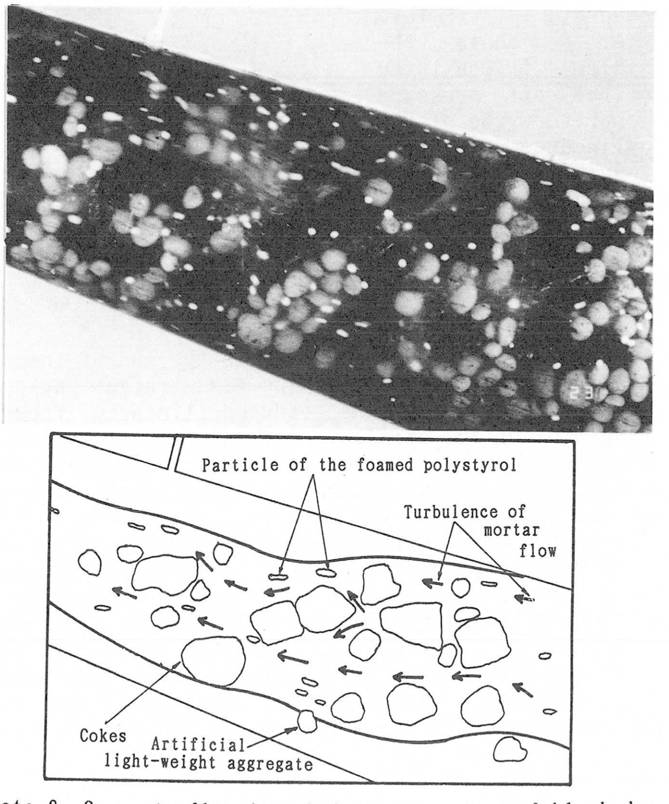

Photo. 3 Concrete flow just before occurrence of blockade

As it is seen in Photo 3, some tracers of artificial lightweight aggregate and mortar were taken blurred near the outlet of pipe. This might be attributed to the fact that there existed turbulence in mortar near coated cokes, and that the turbulence accelerated the movements of styrol particles and artificial lightweight aggregate faster than the shutter speed of camera. The video photographing displayed this phenomenon clearly on the screen as well. Motions displayed on the screen enabled us to observe the relative velocities between coated coke and artificial lightweight aggregate, and between artificial lightweight aggregate and styrol particle, as well as to observe the location and the variation of the turbulence of mortar flow.

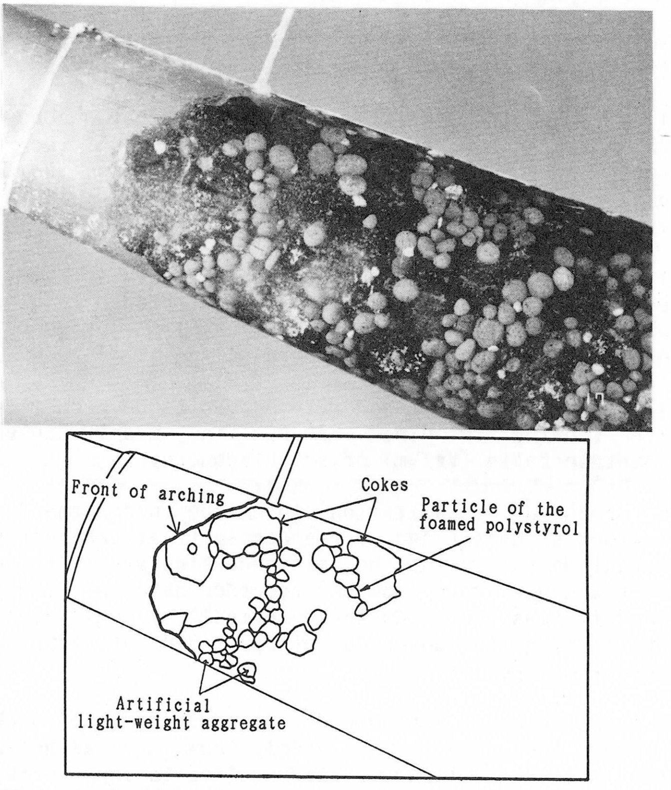

Photo. 4 Arching of aggregates at occurrence of blockade

Photo 4 show the clear plane of the arching of aggregate. The artificial lightweight aggregates gathered around coated cokes to fill up the voids, and got tight with cokes. The observed blockage process coincided with the hypothesis drawn by previous works such that the direct trigger to blockage was not the formation of high frictional resistance zone by dewatering, but the arching of aggregates.

Based on the above discussion, it was concluded that the proposed visualization technique could simulate the arching and blocking process of fresh concrete flowing in pipes, and made the process visualized.

6. CONCLUSIONS

The objective of this study was to develop the visualization technique which made it possible to observe and record the fresh concrete flow in pipes, especially the mechanical behavior of mortar and aggregate at concrete pumping. For visualization of concrete, we proposed a new model concrete which had the requisite properties to simulate the actual fresh concrete flow in pipes. The proposed model made it possible to observe the motion of aggregate in concrete.

The evaluation of the proposed model was conducted by examining the segregation resistance between mortar and coarse aggregate, and the blocking mechanism in the tapered pipe.

The followings are concluded from this study.

(1) It was possible to observe the concrete flow in pipes at pumping by the proposed visualization technique. The concrete was modeled in two phases, such

as the mortar phase and the coarse aggregate phase. The mortar phase was made transparent by use of super absobent polymer. The coarse aggregate consisted of artificial lightweight aggregates and coated cokes.

(2) Varying the additive amount of super absobent polymer, the viscosity of model mortar could be controlled to match with the segregation resistance of actual concrete. Based on the test results, the amount of 1.8 and 3.0 g/l of super absobent polymer made the model mortar equivalent to the actual concrete having the slump of 12 and 21 cm, respectively.

(3) The proposed model concrete was examined in view of blockage in tapered pipes. The process from smooth flow through arching of grouped aggregates and blocking was simulated and visualized by the proposed model, and was taken in continuous pictures with a camera.

(4) The proposed model concrete proved to be proper to simulate the fresh concrete flowing in pipes because the model caused blocking at the similar volumetric ratio (Vg/Vm) of actual concrete.

The proposed visualization technique opened the field to study the mechanical behaviors of mortar and coarse aggregate at concrete pumping. The further study is required to develop the data reduction system for computing the velocities of mortar and aggregate from the recorded data in video system. Such a system makes it easy to study the deformability and dynamic segregation of fresh concrete flowing in deformed pipes, such as tapered pipes, bent pipes and bifurcated pipes.

The proposed model concrete developed the new approach to study the properties of fresh concrete. The model, however, was not perfect enough to represent actual concrete. It was still required to improve the model with respect to the viscosity of model mortar, the grading and surface profile of coarse aggregate, and the development of fine aggregate model.

Finally, we expect to get the new and more fruitful information when the visualization technique will be combined with the theoretical studies which have been conducted to develop the numerical simulation model for the mechanical behaviors of fresh concrete at the construction sites.

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